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Economic Impact Analysis of Bridge Construction

Funda Yavuz
Western Michigan University

ECONOMIC IMPACT ANALYSIS OF BRIDGE CONSTRUCTION

by

Funda Yavuz

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Thesis Committee:

Haluk Aktan, Ph.D., Chair
Upul Attanayake, Ph.D.
Valerian Kwigizile, Ph.D.

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Funda Yavuz, M.S.E.

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Traffic disruption due to bridge construction has been reduced to several hours with the development of methods characterized as Accelerated Bridge Construction (ABC). Associated risks and additional activities involved with the accelerated construction result in an increased initial project cost. This additional cost is offset by the benefits of reduced mobility impact time such as maintenance of traffic cost, life-cycle cost, and economic impact on surrounding communities and businesses as well as the ability to address seasonal limitations. Traditionally, the savings in user cost from reduced mobility impact time is used to justify the additional cost of accelerated construction implementations. This thesis presents a comprehensive cost model for bridge construction that incorporates economic impact on surrounding communities and businesses. Economic impact model for surrounding communities and businesses incorporates user cost, environmental cost, and business revenue change. To demonstrate the application of economic impact analysis concepts and procedures, a case study was developed. The scope of the study is limited to construction duration.

Dedicated to my family

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CHAPTER I

INTRODUCTION

Transportation networks are essential for economic, social, and cultural development. Transportation network components are roads and bridges. Integrity of the transportation network depends on the health of the bridge system. There are approximately 600,000 bridges throughout the United States; however, almost 25% of them are structurally deficient or functionally obsolete and require rehabilitation, repair or total replacement according to the Federal Highway Administration (FHWA) (2017). Nonetheless, bridge replacement results in significant social inconveniences to commuters and nearby businesses. To mitigate those negative effects, accelerated bridge construction (ABC) techniques are introduced over conventional construction (CC). ABC is a remedial approach which minimizes mobility impacts from bridge construction and uses innovative planning, design, materials and construction methods in a safe and cost-effective manner (FHWA 2017). There are more than 120 ABC projects compiled in the United States as of April 2015 (Aktan and Attanayake 2015). ABC procedures are being developed and refined; while highway agencies and contractors are gaining experience through implementations and demonstrations. In this process, there are two metrics defined to gauge the effectiveness of ABC:

- Onsite construction time: The period between the time when general contractor enters the project site until construction is complete and all construction related activities are removed. This includes, but not limited to, the removal of work zone traffic regulations.

- Mobility impact time: The duration of roadway closure due to bridge construction. FHWA (2017) categorized the ABC projects into five tiers based on their mobility impact time (Table 1).

Table 1. FHWA Categorization for ABC Projects (FHWA 2017)

Tier	Mobility Impact Time
1	1 - 24 hours
2	1 – 3 days
3	3 days – 2 weeks
4	2 weeks – 3 months
5	More than 3 months

While CC requires more than 6 months of mobility impact time, ABC requirement can be a lot less as shown in Table 1. The reduction in onsite construction time, mobility impact time and improved durability of the new bridge generate benefits from reduced maintenance of traffic cost, life-cycle cost, and economic impact on surrounding communities and businesses (Aktan and Attanayake 2015). Yet cost of additional required ABC activities, time constraints, and perceived risks increase the project cost by 6% to 21% over CC (Aktan and Attanayake 2015).

Traditionally, economic impact is measured considering the savings from user cost during mobility impact time. However, the evaluation of bridge projects have started to consider societal impact aspects. Bridge construction involves a number of cost and benefit categories together. In that respect, it is not reasonable to compare the construction alternatives depending on only the savings in user cost.

Objective and Goals

The objective of this thesis is to develop and implement a model to quantify economic impact on surrounding communities and businesses from a bridge construction project. The developed model can be used as a planning tool, as well as a post-construction analysis tool after collecting historical site-specific data.

The scope is limited to construction duration including onsite construction time and mobility impact time. The scope incorporates identification of parameters for quantification process of economic impact analysis. The process of model development is explained, and the application is demonstrated on a case study.

Even though the focus is limited to bridge construction projects, the economic impact analysis the model can be used to evaluate impacts of highway construction in general.

Methodology

The methodology implemented in the framework of this thesis is presented in Figure 1. The first task indicates that literature review is carried in diverse disciplinary fields to identify cost categories contributing to economic impact on surrounding communities and businesses from bridge construction. In this task, cost categories as well as their associated parameters are identified. The next task is to develop a model for quantification of economic impact by integrating cost categories. In the third task, the developed model is applied to a case study in Potterville, MI. Two bridge construction alternatives (Slide-in Bridge Construction and CC) are compared thorough the model. Finally, the conclusions and recommendations are provided with capabilities and limitations of the model.

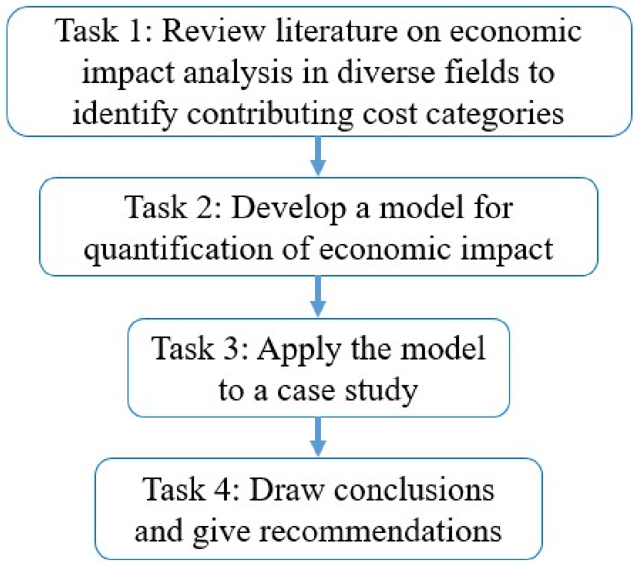


Figure 1. Schematic view of methodology

To reflect the methodology, this thesis is organized into 4 chapters.

Chapter I includes the introduction of the research project.

Chapter II describes economic impact analysis and components documented in literature. This chapter also includes identification of contributing cost categories and associated parameters.

Chapter III describes a model for economic impact on surrounding communities and businesses from a bridge construction project. This chapter provides a detailed breakdown of cost categories and their quantification methods. For calculating the economic impact on surrounding communities, user cost of passenger vehicle driver and passenger and environmental cost from air pollution, water pollution, and climate change are considered. Economic impact on surrounding businesses is quantified by considering user cost for of trucks and business revenue change.

Chapter IV includes the summary, conclusion and future research.

CHAPTER II

LITERATURE REVIEW

Overview

Economic impact of roadway closure and safety within construction zone for a specific site are considered when evaluating bridge construction methods. Accelerated bridge construction (ABC) is recommended over conventional construction (CC) to minimize the roadway closure duration which is called the mobility impact time. The strict mobility impact time constraint will always be a part of ABC to achieve the main purpose. The time constraint can be satisfied by using innovative techniques and additional work activities, which lead to additional costs. Hence, the project cost of ABC is 6% to 21% greater than CC depending on site complexity, time constraints, and perceived risks (Aktan and Attanayake 2015). Even though the initial project cost is higher, ABC yields many benefits that can be quantified using site specific data or evaluated qualitatively based on experience on completed project.

Traditionally, the savings in user cost from reduced mobility impact time is used to justify the additional cost of accelerated construction implementations. In addition to user cost, there are other economical impact effects on neighboring businesses and communities from bridge projects. A variety of modelling approaches are documented in literature, but only a few publications present comprehensive analyses of economic impact. As an example, Ferguson (2012) qualitatively evaluated economic impact on surroundings by defining the contributing cost categories as user cost, environmental cost, and business revenue change. Results obtained from surveys indicated negative impacts on communities and businesses surrounding a construction site. Other examples include the work by Matthews et al. (2014), Gilchrist and Allouche (2004), and Islam et al. (2014) that analyzed the impact of a project by considering user cost, environmental cost, and business revenue change. Matthews et al. (2014) evaluated the economic impact of trenching technologies and demonstrated methods to quantify eight cost categories including user cost, business revenue change, and noise. Gilchrist and Allouche (2004) described adverse effects of a construction project from road closure, air pollution, noise, loss of productivity, etc., and developed valuation methods. Islam et al. (2014) compared five water infrastructure alternatives using a software developed by Trenchless Technology Center (TTC). The cost parameters considered in this study includes traffic delay, air pollution, noise pollution, and business revenue loss. Aktan and Attanayake (2015) evaluated economic impact of bridge construction. They qualitatively evaluated the impact on surrounding businesses but quantified the economic impact on surrounding communities using a predefined county economic value multiplier (Aktan and Attanayake 2015). The authors utilized mobility impact time in quantification process. They converted quantitative values into preference ratings using Michigan Accelerated Bridge Construction Decision (Mi-ABCD) tool.

The primary objective of this research is to present the model for quantifying economic impact of bridge construction on surrounding communities and businesses. For that purpose, the project impacts are grouped under three major cost categories (a) user cost, (b) environmental costs, and (c) business revenue change (the Swiss Federal Office for Spatial Development (ARE) 2010; Allouche and Gilchrist 2004; Delucci 2000; the Federal Highway Administration (FHWA) 1997).

Economic Impact Analysis and Components

User Cost

Motor vehicle user, which is shortly termed as user in this study, is impacted from change in transportation system hence, change in travel distance and travel time. This impact can be quantified as user cost which is the added travel delay cost, vehicle operating cost, and accident cost to road users resulting from construction, maintenance, or rehabilitation activities (the New Jersey Department of Transportation (NJDOT) 2001). User cost is formulated for personal travels and business separately depending on their direct effect on the flow of dollars (Forkenbrock and Weisbrod 2001). User cost of business has a direct monetary amount since business is required to pay hourly rate to a truck driver while personal travel does not have a direct monetary value (e.g. travel delay cost or saving from reduced vehicle operating cost) (Forkenbrock and Weisbrod 2001).

Delay Cost

Travel delay cost is calculated using hourly rate for a person (i.e., the cost of time spent on transport) (Litman 2013). Hourly rate for a user is defined from the nationwide median income for personal travel and the nationwide median hourly wage for business travel according to the U.S. Department of Transportation (USDOT) (2014). Hourly rate for drivers is given in USDOT (2014). In order to calculate user delay cost, hourly rate needs to be defined for the passengers, as well. According to Litman (2013), hourly rate for an adult passenger is 70% of the driver for medium and good operating conditions. These values are prorated to 2015 dollar equivalent value using inflation rate and shown in Table 2 (USDOT 2014). Inflation rate is a percent yearly change in Consumer Price Index (CPI) and calculated as shown in Eq. 1. The prorations were calculated through an online inflation calculator provided by The Bureau of Labor Statistics (2017)

$$Inflation\ rate = \frac{CPI_2 - CPI_1}{CPI_1} \times 100 \tag{1}$$

where CPI_2 is the CPI in the second period; CPI_1 is the CPI in the previous period.

Table 2. Value of Travel Time for 2015

Category	Hourly rate per person (2015 $)
Local Travel	
Personal - driver	12.67
Passenger	8.87
Business - driver	24.82
Intercity Travel	
Personal - driver	17.72
Passenger	12.40
Business - driver	24.82

Vehicle Operating Cost

Vehicle operating cost represents the direct expenses to own and maintain a vehicle. According to the American Automobile Association (AAA) (2015), an average hourly vehicle operating cost for a passenger vehicle is $0.58/mile. This amount covers the cost of fuel, maintenance, tires, insurance, license, registration, taxes, depreciation, and finances. The American Transportation Research Institute (ATRI) (2014) provides an average hourly vehicle operating cost of $1.076/mile for trucks in Midwest region of the U.S that includes Michigan.

Accident Cost

Accident cost accounts for the economic impact on individuals due to injury, loss of life, and property damage (Kostyniuk et al. 2011). Kostyniuk et al. (2011) estimated unit monetary value of injury and property damage based on 2009 crash and crime incidence data in Michigan. These values were converted into 2015 dollar equivalent values and presented in Table 3.

Table 3. Average Cost per Accident in Michigan for 2015

	Fatal	**Serious injury**	**Moderate injury**	**Minor injury**	**Property damage only**
Vehicle damage	15,756	6,913	5,498	4,922	1,808
Comprehensive cost	3,937,034	250,314	74,589	43,501	4,022

Two other parameters for accident cost calculation are needed. These are the number of accidents in a jurisdiction and the total miles travelled in a year. Table 4 shows the number of accidents and the associated property damage in Michigan. The data was obtained from 2014 records of the Michigan Office of Highway Safety and Planning (MOHSP 2014). The annual miles travelled by passenger vehicles and trucks in Michigan during year 2014 was 97.1 billion (the Michigan Department of Transportation (MDOT) 2016).

Percentage of passenger vehicles and trucks travelled on Michigan roads are also required in order to calculate the accident cost separately for passenger vehicles and trucks. As per MOHSP (2014) data, these percentages are shown in Table 5. Accident rate is accounted for passenger vehicles and trucks separately considering their involvement in accidents.

Table 4. Number of Accidents in Michigan during 2014

Fatal	**Injury**	**Property damage**
806	52,523	245,370

Table 5. Vehicle Types Involved in Accidents during 2014

	Fatal	**Injury**	**Property damage**
Passenger vehicles (%)	61.2	77.9	77.7
Trucks (%)	7.7	2.4	2.7

In order to calculate accident severity within a work zone, a crash modification factor (CMF) is used as shown in Eq. 2 (FHWA 2014). Typical work zone CMFs defined in FHWA (2015) are given in Table 6.

$$A_a = CMF \cdot A_n \quad (2)$$

where 'A_n' is accident rate and 'A_a' is accident rate due to work zone.

Table 6. Typical Work Zone Crash Modification Factors

Accident severity	CMF
Injury	1.6
Property damage	1.9
Average	1.77

During ABC, vehicles travel through the work zone as well as the detour. The duration of travel depends on the Traffic Management Plan (TMP) developed for the project by considering the specific ABC method. Hence, accident cost is estimated using crash data, CMF, and the data available in the TMP.

Environmental Cost

Reduced speed limit and detours during construction increase vehicle emission of pollutants and discharge of pollutants. Emissions are primarily responsible for air pollution and climate change while the discharge is responsible for water pollution. Hence, the environmental impact of motorized traffic is divided into three categories of i) air pollution, ii) water pollution, and iii) climate change (Delucci 2000). These three categories can be assigned a monetary value, and environmental impact can be defined as a cost. Based on the information provided in Maibach et al. (2008); Muller and Mendelson. (2007); Delucci (2000); Forkenbrock (1999); and Bein (1997), impact of air pollution is divided into health care cost and general cost, and the general cost is further divided into four subcategories – Reduced visibility, Agricultural damage, Property damage, and Forestry damage. The breakdown of environmental cost is illustrated in Figure 2.

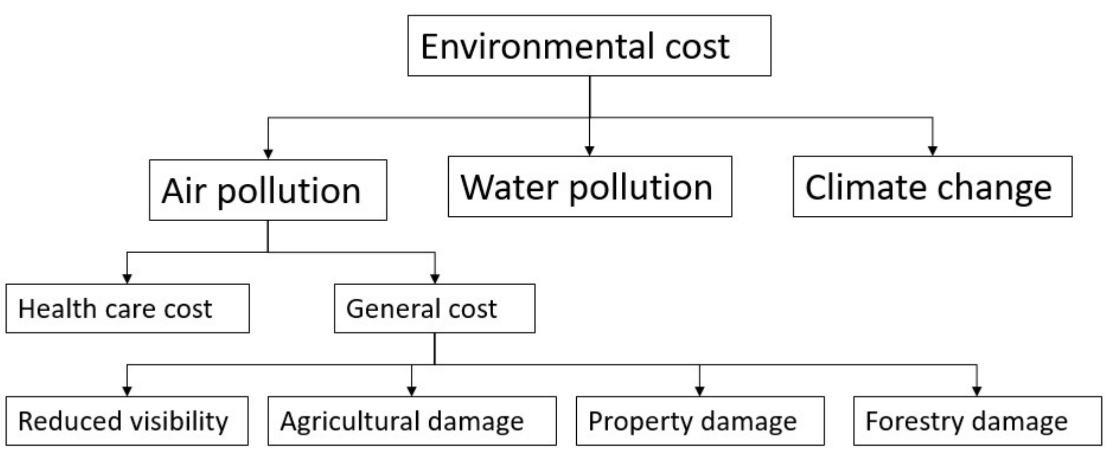


Figure 2. Cost categories for environmental impact of transportation

Air Pollution

Air pollution is caused by the emission of pollutants from vehicles such as carbon monoxide (CO); nitrogen dioxide (NO_2); particulate matter (PM), and volatile organic compounds (VOC). Air pollution impact includes health care and general cost.

Health Care Cost

Air pollution from motor vehicles causes a broad spectrum of serious health impacts on human health such as acute and chronic diseases, premature mortality, and cardiovascular diseases (Cohen et al. 2005; Craig et al. 2005; Gwilliam et al. 2004). The Environmental Protection Agency (EPA) (EPA 2008a; EPA 2008b) provides average emission rates of pollutants from passenger gasoline vehicles and diesel trucks (Table 7). The values are provided for passenger gasoline vehicles and diesel trucks since 99% of passenger vehicles run on gasoline while 80% of trucks run on diesel (USDOT 2015). These emission rates correspond to a 27.6 mph average speed (EPA 2008a and EPA 2008b).

Table 7. Emission Rates of Passenger Gasoline Vehicles and Diesel Trucks

Pollutants	**Passenger vehicles (10^{-3} lbs/mile)**	**Trucks (10^{-3} lbs/mile)**
VOC	2.2708	0.9855
CO	20.7235	5.0949
NO_2	1.5278	18.9884
$PM_{2.5}$	0.0090	0.4453
PM_{10}	0.0097	0.4828

McCubbin and Delucci (1999) follow four-step-procedure to generate the relationship between change in emission and change in health care cost:

1-) *Estimation of emission from motor vehicle use*: Emissions of pollutants (CO; NO_2; PM; and VOC) from gasoline passenger vehicles and diesel trucks are used in the analysis. Estimates of emissions are based on, but not limited to inventories produced by EPA in 1995.

2-) *Estimate changes in exposure to air pollution*: The ambient air (outdoor) method is used to estimate exposure to the defined air pollutants.

3-) *Relate changes in air pollution exposure to changes in human health*: The authors reviewed hundreds of clinical, and epidemiological studies of the health effects of the various pollutants and constructed exposure-response functions using Poisson regression analysis.

4-) *Relate changes in human health to changes in economic welfare*. The results from clinical, and epidemiological studies are reduced to acute morbidity, chronic morbidity, mortality and cancer. Utilizing economic literature, the authors placed values on illnesses. Hence, the impact of air pollution on human health can be monetized using emission rates, unit cost, and the distance travelled.

McCubbin and Delucci (1999) present the associated unit cost of pollutants (Table 8). Since determination of unit cost of pollutants is a tedious and somewhat uncertain process, upper bound representing the worst case scenario (such as Los Angeles with high levels of air pollution and high population density) and lower bound representing the whole nation (including rural areas with very low population density) are provided.

Table 8. Unit cost of pollutants in 2015 Dollars (Converted from 1991 Dollars)

Pollutants	Lower bound ($/lbs)	Upper bound ($/lbs)
VOC	0.079	0.908
CO	0.008	0.071
NO_2	0.924	13.646
$PM_{2.5}$	8.224	125.641
PM_{10}	7.695	105.586

$PM_{2.5}$ represents particles less than 2.5 microns in aerodynamic diameter; PM_{10} represents particles between 2.5 microns and 10 microns in aerodynamic diameter.

The emission rates depend on the speed limit, as well. Therefore, the change in emission rate should be modified by speed correction factor (EPA 2001). Table 9 from EPA (2001) shows the speed correction factors (SCF) for 2 pollutants from passenger gasoline vehicles. Speed correction factors for other pollutants do not show a statistical significant change with varying speed (EPA 2011; Yao et al. 2014).

Table 9. Speed Correction Factors for Arterials/Collectors

Average speed (mph)	CO	NO_2
10	1.35	1.52
15	1.13	1.28
20	1.02	1.16
25	0.97	1.08
30	0.95	1.04
35	0.98	1.02
40	1.06	1.04
45	1.14	1.07
50	1.21	1.09
55	1.29	1.12
60	1.37	1.15
65	1.45	1.17

Commuters travel extra miles on a detour. As a result, amount of pollutants released to the environment is expected to increase. However, based on the speed correction factor, emission rates of two pollutants can be lower if the commuters travel at a speed ranging from 25 mph to 35 mph instead of travelling at typical highway speeds.

General Cost

Non-health cost of air pollution from motor vehicle use is defined as the general cost. General cost includes the impact of air pollution on visibility, agriculture, nearby properties, and forestry.

Particles in the atmosphere scatter and absorb sun light, hence reduce visibility (Watson and Chow 1994). Smith and Huang (1995) show that people are willing to pay less for homes in area with poor visibility. The reduced visibility cost is established by considering the relationship between asset value of homes and air pollution using simple hedonic model (Delucci et al. 2000). Delucci et al. (2000) used the annual interest rate for investment in homes as 4% for lower bound and 7% for upper bound. The authors also estimated the term of the investment in homes of 40 years for lower bound and 30 years for upper bound.

The pollutant ozone (O_3) from motor vehicle use has detrimental effect on crops (EPA 1984). O_3 is soaked in by plant leaves and causes reduction in photosynthesis which results in crop losses (California Air Source Board (CARB) 1987). The agricultural damage cost is established by considering the relationship between crop shortfalls and air pollution (Delucci et al. 1996). Delucci et al. (1996) employed yield-response functions estimating low dose of O_3 (natural level) for lower bound and possible high dose for upper bound.

The pollutant oxidant, and PM_{10} from motor vehicle use not only harms human health but also discolors and damages building facades (the Swiss Federal Office of Spatial Development (ARE) 2010; Delucci 2000). The property damage cost is established based on the relationship between discoloration and building facade damage, and air pollution (Delucci 2000). Delucci (2000) investigated related literature and defined upper and lower bounds based on the previous findings.

Ozone and acid air pollution damage trees, hence they produce less timber than their healthy counterparts (Delucci 2000). The forestry damage cost is established based on the relation between the decline in timber growth and air pollution (Delucci and McCubbin 2010). However, Delucci (2000) states that upper and lower bounds are defined based on previous literature due to lack of data and lack of appropriate methodology.

As shown in Table 10, these general cost categories from air pollution are quantified with upper and lower bounds as a percentage of total health care cost for passenger vehicles and trucks based on the study of Delucci and McCubbin in 2010. That study incorporates the authors' previous works such as Delucci et al. (1996), Delucci et al. (2000), Delucci (2000) with further improvements.

Table 10. Non-health Impacts of Motor Vehicle Air Pollution as a Percentage of the Health Care Cost

General Cost Category	General Cost (% of Health Care Cost)	
	Lower bound	Upper bound
Reduced visibility	10	19
Agricultural damage	2	17
Property damage	3	5
Forestry damage	1	1

Water Pollution

Fuels and chemicals discharged or spilled from motor vehicles leak into oceans, rivers, lakes, and groundwater. Water polluted with fuels and chemicals results in human health problems and harming or killing wildlife, especially marine ecosystems. It can corrode materials and despoil scenic recreation areas, as well. Delucci (2000) reviewed the discussion, data and estimates provided by Steve and Peterson (1993), Behrens et al. (1992), and DeLuchi et al. (1987) to estimate upper and lower bounds water pollution from motor vehicle use due to lack of data and modelling tools. Delucci and McCubbin (2010) proposed a quantification based on the study of Delucci (2000) for the impact of water contamination from passenger vehicles in terms of passenger miles travelled (pmt) and trucks in terms of ton-miles (tm). Table 11 shows the unit cost of water pollution from motor vehicle use.

Table 11. Unit Cost of Water Pollution from Transportation Activities in 2015 Dollars (Converted from 2006 Dollars)

Vehicle type	Unit Cost of Water Pollution	
	Lower bound	Upper bound
Passenger car ($ per pmt)	0.01650	0.060
Truck ($ per tm)	0.00354	0.060

Quantification of water pollution cost from trucks requires weight of trucks. For this purpose, truck classification and gross vehicle weights presented by EPA, FHWA, or respective Departments of Transportation (DOTs) is used. As an example, Table 12 shows truck classification and gross vehicle weights presented by EPA (2011). Similarly, Table 13 and Table 14 present truck classification by the U.S. Department of Energy (USDOE) (2014) and MDOT (2013). Even though many different classifications exist, use of state specific truck configurations is feasible because truck volume and associated weight can be obtained through weigh-in motion (WIM) data records. WIM is the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle (the American Society for Testing and Materials (ASTM) 2017).

Table 12. EPA Truck Classification by Gross Weight

Truck classification	Gross vehicle weight interval (lbs)
Heavy duty vehicle 2b	8,501-10,000
Heavy duty vehicle 3	10,001-14,000
Heavy duty vehicle 4	14,001-16,000
Heavy duty vehicle 5	16,001-19,500
Heavy duty vehicle 6	19,501-26,000
Heavy duty vehicle 7	26,001-33,000
Heavy duty vehicle 8	heavier than 33,001

Table 13. FHWA Truck Classification by Gross Weight

Truck classification	Gross vehicle weight interval (lbs)
Class 3	10,001-14,000
Class 4	14,001-16,000
Class 5	16,001-19,500
Class 6	19,501-26,000
Class 7	26,001-33,000
Class 8	heavier than 33,001

Table 14. MDOT Truck Classification by Gross Weight

Truck classification	Gross vehicle weight (lbs)
Medium truck	32,000
Standard semi-trailer	73,000
Standard interstate semi-trailer	80,000
Michigan 8-axle log truck	125,000
Michigan multi-axle truck	150,000
Michigan multi-axle single trailer	150,000

Climate Change

Emissions from motor vehicle use contribute to climate change. The pollutants that contribute to climate change are classified as greenhouse gases (GHGs) and consist of carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O) from tailpipes, and chlorofluorocarbon (CFC) leaking from air conditioners (EPA 2014). Greenhouse gases are presented using a common measure known as the global warming potential (GWP) (EPA 2014). The international standard of this measurement is to express GHGs in terms of equivalent CO_2. Table 15 shows the GWP of typical GHGs. As an example, GWP of CH_4 is 28 times greater than that of CO_2.

Table 15. Global Warming Potentials (GWPs) of Greenhouse Gases (GHGs)

Greenhouse Gases (GHGs)	**Global Warming Potential (GWP)**
Carbon Dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous Oxide (N_2O)	298
Chlorofluorocarbon (CFCs)	1,430

EPA annually releases transportation related GHG emissions in millions of metric tons (MMT). Table 16 presents emissions in the U.S. for year 2009 through 2013 (EPA 2015). These values are corrected with the GWP of each pollutant.

Table 16. GHG Emissions by Vehicle Type

Vehicle Type	**GHG**	**Emissions in CO_2 Equivalent Values (MMT)**				
		2009	**2010**	**2011**	**2012**	**2013**
Passenger Vehicle	CO_2	748.0	742.0	736.9	735.6	735.5
	CH_4	1.2	1.2	1.2	1.1	1.1
	N_2O	13.8	12.9	12.3	10.7	9.4
	CFC	29.9	27.5	23.9	20.6	17.3
	Total	**792.9**	**783.6**	**773.4**	**768.0**	**763.3**
Truck	CO_2	375.1	388.4	386.8	386.8	393.2
	CH_4	0.1	0.1	0.1	0.1	0.1
	N_2O	1.2	1.2	1.1	1.1	1.1
	CFC	13.2	13.2	13.3	13.3	13.3
	Total	**389.6**	**403.0**	**401.3**	**401.4**	**407.7**

In order to calculate the emission rates in terms of lbs/mile, the total annual miles travelled by passenger vehicles and trucks are required. As an example, in 2013, passenger vehicles and trucks travelled 2,074,458 million miles and 106,582 million miles throughout the U.S., respectively (FHWA 2013a). The primary reason for including Highway Statistics provided by FHWA for 2013 are (i) to be compatible with the most recent data given in Table 16 and (ii) to have the most recent data at the time this study is developed.

The unit cost of CO_2 is required to calculate the impact of climate change. According to EPA (2016), the average unit cost of climate change is $\$1.8665\times10^2$ per a pound of CO_2 for 2015. EPA uses the term "social cost of carbon" and this terminology will be utilized throughout the document.

Business Revenue Change

Bridge construction disrupts traffic flow and direct customer access to surrounding businesses. The change in regular flow of customers could result in either an increase in business revenue or a loss (De Solminac and Harrison 1993). Even though loss in business revenue is temporary, the negative impacts is a major concern because it can lead to closure of some businesses (Wolffing et al. 2004). At present, there is limited literature on quantification of business revenue change. Wolffing et al. (2004) and Schieck and Young (2005) conducted research evaluating economic impacts on surrounding businesses during and after highway rehabilitation projects in Wyoming. A number of Wyoming cities was identified as a case study and the economic impact was calculated from tax revenue data and data collected through surveys. It was reported that the survey results are likely to be more pessimistic during construction than the findings from actual tax data analysis. Schieck and Young (2005) and Wolffing et al. (2004) observed an increase in revenue for certain businesses while others showed a shortfall in revenue. In limited number of cities, there was a slight increase (~3%) in overall business revenue while a majority of the cities showed a decline in business revenue (~10%) during construction.

Handy et al. (2000), Kockelman et al. (2000), and Mills and Fricker (2011) evaluated business revenue change during a bypass construction projects using econometric models such as panel data analysis, mixed effects models, and spatial econometric models. Panel data analysis and mixed effects models combine time series data (e.g. years between 1970-1997) with cross sectional data (e.g. 7 cities) (Mills and Fricker 2011). Panel data analysis has closed form which can be solved via linear algebra. In contrast, mixed effects model does not have closed form, hence it must be solved by nonlinear numerical optimization (Croissant and Millo 2008). In addition to time series and cross sectional data, spatial econometric models include social interactions which are not directly observable (Mills and Fricker 2011). The application of these models requires local sales data for an adequate number of locations and for a long duration to generate a large sample to achieve statistical accuracy. The data was obtained through the U.S. Census of Retail

Trade, the U.S Census of Population and Housing, local traffic counts in the study of Mills and Fricker (2011). In addition to those data sources, local sales tax data was used in the studies of Handy et al. (2000) and Kockelman et al. (2000). Traffic data, employment rate etc. play a significant role when using these econometric models. Findings from the studies show 31% to 11% business revenue loss in a city with a population of around 5000. Whereas, in cities with a population around 13,000, the business revenue loss was as high as 63% while the gain was about 1%.

Gangavarapu et al. (2004), Matthews et al. (2014), Islam et al. (2014) evaluated economic impact from open cut methods vs trenchless techniques to justify implementation of trenchless technology with a high initial cost. Gangavarapu et al. (2004) qualitatively evaluated business revenue change from open cut methods, however, did not provide a quantification method. Matthews et al. (2014) suggested a method for quantification of business revenue loss and applied the method to a case study which is an upgrade of a sewer system in Kessel-Dorp, Belgium. The outcome of the case study shows that business revenue loss with open cut method is more than 8 times the one with trenchless technique. Islam et al. (2014) presented a new software including calculation of business revenue loss, however, neither background methodology nor outcome is provided.

Konduri et al. (2013); Forkenbrock and Weisbrod (2001); Gilchrist and Allouche (2004); the National Cooperative Highway Research Program (NCHRP) (2002), and the California Department of Transportation (CALTRANS) (2011) show that evaluating business revenue change requires defining a commercial area influenced by the bridge construction since the effect of it occurs within a distance. This area is defined with the term "influence area". The boundaries should be set during bridge construction (NCHRP 2002). NCHRP (2002) describes techniques for determining boundaries of influence area as shown below:

1-) Boundaries are set based on the limits of political jurisdictions or geographical features.

2-) Boundaries depend on changes in accessibility therefore trafficshed.

3-) Influence area location and boundaries are defined by consulting experts in this field.

The techniques given above are simple yet powerful methods as long as they are presented with detailed descriptions and maps showing how they are developed (NCHRP 2002). In addition, the Wisconsin Department of Transportation (WisDOT) (2014) reports that boundaries of influence area can be established by utilizing traffic demand models, which is a computer model used to estimate travel behavior and travel demand, depending on the complexity of the road network.

Data Need and Sources for Economic Impact Analysis

Use of site-specific data is important to accurately evaluate economic impact on surrounding businesses and communities. Even though there are different methodologies for site-specific data collection, data collection through community surveys is a feasible and powerful technique (the Office of Quality Improvement (OQI) 2010). OQI (2010) and Peters (2016) suggest the following steps to conduct an effective survey:

Step 1. Design the survey process after defining the goals, target population, timeline, and the survey methods.

Step 2. Develop questions and make sure that the questions are valid, easy to understand, and yields reliable results.

Step 3. Train the survey (Note: Writing a survey is an iterative process. This requires reviewing, testing, and revising survey questionnaire to yield reliable results).

Step 4. Execute the survey and collect data.

Step 5. Analyze data and generate conclusions.

According to (Kelley et al. 2003), the primary objective of conducting a survey is to collect data on a certain site or a problem, as well as to educate the participants - the public. The education purpose of survey can be achieved through informative paragraphs or questions which create awareness. A survey can have either of or both these objectives. In that case, the survey goals are determined and the questions are designed such that the answers fall into four main categories; i) nominal - indicating specific names or colors, ii) ordinal - indicating categories of importance, iii) interval - giving ordered values, and iv) ratio - requiring precise measurement to help data analysis and interpretation of results.

Summary

Economic impact and safety within construction zones are two major parameters considered when evaluating bridge construction methods for a specific site. ABC methods are implemented over CC techniques to reduce the roadway closure duration termed as mobility impact time. The strict time constraints will always be a part of ABC to achieve the main purpose, reduction in mobility impact time. These time constraints can be satisfied by using innovative techniques and additional work, which lead to additional costs. Hence, the project cost of ABC is 6% to 21% greater than CC depending on site complexity, time constraints, and perceived risks (Aktan and Attanayake 2015). Even though the initial project cost is higher, ABC yields many benefits that can be quantified using site-specific data or evaluated qualitatively based on experience on completed project. Traditionally, the savings in user cost from reduced mobility impact time is defined as a benefit of ABC implementations. However, there are other economical impacts on neighboring businesses and communities from bridge projects.

Ferguson (2012) qualitatively evaluated economic impact on surroundings in terms of user cost, environmental cost, and business revenue change. The outcome from surveys indicated negative impacts on communities and businesses surrounding a construction site. Matthews et al. (2014), Gilchrist and Allouche (2004), and Islam et al. (2014) analyzed the impact of a project by considering user cost, environmental cost, and business revenue change. Matthews et al. (2014) evaluated trenching technologies and demonstrated methods to quantify eight cost categories including user cost, business revenue change, and noise as subcategories of economic impact analysis. Gilchrist and Allouche (2004) described adverse effects of a construction project from road closure and developed valuation methods for air pollution, noise, loss of productivity, etc. Islam et al. (2014) used a software developed by Trenchless Technology Center (TTC) to compare five water infrastructure alternatives. The author considered cost parameters including traffic delay, air pollution, noise pollution, and business revenue loss. Aktan and Attanayake (2015) evaluated economic impact of bridge construction. They evaluated the impact on surrounding businesses qualitatively but quantified the economic impact on surrounding communities using a predefined county economic value multiplier (Aktan and Attanayake 2015). The authors utilized mobility impact time to convert quantitative values into preference ratings with the help of Michigan Accelerated Bridge Construction Decision (Mi-ABCD) tool.

Even though large scale of approaches are documented in literature, only a few of them present comprehensive analyses of economic impact. Based on the primary objective of this research, which is to present the analysis process for quantifying economic impact of bridge construction on surrounding communities and businesses, the project impacts are grouped under three major cost categories (a) user cost, (b) environmental costs, and (c) business revenue change.

CHAPTER III

ECONOMIC IMPACT ANALYSIS OF BRIDGE CONSTRUCTION

Economic Impact Analysis Need in Bid Evaluation Practices

Traditional contractual and bid evaluation practices account for initial project cost and user cost for selection of bridge construction alternatives (Aktan and Attanayake 2015). These limitations result in the lowest initial project cost to be the more favorable choice (Heiber 1996). However, there has been a growing awareness among the highway departments and the public to the fact that bridge construction activities bring many disturbances to its surroundings (Gilchrist and Allouche 2004). The public has started to expect that the bridge construction activities will not impact the quality of social and economical life and seek for alternative construction methods and technologies (Gilchrist and Allouche 2004). In this manner, accelerated bridge construction (ABC) methods are implemented by highway departments over conventional construction (CC) techniques to reduce mobility impact time, hence, mitigate effects of unwanted disturbances from bridge construction. To be able to justify bridge alternatives through economic impact on surroundings, economic impact analysis should be incorporated in cost estimate and bid evaluation processes (Setunge 2002; Klatter et al. 2004). This study proposes a model to quantify economic impact on surrounding communities and businesses that can be utilized in justification of bridge construction alternatives. Even though the focus is limited to bridge construction projects, the economic impact analysis model presented in this research is sufficient to evaluate impacts of highway construction in general.

Definition of Surroundings

The term “surroundings” refers to ecological, sociological, and economical systems neighboring bridge construction site or that are directly impacted by construction activities in the context of this study (Gilchrist and Allouche 2004). Economic impact on surroundings is further divided into two categories; i) communities, and ii) businesses. This classification depends on the costs on communities or businesses having direct effect on the flow of dollars or not (Forkenbrock and Weisbrod 2001). User cost of passenger vehicles and environmental cost which contribute to economic impact on surrounding communities (Figure 3) do not have an immediate direct effect on flow of dollars. They are quantified in terms of their respective monetary values. On the other hand, user cost of trucks and business revenue change, which are components of economic impact on surrounding businesses (Figure 3), have a direct impact on flow of dollars as well as local, state and federal tax revenue. If a business suffers from lack of customers solely due to bridge construction, business revenue loss occurs in terms of real monetary amount.

Overview

Chapter 2 presents quantification models for (a) user cost, (b) environmental cost, and (c) business revenue change. This chapter presents a comprehensive model to quantify economic impact on surrounding communities and businesses.

Cost categories of economic impact of bridge construction are summarized in Figure 3. As shown in Figure 3 economic impact is quantified using user cost, environmental cost, and business revenue change. User cost (for passenger vehicle drivers and passengers) and environmental cost from air pollution, water pollution, and climate change are considered for quantifying economic impact on surrounding communities. Impact of air pollution is quantified considering health care cost and general cost. Economic impact on surrounding businesses is quantified by calculating user cost for trucks and business revenue change. The scope of analysis presented in this chapter is limited to the construction duration only and the impacts during other life-cycle activities such as Capital Preventive Maintenance (CPM) and Capital Scheduled Maintenance (CSM) are not included.

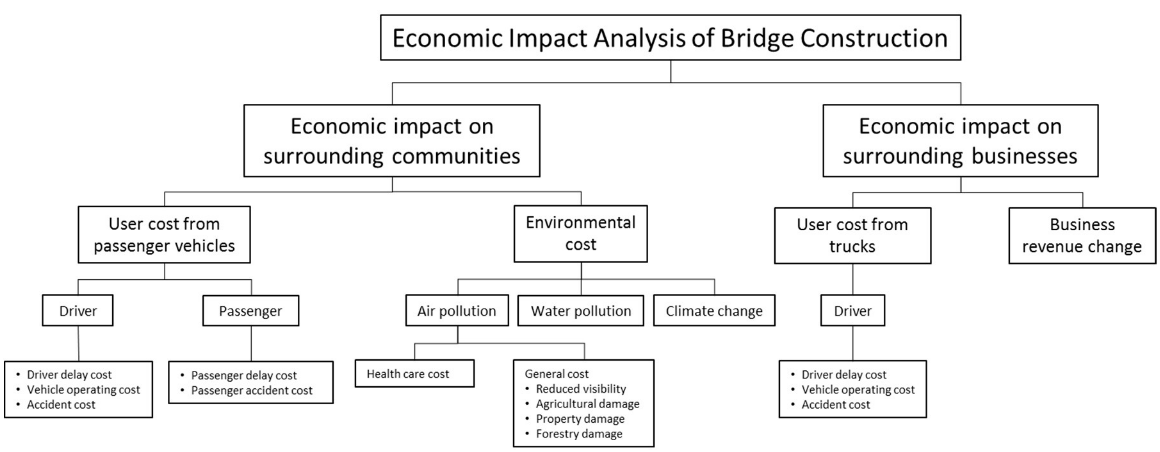


Figure 3. Cost categories for economic impact analysis.

Economic Impact on Surrounding Communities

As shown in Figure 3, economic impact on surrounding communities is evaluated using user cost and environmental cost. User cost includes driver and passenger costs while the environmental cost includes impact of air pollution, water pollution, and climate change. Impact of air pollution is quantified using heath care cost and general cost. General cost are from reduced visibility, agricultural damage, property damage, and forestry damage.

User Cost

Eq. 3, 4, and 5 define user cost due to work zone as driver delay cost (DDC), vehicle operating cost (VOC), and accident cost (AC) respectively (Aktan and Attanayake 2015; Ehlen and Marshall 1996; Walls and Smith 1998).

$$DDC = \left[\frac{L}{S_a} - \frac{L}{S_n}\right] \cdot ADT_{pv} \cdot N \cdot w_{pvd} \tag{3}$$

$$VOC = \left[\frac{L}{S_a} - \frac{L}{S_n}\right] \cdot ADT_{pv} \cdot N \cdot r_{pv} \tag{4}$$

$$AC = L \cdot ADT_{pv} \cdot N \cdot \left(A_{apv} - A_{npv}\right) \cdot C_a \tag{5}$$

where, 'L' is length of the affected roadway due to bridge construction (i.e., work zone length); 'S_a' is work zone speed limit; 'S_n' is normal speed limit of roadway; 'ADT_{pv}' is average daily passenger vehicle traffic; 'N' is construction duration in days affecting the work zone; 'w_{pvd}' is hourly rate for passenger vehicle drivers; 'r_{pv}' is average hourly vehicle operating cost for passenger vehicles; 'A_{apv}' is accident rate per passenger vehicle-mile due to work zone; 'A_{npv}' is normal accident rate for passenger vehicles; and 'C_a' is average cost per accident (includes damage to the driver and the vehicle).

The user cost also includes passenger cost and calculated using average vehicle occupancy (AVO). AVO represents the number of people in a passenger vehicle, including the driver (Paracha and Mallela 2011). Hence (AVO -1) represents the number of passengers. Eq. 3 and Eq. 5 are modified, as shown in Eq. 6 and Eq. 7, to calculate the passenger delay cost (PDC) and passenger accident cost (PAD). Vehicle operating cost is not included in passenger cost and only included in the driver cost.

$$PDC = \left[\frac{L}{S_a} - \frac{L}{S_n}\right] \cdot ADT_{pv} \cdot N \cdot w_p \cdot (AVO - 1) \tag{6}$$

$$PAC = L \cdot ADT_{pv} \cdot N \cdot \left(A_{apv} - A_{npv}\right) \cdot C_{ap} \cdot (AVO - 1) \tag{7}$$

where, 'w_p' is hourly rate for a passenger; 'C_{ap}' is average medical cost per accident per person (i.e., accident cost excluding cost of damages to the vehicle).

During bridge construction, with the facility carried being closed to traffic, a detour route is designated. The user cost that includes driver delay cost (DDC), vehicle operating cost (VOC), accident cost for drivers (AC), passenger delay cost (PDC), and passenger accident cost (PAC), due to detour arising from the additional distance travelled on detour are calculated using Eq. 8 to Eq. 12 (Aktan and Attanayake 2015; Ehlen and Marshall 1996; Walls and Smith 1998).

$$DDC = \left(T_{Dpv} - T_{WZpv}\right) \cdot V_{pv} \cdot T_M \cdot w_{pv} \tag{8}$$

$$VOC = \left(T_{Dpv} - T_{WZpv}\right) \cdot V_{pv} \cdot T_M \cdot r_{pv} \tag{9}$$

$$AC = (L_{Dpv} - L_{WZpv}) \cdot V_{pv} \cdot T_M \cdot A_{npv} \cdot C_a \tag{10}$$

$$PDC = \left(T_{Dpv} - T_{WZpv}\right) \cdot V_{pv} \cdot T_M \cdot w_p \cdot (AVO - 1) \tag{11}$$

$$PAC = (L_{Dpv} - L_{WZpv}) \cdot V_{pv} \cdot T_M \cdot A_{npv} \cdot C_{ap} \cdot (AVO - 1) \tag{12}$$

where, 'T_{Dpv}' is time to travel via detour for passenger vehicles; 'T_{WZpv}' is time to travel along a distance equal to the road segment closed due to construction at the normal posted speed; 'V_{pv}' is volume of passenger vehicle traffic on the roadway to be closed during construction; 'T_M' is the mobility impact time; 'L_{Dpv}' is the length of detour for passenger vehicles; 'L_{WZpv}' is the length of the road segment closed to passenger vehicles during construction.

Environmental Cost

Air pollution, water pollution and other forms of environmental damage are a result of motor vehicle use (Delucci 2000). As it is shown in Figure 3, impact of air pollution, water pollution, and climate change are three major categories considered for calculating the environmental cost that contributes to economic impact on surrounding communities. Use of heavy machinery and construction equipment also contribute to environmental cost; however, the procedures presented in this study only considers the passenger vehicle and truck traffic impacts.

Air Pollution

Health care cost and general cost are the two major categories impacted from air pollution. General cost represents non-health impacts such as i) reduced visibility, ii) agricultural damage, iii) property damage, and iv) forestry damage.

Health Care Cost

Air pollutants have serious impact on human health such as acute and chronic health diseases, premature mortality, and cardiovascular diseases (Cohen et al. 2005; Craig et al. 2005; Gwilliam et al. 2004; Sirikijpanickul et al. 2006). Health care cost can be calculated by using treatment cost data for variety of disorders related with air pollution from motor vehicle use.

The pollutants impacting health, used in the analysis are carbon monoxide (CO); nitrogen dioxide (NO_2); volatile organic compounds (VOC); and particulate matter (PM). Particulate matter considered in this study includes PM less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$) and PM between 2.5 microns and 10 microns (coarse PM_{10}). The cost of a pollutant for passenger vehicles and trucks respectively when traffic is allowed through work zone during construction are represented by Eq. 13 and Eq. 14. The health care cost from a pollutant (CP) for passenger vehicles and trucks respectively when travelling through detour during T_M are represented in Eq. 15 and Eq. 16. Speed correction factor (SCF) is used because the emission rate of a pollutant is a function of speed. The emission rates presented in literature is for an average speed and requires modifying if the data shows a statistical difference with speed.

$$CP = UC_p \cdot E_{pv} \cdot ADT_{pv} \cdot N \cdot L \cdot (SCF_{NSpv} - SCF_{WZpv}) \tag{13}$$

$$CP = UC_p \cdot E_t \cdot ADTT \cdot N \cdot L \cdot (SCF_{NSt} - SCF_{WZt}) \tag{14}$$

$$CP = UC_p \cdot E_{pv} \cdot V_{pv} \cdot T_M \cdot \left(L_{Dpv} \cdot SCF_{Dpv} - L_{WZpv} \cdot SCF_{NSpv}\right) \tag{15}$$

$$CP = UC_p \cdot E_t \cdot V_t \cdot T_M \cdot (L_{Dt} \cdot SCF_{Dt} - L_{WZt} \cdot SCF_{NSt}) \tag{16}$$

where 'UC_p' is unit cost of a pollutant, 'E_{pv}' is emission of a pollutant from a passenger vehicle; 'E_t' is emission of a pollutant from a truck; 'ADTT' is the average daily truck traffic; 'SCF_{NSpv}' and 'SCF_{NSt}' are the speed correction factors for normal speed limit within the road segment with no construction for passenger vehicles and trucks respectively; 'SCF_{WZpv}' and 'SCF_{WZt}' are the work zone speed correction factors for passenger vehicles and trucks respectively; 'L_{Dt}' is the length for detour for trucks; 'L_{WZt}' is the length of the road segment closed to trucks during construction; 'SCF_{Dpv}' and 'SCF_{Dt}' are detour speed correction factors for passenger vehicles and trucks respectively; 'V_t' is volume of truck traffic on the roadway to be closed during construction.

Emission rate of each pollutant is different, thus, as shown in Eq. 17, the total health care cost of passenger vehicles from pollutants (HC_{pv}) is represented as the summation of cost of each pollutant. Similarly, Eq. 18 shows the associated health care cost from truck traffic (HC_t). Finally, the total health care cost (HC) is calculated as the summation of HC_{pv} and HC_t as shown in Eq. 19.

$$HC_{pv} = CP_{CO} + CP_{NO2} + CP_{VOC} + CP_{PM2.5} + CP_{PM10} \tag{17}$$

$$HC_t = CP_{CO} + CP_{NO2} + CP_{VOC} + CP_{PM2.5} + CP_{PM10} \tag{18}$$

$$HC = HC_{pv} + HC_t \tag{19}$$

General Cost

The impact of pollution on visibility and damages to property, agriculture, and forestry are included into general cost. The reduced visibility cost is defined based on the asset value of homes. The agricultural damage cost is defined based on crop shortfalls. The property damage cost is defined based on discoloration and building facade damage. The forestry damage cost is defined based on the decline in timber growth from air pollution (Delucci et al. 1996; Delucci et al. 1998; Delucci et al. 2000; Delucci 2000; the Swiss Federal Office for Spatial Development (ARE) 2010). In this study, general cost is defined as a percentage of health care cost of air pollution defined with a lower and upper bounds as shown in Table 10. For the rest of the calculations presented in this study, the average of lower and upper bounds are used (Table 17).

Table 17. General Cost as an Average Percentage of Health Care Cost

General Cost Category	General Cost (% of Health Care Cost)
Reduced visibility	14.5
Agricultural damage	8.5
Property damage	4.0
Forestry damage	1.0

Water Pollution

Transportation activities cause fuel and chemical discharge and spills which contaminate the watershed. The impact of contamination is harmful to human health, and can harm or kill wildlife (Delucci and McCubbin 2010). Eq. 20 and Eq. 21 show the quantification of water pollution damage from passenger vehicles (WP_{pv}) and trucks (WP_t) from a bridge construction, respectively. Total water pollution damage (WP) is calculated as the summation of WP_{pv}, and WP_t as shown in Eq. 22. WP is measured in terms of extra miles a vehicle has to travel due to a detour.

$$WP_{pv} = UC_{wpv} \cdot V_{pv} \cdot T_M \cdot (L_{Dpv} - L_{WZpv}) \tag{20}$$

$$WP_t = UC_{wt} \cdot V_t \cdot T_M \cdot (L_{Dt} - L_{WZt}) \tag{21}$$

$$WP = WP_{pv} + WP_t \tag{22}$$

where 'UC_{wpv}' is the unit cost of water pollution from per mile travel of passenger vehicle; 'UC_{wt}' is the unit cost of water pollution per ton-mile travel of trucks.

Climate Change

Emissions from transportation activities contribute to climate change. The pollutants are called greenhouse gases (GHG) and consist of carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (N_2O), and chlorofluorocarbons (CFCs). To express the global warming contributions of different GHGs, global warming potential (GWP) concept is developed. It is an international standard expressing GHG in terms of equivalent CO_2 emissions.

Impact to climate change (CC) is calculated using the equivalent amount of total CO_2 emissions (E) and the unit social cost of CO_2 (SC_{CO2}) (Environmental Protection Agency (EPA) 2013). Eq. 23 and Eq. 24 show the impact to climate change from passenger vehicles and trucks respectively when traffic is allowed in the work zone during construction. Eq. 25 and Eq. 26 represent impact to climate change from passenger vehicles and trucks respectively travelling through detour during T_M. Similar to health care cost quantified under air pollution cost, SCF is included for modification of emissions given for an average speed.

Emission rate of GHG therefore CO_2 is different for passenger vehicles and trucks. Hence, total impact to climate change (CC) is the summation of impact to climate change from passenger vehicles (CC_{pv}), and trucks (CC_t) (Eq. 27).

$$CC_{pv} = SC_{CO2} \cdot E_{pv} \cdot ADT_{pv} \cdot N \cdot L \cdot (SCF_{NSpv} - SCF_{WZpv}) \quad (23)$$

$$CC_t = SC_{CO2} \cdot E_t \cdot ADTT \cdot N \cdot L \cdot (SCF_{NSt} - SCF_{WZt}) \quad (24)$$

$$CC_{pv} = SC_{CO2} \cdot E_{pv} \cdot V_{pv} \cdot T_M \cdot \left(L_{Dpv} \cdot SCF_{Dpv} - L_{WZpv} \cdot SCF_{NSpv}\right) \quad (25)$$

$$CC_t = SC_{CO2} \cdot E_t \cdot V_t \cdot T_M \cdot (L_{Dt} \cdot SCF_{Dt} - L_{WZt} \cdot SCF_{NSt}) \quad (26)$$

$$CC = CC_{pv} + CC_t \quad (27)$$

where 'E_{pv}' is equivalent amount of total CO_2 emission from passenger vehicles; 'E_t' is equivalent amount of total CO_2 emission from trucks.

Economic Impact on Surrounding Businesses

Economic impact on surrounding businesses measure consists of user cost and business revenue change due to bridge construction. In this study, a method of quantification is presented for user cost of commercial vehicles, the change in businesses revenue due to traffic disruption, and therefore customer access disruption to businesses.

User Cost

The user cost of trucks contributes to economic impact on surrounding businesses. Similar to user cost from passenger vehicles, Eq. 28, 29, and 30 represent driver delay cost (DDC), vehicle operating cost (VOC), and accident cost (AC) respectively for trucks within the work zone during construction (Aktan and Attanayake 2015; Ehlen and Marshall 1996; Walls and Smith 1998).

$$DDC = \left[\frac{L}{S_a} - \frac{L}{S_n}\right] \cdot ADTT \cdot N \cdot w_t \tag{28}$$

$$VOC = \left[\frac{L}{S_a} - \frac{L}{S_n}\right] \cdot ADTT \cdot N \cdot r_t \tag{29}$$

$$AC = L \cdot ADTT \cdot N \cdot (A_{at} - A_{nt}) \cdot C_a \tag{30}$$

where, 'w_t' is hourly rate for a truck driver; 'r_t' is average hourly vehicle operating cost for a truck; 'A_{at}' is accident rate per truck-mile due to work zone; and 'A_{nt}' is normal accident rate for trucks.

During bridge construction when the facility carried is closed to traffic, trucks travel along designated detours. Therefore, user cost needs to include the additional costs due to travel along the detours similar to the procedure described in Chapter II- User Cost. Aktan and Attanayake (2015), Ehlen and Marshall (1996), and Walls and Smith (1998) proposed Eq. 31 for driver delay cost (DDC) and Eq. 32 for vehicle operating cost (VOC), Eq. 33 for accident cost (AC) for trucks travelling through detour.

$$DDC = (T_{Dt} - T_{WZt}) \cdot V_t \cdot T_M \cdot w_t \tag{31}$$

$$VOC = (T_{Dt} - T_{WZt}) \cdot V_t \cdot T_M \cdot r_t \tag{32}$$

$$AC = (L_{Dt} - L_{WZt}) \cdot V_t \cdot T_M \cdot A_{nt} \cdot C_a \tag{33}$$

where, 'T_{Dt}' is time to travel via detour for trucks; 'T_{WZt}' is time to travel along a distance equal to the road segment closed due to construction at the normal posted speed for trucks; 'V_t' is volume of truck traffic on the roadway to be closed during construction; 'T_M' is the mobility impact time; 'L_{Dt}' is the length of detour for trucks; 'L_{WZt}' is the length of the road segment closed to trucks during construction.

Business Revenue Change

Bridge construction disrupts the traffic flow, therefore the customer flow to surrounding businesses. The disruption of regular flow of customers could result in either positive or negative revenue change. The business revenue change during the road closure is a component of economic impact on surrounding businesses.

The objective of the procedure given below is to quantify the business revenue loss since it is described as a concern in the literature discussed in Literature Review- Business Revenue Change section.

The business revenue loss (ΔR) is directly linked to the change in number of customer (ΔC). It is also a function of average expenditure per household (AE), and mobility impact time (T_M) as it is shown in Eq. 34.

$$\Delta R = AE \cdot \Delta C \cdot T_M \quad (34)$$

Influence area is an important parameter in the quantification of revenue change. Influence area indicates that the businesses in that area experience revenue loss. In order to collect site-specific data or conduct impact mitigation studies, the influence area is needed to be specified. The influence area of a bridge construction project is established by either utilizing the traffic demand models or with a simple evaluation of the road network, depending on the complexity of the road network (the Wisconsin Department of Transportation (WisDOT) 2014).

The change in the number of customers require the location of households without direct access to the influence area of the bridge construction during mobility impact time. The influence area can be defined by unifying the mid-points of shortest distances to the closest commercial centers. The number of households in the area without direct access can be calculated using the city maps depending on the simplicity of the traffic network. If the traffic network is large and complex, the manual calculations can be cumbersome. In this case, the traffic demand models should be utilized.

The change in number of customers as shown in Eq. 35, is a function of number of households without direct access (HWA) during mobility impact time, percent of households without direct access and avoiding the area influenced by the project (P), and the frequency of patronizing a specific business (F).

$$\Delta C = HWA \cdot P \cdot F \tag{35}$$

The cost can be calculated from reasonable estimates of P, and F or more rational quantification for business revenue loss can be obtained if site-specific values of P and F are established using survey data. Hence, a survey can be conducted including following questions or similar ones to determine site-specific data on P, and F:

- If bridge is closed to traffic for _____ days, would you still travel to the area influenced by the construction and continue your routine shopping, eating, etc.?

- If your answer to the above question is *NO*, what category of business/store (gas station, party store, grocery store, pharmacy, auto repair, etc.) located within the influence area would you still make an effort to go to?

- When there is no construction, how often do you go to the following businesses/stores?
  Restaurants:________ per week
  Party/liquor Store:__________ per week
  Gas Stations:________ per month
  Pharmacy:__________ per quarter
  Auto Repair:________ per quarter

The application of survey can be upgraded to an automated survey by employing mobile devices which allow participants to view and edit their travel behavior with the use of maps. In addition to surveys, there are recently developed apps to record travel behavior to obtain more refined data on percent of households without direct access and avoiding the area influenced by the project (P), and the frequency of patronizing a specific business (F).

Case Study – ABC in Potterville, MI

The M-100 over CN Railroad in Potterville, Michigan, shown in Figure 4 is the 3rd sliding project implemented by the Michigan Department of Transportation (MDOT). Insufficient under clearance over the railroad required the bridge replacement. Even though the bridge is not highly special, it links the school district to emergency services and the residential areas in Potterville. Moreover, the alternative detours for the bridge are overlong. As a solution, Slide – in Bridge Construction (SIBC) alternative, which is an ABC technology, was chosen for this project. The Federal Highway Administration (FHWA) (2013b) explains the SIBC procedure in "Slide-in Bridge Construction Implementation Guide". According to FHWA (2013b), SIBC allows for the new bridge to be built on temporary supports adjacent to the existing one (Figure 4). Hence, traffic on the existing bridge is not disrupted but speed limits are reduced due to work zone activities nearby while construction of the new bridge continues. Once construction is completed, the traffic is detoured due to road closure. Then the existing bridge is demolished and the new bridge is slid into its final alignment.

Figure 4. Bridge location

The bridge was slid in final alignment during a weekend (November 14-15, 2015) with a mobility impact time (T_M) of 2 days. SIBC projects require mobility impact time of seven hours to seven days since the demolishing and sliding process can be finalized in this short notice (FHWA 2013b). The total duration of construction activities at the work zone (N) was 237 days requiring reduced speed limits. For comparison purposes, conventional construction (CC) which requires a mobility impact time (T_M) of 180 days is considered. The detour length (L_{Dpv}, L_{Dt1}, and

L_{Dt2}), the length of the affected roadway due to bridge construction (i.e., work zone length) (L), speed limits (S_n, S_a, V_{WZpv}, V_{WZt}, V_{Dpv}, and V_{Dt}), average daily passenger vehicle traffic (ADT_{pv}), and average daily truck traffic (ADTT) are obtained from the project data. The length of detour for trucks is measured with two different parts as L_{Dt1}, and L_{Dt2} since their speed limits are different. 'V_{WZpv}' and 'V_{WZt}' are speed limits of the closed section of the road for passenger vehicles and trucks respectively. 'V_{Dpv}' and 'V_{Dt}' are speed limits when travelling through detour for passenger vehicles and trucks respectively.

The comparative values of parameters for SIBC and CC are given in Table 18. The data are obtained from project data, city maps and traffic regulations. The length of the affected roadway due to bridge construction (i.e., work zone length) (L) is established as shown in Figure 5 based on the reduced speed limit signals start, and end locations. Normal speed limit of roadway (S_n) was 55 mph and reduced to work zone speed limit (S_a) of 25 mph due to construction activities. The length of detour (L_D), and the length of the road segment closed during construction (L_{WZ}) are needed separately for passenger vehicles, and trucks since their designated detours are different based on traffic management plans of the bridge. Figure 6 shows the length of the detour and length of the road segment closed during construction for passenger vehicles. Figure 7 shows the length of the detour and length of the road segment closed during construction for trucks.

Table 18. Project Specific Parameters and Respective Values

Parameters	SIBC	CC
T_M	2 days	180 days
N	237 days	-
L	0.5 mile	-
ADT_{pv}	5045 vehicles/day	5045 vehicles/day
ADTT	190 vehicles/day	190 vehicles/day
S_a	25 mph	-
S_n	55 mph	-
L_{WZpv}	1.6 mile	1.6 mile
V_{WZpv}	55 mph	55 mph
T_{WZpv}	0.029 hr	0.029 hr
L_{Dpv}	4.5 mile	4.5 mile
V_{Dpv}	35 mph	35 mph
T_{Dpv}	0.129 hr	0.129 hr
L_{WZt}	8.5 mile	8.5 mile
V_{WZt}	55 mph	55 mph
T_{WZt}	0.141 hr	0.141 hr
L_{Dt1}	9.8 mile	9.8 mile
L_{Dt2}	3.6 mile	3.6 mile
V_{Dt1}	60 mph	60 mph
V_{Dt2}	55 mph	55 mph
T_{Dt}	0.229 hr	0.229 hr

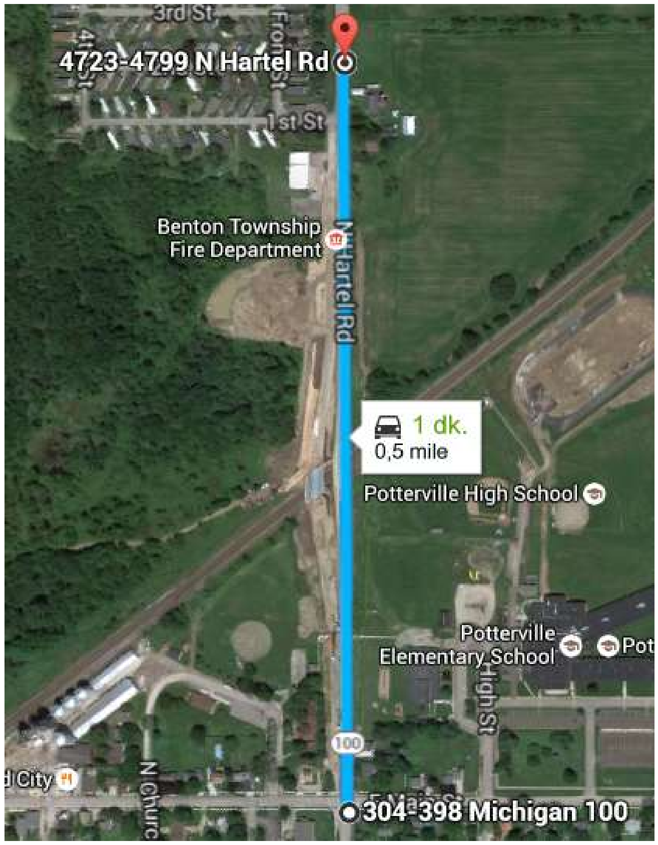


Figure 5. Length of the affected roadway due to bridge construction (L) (i.e. work zone length)

Figure 6. Length of detour, and road segment closed during construction for passenger vehicles

Figure 7. Length of detour, and road segment closed during construction for trucks

Economic Impact on Surrounding Communities, Potterville

User Cost

The user cost parameters, and databases are given in Table 19 for Potterville case study. Explanations and derivations of input parameters are provided below;

- Hourly rate for a passenger vehicle driver (w_{pv}) and hourly rate for a passenger (w_p) are obtained by considering the local travel category given in Table 2 in Chapter II - User Cost section (USDOT 2014).

- Hourly rate for a passenger (w_p) is defined as 70% of hourly rate of driver (w_{pv}) (Litman 2013).

- Average hourly vehicle operating cost for passenger vehicles (r_{pv}) is given in units of 'dollar per mile' (the American Automobile Association (AAA) 2015). It is assumed that passenger vehicle speed is 55 miles per hour; and, the average hourly vehicle operating cost for a passenger vehicle is calculated in 'dollar per hour' by multiplying units of 'dollar per mile' and units of 'miles per hour'.

- Normal accident rate for passenger vehicles (A_{npv}) is calculated by dividing the number of total injury level accidents in Michigan in 2014 (52,523) (the Michigan Office of Highway Safety and Planning (MOHSP) 2014) by annual vehicle miles travelled in Michigan in 2014 (97.1 billion) (the Michigan Department of Transportation (MDOT) 2016). In order to obtain normalized accident rate for passenger vehicles, the ratio is multiplied with the percentage of involvement (77.9% for passenger vehicles) given by MOHSP (2014).

- Accident rate per vehicle-mile due to work zone (A_{apv}) is calculated by multiplying normal accident rate for passenger vehicle (A_{npv}) by average crash modification factor 'CMF' (FHWA 2015).

- Average cost per accident (C_a) and is average medical cost per accident per person (C_{ap}) are obtained depending on the minor injury assumption since the speed limits are relatively low (Kostyniuk et al. 2011).

- Average vehicle occupancy (AVO) is obtained for all trip purposes in 2009 (Paracha and Mallela 2011).

- Volume of passenger vehicle traffic on the roadway to be closed during construction (V_{pv}) is assumed to be equal to average daily passenger vehicle traffic (ADT_{pv}) assuming that 100% of users travel through designated detour.

Table 19. User Cost Calculation Parameters and Data for Economic Impact on Surrounding Communities (2015 Value)

Databases	Parameters	SIBC	CC
USDOT 2014	w_{pv}	$12.67/vehicle/hr	$12.67/vehicle/hr
USDOT 2014; Litman 2013	w_p	$8.87/vehicle/hr	$8.87/vehicle/hr
AAA 2015	r_{pv}	$31.90/vehicle/hr	$31.90/vehicle/hr
OHSP 2014; MDOT 2016	A_{npv}	4.21 accidents/10 million veh-mile	4.2 accidents/10 million veh-mile
FHWA 2014	CMF	1.77	-
OHSP 2014; MDOT 2016; FHWA 2014	A_{apv}	7.45 accidents/10 million veh-mile	-
Kostniuk et al. 2011	C_a	$43,501/accident	$43,501/accident
Kostniuk et al. 2011	C_{ap}	$38,579/accident	$38,679/accident
NHTS 2009	AVO	1.67	1.67
Project data	V_{pv}	5,235 vehicles/day	5,235 vehicles/day

The analysis results of the user cost model for the economic impact on surrounding communities are given in Table 20. The costs are presented for driver delay cost (DDC), vehicle operating cost (VOC), accident cost (AC), passenger delay cost (PDC), and passenger accident cost (PAC) while commuters travelling thorough work zone and detour. The cost analysis is based on the Potterville specific data shown in Table 18, and Table 19. User cost of passenger vehicles with SIBC is slightly below $725,000 while with CC is about $4,640,000. Hence, user cost contribution to economic impact on surrounding communities during SIBC is under 16% of what could have been if bridge was delivered with CC.

Table 20. User Cost Contributing to Economic Impact on Surrounding Communities (2015 Value)

Cost category	Travelling thorough	SIBC	CC	Method
DDC	Work zone	$165,263	-	Eq. 3
VOC	Work zone	$416,091	-	Eq. 4
AC	Work zone	$8,426	-	Eq. 5
PDC	Work zone	$77,517	-	Eq. 6
PAC	Work zone	$5,007	-	Eq. 7
DDC	Detour	$12,718	$1,144,586	Eq. 8
VOC	Detour	$32,020	$2,881,790	Eq. 9
AC	Detour	$536	$48,230	Eq. 10
PDC	Detour	$5,965	$536,871	Eq. 11
PAC	Detour	$318	$28,658	Eq. 12
	Total	**$723,861**	**$4,640,135**	

Driver delay cost (DDC), passenger delay cost (PDC), and vehicle operating cost (VOC) develop because of work zone speed limit during total duration of construction activities (N). Even though work zone speed limit is the primary source of these costs, the major parameter contributing to those costs is the total duration of construction activities at the work zone (N) (Eq. 3, Eq. 4, and Eq. 6). Presence of work zone generates a change in expected accident rates. Similarly, major contributor to accident cost (AC) and passenger accident cost (PAC) is the total duration of construction activities at the work zone (N) (Eq.5 and Eq. 7). When the detour route is designated with the bridge is being closed to traffic, driver delay cost (DDC), vehicle operating cost (VOC), accident cost (AC), passenger delay cost (PDC), and passenger accident cost (PAC) are born by the extra miles travelled. Therefore, the most significant criterion are the length of detour for passenger vehicles (L_{Dpv}), and mobility impact time (T_M) since other parameters do not have a flexibility to change for a specific site (Eq. 8, Eq. 9, Eq. 10, Eq. 11, and Eq. 12).

Environmental Cost

The environmental cost parameters, and associated unit costs are given in Table 21. Descriptions and derivations of input parameters are given below;

- The emissions of passenger vehicles (E_{pv}) are measured for 27.6 mph average speed (EPA 2008a and EPA 2008b); The presented speed correction factors (SCF) are used to modify the average emission values according to the speed limits for passenger vehicles. Since carbon monoxide (CO) and nitrogen dioxide (NO_2) shows statistical difference by varying speeds, corrections for only SCFs of those pollutants are presented (EPA 2011; Yao et al. 2014). Speed correction factor (SCF) for trucks assumed as '1' due to lack of available data and not included in Table 21.

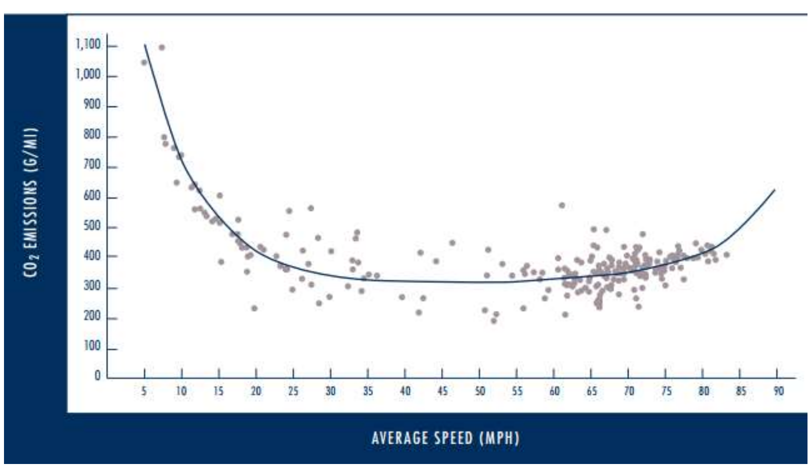
- The unit cost of each pollutant (UC_p) from passenger vehicle and truck (EPA 2008a) given in Literature Review-Health Care Cost section, and the unit cost of water pollution from passenger vehicle, and truck (UC_{wpv} and UC_{wt}) (Delucci and McCubbin 2010) as described in Literature Review-Water Pollution section are presented as average of upper and lower bounds.

- In literature, unit cost of water pollution from passenger vehicle (UC_{wpv}) is given in terms of 'dollar per passenger miles traveled'. This unit cost needs to be converted to 'dollar per mile' by multiplying the 'dollar per passenger miles traveled' by average vehicle occupancy (AVO) (Delucci and McCubbin 2010; Paracha and Mallela 2011).

- Unit cost of water pollution from trucks (UC_{wt}) is given in 'dollar per ton-mile', the average weight of a truck is assumed as 80,000 lbs (MDOT-Standard Interstate Semi-trailer) and the final unit cost is presented as a unit of 'dollar per mile' (Delucci and McCubbin 2010; MDOT 2013).

- The value of social cost of carbon (SC_{CO2}) is an estimate of climate change damage for 2015 as described in Chapter II – Climate Change section. The speed correction factors (SCFs) are assumed as '1' indicating that the emission of green house gases (GHGs) does not vary within the limited speed limit range of the Potterville case study (25 mph - 60 mph) for quantification of climate change cost as shown in Figure 8 (Barth and Boriboonsomsin 2010). Hence, this parameter is not included in Table 21.

- The carbon dioxide (CO_2) emission from passenger vehicles, and trucks (E_{pv} and E_t) are calculated by dividing the equivalent value of carbon dioxide (CO_2) emitted by passenger vehicle, and truck in 2013 (EPA 2015) by passenger vehicle and truck miles travelled in 2013 throughout the U.S. (FHWA 2013a).



1 g/mile=0.0022046 lbs/mile

Figure 8. Emissions of CO_2 vs speed for gasoline passenger vehicles

Table 21. Environmental Cost Calculation Parameters and Data for Economic Impact on Surrounding Communities (2015 Value)

Databases	Parameters	SIBC	CC
EPA 2008	E_{pv} (VOC)	2.2708×10^{-3}lbs/mile	2.2708×10^{-3}lbs/mile
EPA 2008	E_{pv} (CO)	20.7235×10^{-3}lbs/mile	20.7235×10^{-3}lbs/mile
EPA 2008	E_{pv} (NO_x)	1.5278×10^{-3}lbs/mile	1.5278×10^{-3} lbs/mile
EPA 2008	E_{pv} ($PM_{2.5}$)	0.0090×10^{-3} lbs/mile	0.0090×10^{-3} lbs/mile
EPA 2008	E_{pv} (PM_{10})	0.0097×10^{-3} lbs/mile	0.0097×10^{-3} lbs/mile
EPA 2015; Highway Statistics 2013	E_{pv} (CO_2)	0.736 lbs/mile	0.736 lbs/mile
EPA 2008	E_t (VOC)	0.9855×10^{-3} lbs/mile	0.9855×10^{-3} lbs/mile
EPA 2008	E_t (CO)	5.0949×10^{-3} lbs/mile	5.0949×10^{-3} lbs/mile
EPA 2008	E_t (NO_x)	18.9884×10^{-3} lbs/mile	18.9884×10^{-3} lbs/mile
EPA 2008	E_t ($PM_{2.5}$)	0.4453×10^{-3} lbs/mile	0.4453×10^{-3} lbs/mile
EPA 2008	E_t (PM_{10})	0.4828×10^{-3} lbs/mile	0.4828×10^{-3} lbs/mile
EPA 2015; Highway Statistics 2013	E_t (CO_2)	7.65 lbs/mile	7.65lbs/mile
McCubbin and Delucci 1999	UC_p (VOC)	$0.4935 per pound	$0.4935 per pound
McCubbin and Delucci 1999	UC_p (CO)	$0.0395 per pound	$0.0395 per pound
McCubbin and Delucci 1999	UC_p (NO_x)	$7.2850 per pound	$7.2850 per pound
McCubbin and Delucci 1999	UC_p ($PM_{2.5}$)	$66.9325 per pound	$66.9325 per pound
McCubbin and Delucci 1999	UC_p (PM_{10})	$56.6405 per pound	$56.6405 per pound
EPA 2016	SC_{CO2}	$\$18.665\times10^{-3}$ per pound	$\$18.66\times10^{-3}$ per pound
EPA 2001	SCF_{WZpv} (CO)	1.01	-
EPA 2001	SCF_{WZpv} (NO_x)	1.02	-
EPA 2001	SCF_{NSpv} (CO)	1.34	1.34
EPA 2001	SCF_{NSpv} (NO_x)	1.16	1.16
EPA 2001	SCF_{Dpv} (CO)	1.02	1.02
EPA 2001	SCF_{Dpv} (NO_x)	0.96	0.96
Delucci and McCubbin 2010	UC_{wpv}	$0.075 per mile	$0.075 per mile
Delucci and McCubbin 2010	UC_{wt}	$1.499 per mile	$1.499 per mile

The environmental cost model analysis results contributing to the economic impact on surrounding communities are given in Table 22. The values presented for costs associated with health care (HC), reduced visibility, agricultural damage, property damage, forestry damage, water pollution (WP) and climate change (CC). The results obtained by incorporating the Potterville specific data shown in Table 18, and Table 21 Environmental cost with SIBC is calculated about $7,200 while that with CC is about $600,000. Hence, the environmental impacts on surrounding communities with to SIBC is about 1% of what could have been if bridge was constructed conventionally (CC).

Table 22. Environmental Cost Contributing to Economic Impact on Surrounding Communities (2015 Value)

Cost category	SIBC	CC	Method
Air pollution			
Health care cost	$1,163	$67,354	Eq. 13 to Eq. 19
Reduced visibility	$169	$9,766	Table 17
Agricultural damage	$99	$5,725	Table 17
Property damage	$47	$2,694	Table 17
Forestry damage	$12	$674	Table 17
Water pollution	$4,998	$449,794	Eq. 20 to Eq. 22
Climate change	$736	$66,268	Eq. 23 to Eq. 27
Total	**$7,222**	**$602,276**	

Air pollution and climate change takes place due to reduced work zone speed limit and extra miles travelled with detour. Hence, major contribution come from i) the total duration of construction activities at the work zone (N), ii) mobility impact time ™, and iii) the length of detour for passenger vehicles and trucks (L_{Dpv} and L_{Dt}). Emission rates are higher with slower velocities (EPA 2001; Barth and Boriboonsomsin 2010); therefore, one other significant consideration is possible traffic congestion on detour (Eq. 13 to Eq. 16, Table 17, and Eq. 23 to Eq. 27). If there is a congestion, the traffic speed is slower yielding higher air pollution. Depending on site, congestion, hence speed correction factor (SCF) can become indicative.

Water pollution occurs due to extra miles travelled with detour; therefore, i) the total duration of construction activities at the work zone (N), mobility impact time (T_M), and the length of detour for passenger vehicles and trucks (L_{Dpv} and L_{Dt}) are decisive parameters. Another effective factor for water pollution form trucks is their associated weight since the unit cost of water pollution (UC_{wt}) is based on ton-mile travel of trucks (Eq. 20 to Eq. 22).

Economic Impact on Surrounding Businesses, Potterville

The economic impact on surrounding businesses includes i) the user cost from trucks, and ii) business revenue change. The site-specific parameters of Potterville for quantification of economic impact on surrounding businesses are described, and given below. The results obtained from the analysis are presented for SIBC, and CC.

User Cost

- The user cost parameters, and databases are given in Table 23 for Potterville case study. Explanations and derivations of input parameters are provided below;Table 2 Hourly rate for a truck driver (w_t) is obtained by considering the local travel category given in Table 2 in Chapter II - User Cost section (USDOT 2014).

- Average hourly vehicle operating cost for trucks (r_t) is given in units of 'dollar per mile' (ATRI 2014). It is assumed that truck speed is 55 miles per hour. The average hourly vehicle operating cost for trucks is calculated in 'dollar per hour' by multiplying units of 'dollar per mile' and units of 'miles per hour'.

- Normal accident rate for trucks (A_{nt}) is calculated by dividing the number of injury level car accidents in Michigan in 2014 (52,523) (MOHSP 2014) by annual vehicle miles travelled in Michigan in 2014 (97.1 billion) (MDOT 2016b). In order to obtain normal accident rate for trucks, the ratio is multiplied with the percentage of involvement of trucks (2.4%) (MOHSP 2014).

- Accident rate per truck-mile due to work zone (A_{at}) is calculated by multiplying normal accident rate for trucks (A_{nt}) by average crash modification factor 'CMF' (FHWA 2015).

- Volume of truck traffic on the roadway to be closed during construction (V_t) is assumed to be equal to average daily truck traffic (ADTT) indicating that 100% of users travel through the designated detour.

Table 23. User Cost Calculation Parameters and Data for Economic Impact on Surrounding Businesses (2015 Value)

Databases	Parameters	SIBC	CC
USDOT 2014	w_t	$24.82/vehicle/hr	$24.82/vehicle/hr
ATRI 2014	r_t	$59.18/vehicle/hr	$59.18/vehicle/hr
OHSP 2014; MDOT 2016	A_{nt}	1.30 accidents/100 million veh-mile	1.30 accidents/100 million veh-mile
FHWA 2014a	CMF	1.77	-
OHSP 2014; MDOT 2016; FHWA, 2014	A_{at}	2.30 accidents/100 million veh-mile	-
Project data	V_t	190 vehicles/day	190 vehicles/day

The results of the user cost model analysis contributing to the economic impact on surrounding businesses are given in Table 24. The costs are presented for driver delay cost (DDC), vehicle operating cost (VOC), accident cost (AC) while trucks travelling thorough work zone and detour. The analysis results are obtained from the Potterville specific data which is shown in Table 18, and Table 23. User cost for trucks with SIBC is about $43,600 and $213,350 with CC. Hence, the user cost contribution to economic impact on surrounding businesses during SIBC is about 20% of the cost if bridge was delivered with CC.

Table 24. User Cost Contributing to Economic Impact on Surrounding Businesses (2015 Value)

Cost category	Travelling thorough	SIBC	CC	Method
DDC	Work zone	$12,192	-	Eq. 28
VOC	Work zone	$29,071	-	Eq. 29
AC	Work zone	$10	-	Eq. 30
DDC	Detour	$700	$63,020	Eq. 31
VOC	Detour	$1,670	$150,263	Eq. 32
AC	Detour	$1	$73	Eq. 33
	Total	**$43,644**	**$213,356**	

The process of calculating user cost from trucks is the same as user cost from passenger vehicles except passenger delay cost (PDC) and passenger accident cost (PAC). Therefore, the most significant parameters for diver delay cost (DDC), vehicle operating cost (VOC and accident cost (AC) travelling though work zone is the total duration of construction activities at the work zone (N).

While trucks are traveling through detour, the most significant parameters are the length of detour for passenger vehicles (L_{Dt}), mobility impact time (T_M) for calculation of driver delay cost (DDC), vehicle operating cost (VOC), accident cost (AC) (Eq. 28 to Eq. 33).

Business Revenue Change

The procedure described in Chapter II - Business Revenue Change section is implemented for the Potterville M-100 bridge replacement project. Figure 9 shows Potterville city limits and the area defined as the influence area. A part of the city located south of the railway line is defined as the influence area with simple assessment of road network.

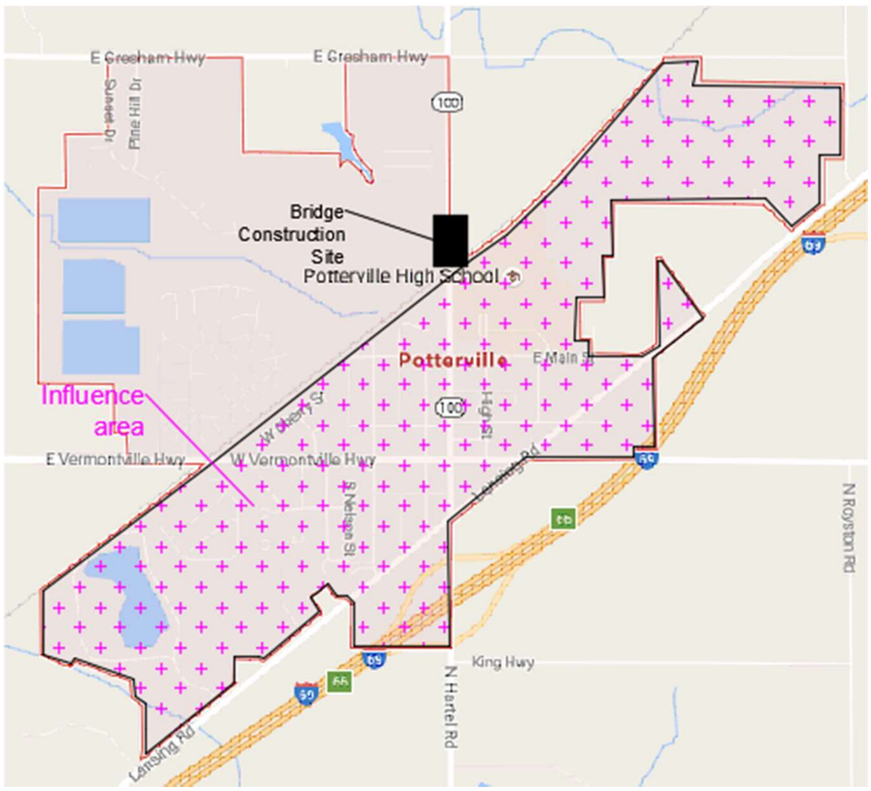


Figure 9. Influence area of the bridge project (Commercial center of Potterville)

The number of households without direct access to the influence area during the bridge project is also established in 4 steps. The closest commercial centers, which have the same business types a shown in Table 25, to Potterville are identified in the first step of analysis. From a bird's eye view, the shortest distances between Potterville and the commercial centers are drawn as shown in Figure 10 (a). Figure 10 (b) illustrates the second step where the midpoints of the shortest distances are unified to generate slices which are closer to Potterville rather other commercial centers. The third step is to identify the areas without direct access to Potterville influence area during construction as illustrated in Figure 10 (c). The techniques on how to define boundaries of influence area are given in Chapter II– Business Revenue Change section. Based on blue hatched area shown in Figure 10 (c), the second technique is employed for the boundaries of the influence area which is defined based on the nearest roads as natural borders and anticipating the effect of highway and detour for trucks for a practical estimation (NCHRP 2002) (Figure 10 (d)). The number of households without direct access to the influence area is calculated from the blue hatched area shown in Figure 10 (d) as 250. The influence area and the area without direct access to the influence area are shown in Figure 11.

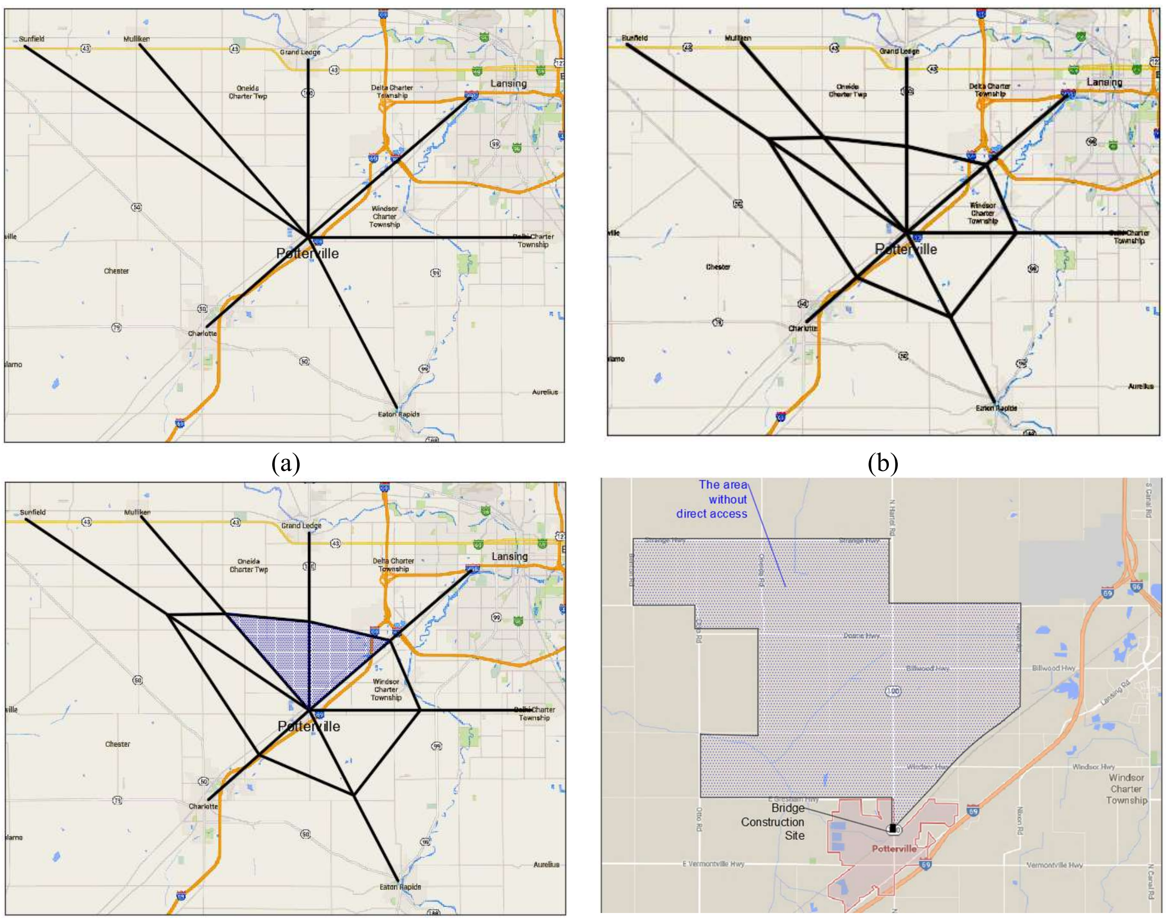


Figure 10. Steps taken to establish the area without direct access during construction

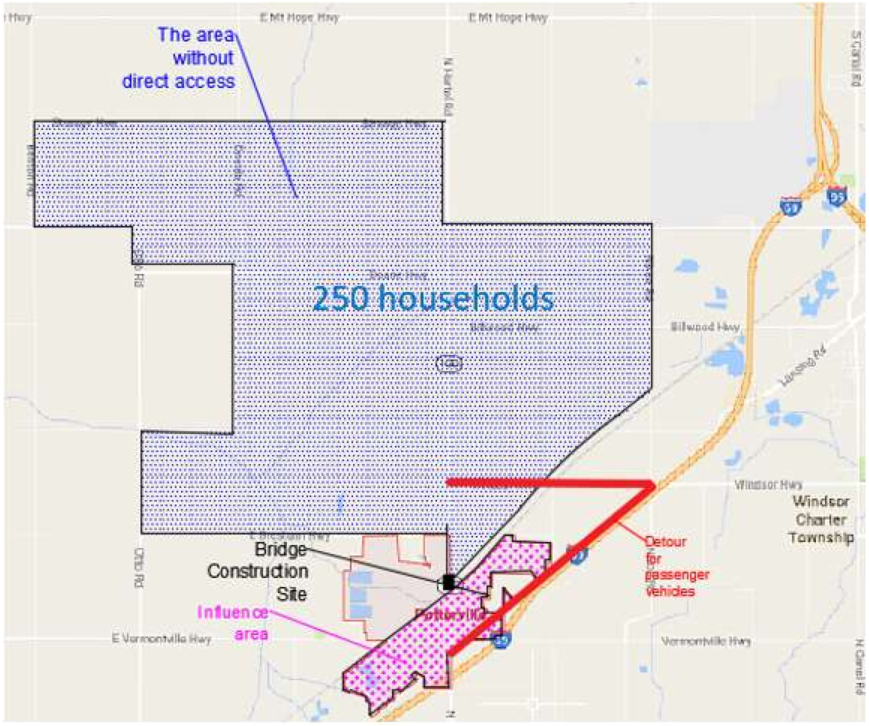


Figure 11. Influence area and the area without direct access to the influence area

The business revenue change parameters and databases are included in Table 25. Descriptions and derivations of input parameters are provided below;

- The business types are determined according to common businesses in Potterville such as auto repair shop, party/liquor store, restaurant, gas station and pharmacy.

- The frequency (F) of one household's visits to a restaurant and a party/liquor store per household is assumed as once per week, gas station and pharmacy once per month; and auto repair shop once per quarter.

- The site-specific data required for average expenditure per household (AE) is obtained from *GALE Cengage Learning, DemographicsNow* tool (Gale 2016). The database requires subscription and is accessed through the Western Michigan University (WMU) Library Services.

It is assumed that households without direct access do not travel to the influence area (i.e., P =100%).

Table 25. Business Revenue Change Calculation Parameters and Data for Economic Impact on Surrounding Businesses (2015 Value)

Databases	Parameters	SIBC	CC
Maps	HWA	250 households	250 households
Assumption	F (to auto repair shop)	1visit/90 days	1visit/90 days
Assumption	F (to party/liquor store)	1visit/7 days	1 visit /7 days
Assumption	F (to restaurant)	1 visit /7 days	1 visit /7 days
Assumption	F (to gas station)	1 visit /30 days	1 visit /30 days
Assumption	F (to pharmacy)	1 visit /30 days	1 visit /30 days
DemographicsNow	AE (to auto repair shop)	$42/household/visit	$42/household/visit
DemographicsNow	AE (party/liquor store)	$3/household/visit	$3/household/visit
DemographicsNow	AE (to restaurant)	$23/household/visit	$23/household/visit
DemographicsNow	AE (to gas station)	$235/household/visit	$235/household/visit
DemographicsNow	AE (to pharmacy)	$39/household/visit	$39/household/visit
Assumption	P	100%	100%

The results presented for revenue losses of auto repair shops, party/liquor stores, restaurants, gas stations and pharmacies in influence area during T_M. The results are obtained by incorporating the Potterville specific data shown in Table 18, and Table 25. The business revenue change analysis results contributing to economic impact on surrounding businesses are given in Table 26. As shown in Table 26, a revenue loss is calculated for the businesses in the influence area. The revenue loss with SIBC is about $6,670; whereas the loss is in excess of $600,000 with CC. Hence, the economic impact on surroundings businesses due to business revenue loss with SIBC is about 1% of CC.

Table 26. Business Revenue Change Contributing to Economic Impact on Surrounding Businesses during Bridge Construction (2015 Value)

Business category	SIBC	CC	Method
Auto repair shop	$232	$20,875	Eq. 34 and Eq. 35
Party/Liquor Store	$211	$19,038	Eq. 34 and Eq. 35
Restaurant	$1,655	$148,970	Eq. 34 and Eq. 35
Gas Station	$3,925	$353,250	Eq. 34 and Eq. 35
Pharmacy	$646	$58,125	Eq. 34 and Eq. 35
Total	**$6,669**	**$600,258**	

The accurate assessment of business revenue change requires site-specific data for post-construction analysis. The community and the businesses influenced by the bridge construction project can be surveyed through data collection tools to obtain accurate data for percent of households without direct access and avoiding the area influenced by the project (P), and the frequency of patronizing a specific business (F). Business revenue change quantification is a challenging process, hence every parameter contributing to it and maps helping to define those parameters are site-specific. Therefore, each parameter needs to be defined and used in the quantification process.

In the framework of the study, general community and business surveys and their associated rationales are presented in Appendix A. These surveys are applicable to any size of economic impact analysis with minor modifications based on the site and population characteristics. The survey goals are to collect site-specific data as well as to educate the public on ABC. The questions are worded accordingly to improve the effectiveness of the survey as described in the literature (the Office of Quality Improvement (OQI) 2010; Peters 2016). Additionally, the survey rationales are provided to clarify the goal and purpose of the questions.

Result Interpretation

The case study conducted in Potterville, MI compares SIBC and CC in terms of economic impact on surrounding communities and businesses. Economic impact on surrounding communities with SIBC is $731,083 while it is $5,242,411 with CC (Table 27). User cost and environmental cost are two contributing parameters to economic impact on surrounding communities. However, the significant contribution comes from user cost. The percentage of user cost in economic impact on surrounding communities with SIBC and CC are 99% and 89%, respectively. Hence, environmental cost can be eliminated from economic impact on surrounding communities for simplicity for rural networks. However, it is important to incorporate those effects in economic impact analysis for more complicated road networks (such as high population cities) if traffic congestion is a problem. Traffic congestion requires slower speed limits and increases the environmental cost by increasing emission rates.

Economic impact on surrounding businesses with SIBC is $50,313 while it is $813,614 with CC (Table 27). User cost and business revenue change contribute to economic impact on surround businesses. Similar to economic impact on surrounding communities, user cost play an influential part in economic impact on surrounding businesses with a percentage of 87% for SIBC. However, business revenue change having a percentage of 74% contributes more significantly when longer duration of mobility impact time is considered with CC. Hence, both parameters are necessary to account for business disturbances due to bridge construction.

Table 27. Economic Impact on Surrounding Communities and Businesses

	SIBC	CC
Economic impact on surrounding communities	$731,083	$5,242,411
Economic impact on surrounding businesses	$50,313	$813,614
Total	**$781,396**	**$6,056,025**

Economic impact analysis considered in this research can be utilized to evaluate impacts of highway construction in general. However, the application of economic impact analysis to different case studies generates a wide variety of results due to the use of site-specific data. Therefore, larger cities with more complicated road networks yield different results than smaller cities with simpler road networks. Hence, if a large sample of case studies can be collected to conduct economic impact analysis, then the statistical accuracy is achieved to generate aggregate unit daily cost for economic impact on surrounding communities and businesses depending on the complexity of road network.

Summary

Three major categories contributing to economic impact are user cost, environmental cost, and business revenue change. In quantifying the economic impact on surrounding communities, user cost (for passenger vehicle drivers and passengers) and environmental cost from air pollution, water pollution, and climate change are considered. Air pollution is further divided in two categories i) health care cost and ii) general cost. Economic impact on surrounding businesses is quantified by calculating user cost for trucks and business revenue change. The scope of analysis presented in this chapter is limited to the construction duration time period and the impacts during other life-cycle activities such as Capital Preventive Maintenance (CPM), which aims to preserve the structural integrity and extend the service life, and Capital Scheduled Maintenance (CSM), which aims to preserve bridges in their current condition for longer period of time, are not included (MDOT 2010a; MDOT 2010b).

M-100 over CN Railroad bridge replacement project is the 3rd slide-in project completed by MDOT. Slide-in bridge construction (SIBC) is one of the ABC methods with the Michigan Department of Transportation that has previously completed three additional bridge replacements. This project is showcased to demonstrate the application of economic impact analysis concepts and procedures. In order to perform a comparative analysis, SIBC is compared to bridge replacement with CC.

Economic impact on surrounding communities has two major categories; i) user cost from passenger vehicles and ii) environmental cost. The most significant parameters contributing to user cost are the total duration of construction activities at the work zone (N), and mobility impact time (T_M), the length of detour for passenger vehicles (L_{Dpv}). The most significant parameters taking part in environmental cost are i) the total duration of construction activities at the work zone (N), mobility impact time (T_M), and the length of detour for passenger vehicles and trucks (L_{Dpv} and L_{Dt}). In addition, weight of trucks and speed correction factor (SCF) play significant role in environmental cost, as well.

Table 27 presents analysis results of the economic impact on surrounding communities, and businesses. The economic impact on surrounding communities by SIBC and CC are $731,083 and $5,242,411 respectively. The analysis results show that the economic impact on surrounding communities with CC is 7.2 times greater than the impact with SIBC. The model of economic impact on surrounding communities can be simplified by eliminating environmental cost for rural networks. However, it is encouraged to include environmental cost for more complicated road networks such as highly populated cities due to possible traffic congestion effects.

Economic impact on surrounding business include; i) user cost from trucks and ii) business revenue change. Similar to quantification of user cost from passenger vehicles, the most crucial parameters contributing to user cost from trucks are the total duration of construction activities at the work zone (N), and mobility impact time (T_M), the length of detour for passenger vehicles (L_{Dpv}). Each and every parameter contributing to business revenue change and maps helping to define those parameters are site-specific. Therefore, each parameter is significant and should be utilized.

The economic impacts on surrounding businesses by SIBC and CC are $50,313 and $813,614 respectively. Hence, the economic impact on surrounding businesses by CC is about 16 times greater than the impact by SIBC. The overall economic impact due to CC is 7.8 times greater than SIBC. User cost is a significant contributor when shorter mobility impact time is considered, however, business revenue change becomes a significant contributor when longer mobility impact time is accounted for. Several assumptions are incorporated in the calculations due to lack of site-specific data. Two surveys and their associated rationales presented in Appendix A can be utilized to collect site-specific data in order to improve the accuracy of the analysis if needed.

It is not feasible to deduct any aggregate unit daily cost for economic impact on surrounding communities and businesses out of this research. However, the model developed is capable to be applied to not only bridges but highway construction in general. Hence, if a large sample of case studies for statistical accuracy is achieved using the model developed here, aggregate unit daily cost for economic impact on surrounding communities and businesses can be developed depending on the complexity of road network.

CHAPTER IV

SUMMARY, CONCLUSION, AND FUTURE RESEARCH

Summary and Conclusion

Economic impact of a roadway closure defined as the mobility impact time and safety within construction zone are two major parameters considered when evaluating the bridge construction methods for a specific site. Accelerated bridge construction (ABC) methods are implemented over conventional construction (CC) techniques to reduce the mobility impact time. However, site complexities, time constraints, and perceived risks increase the project cost by 6% to 21% over CC. Nonetheless, ABC incorporates immediate benefits of reduced mobility impact time such as maintenance of traffic cost, lifecycle cost, construction duration, and seasonal limitations, economic impact on surrounding communities and economic impact on surrounding businesses. Ferguson (2012) qualitatively evaluated while Matthews et al. (2014), Gilchrist and Allouche (2004), and Islam et al. (2014) quantitatively analyzed the impact of a project by considering user cost, environmental cost, and business revenue change. Matthews et al. (2014) evaluated trenching technologies; Gilchrist and Allouche (2004) described adverse effects of a construction project from road closure; Islam et al. (2014) compare water infrastructure alternatives; and Aktan and Attanayake (2015) evaluated bridge construction. The authors evaluated the economic impact on surrounding businesses qualitatively but quantified the economic impact on surrounding communities using mobility impact time. They converted quantitative values into preference ratings with the help of Michigan Accelerated Bridge Construction Decision (Mi-ABCD) tool.

After amalgamating models, parameters and processes documented in literature, a comprehensive cost analysis method is developed and presented for quantifying the economic impact on surrounding communities, and economic impact on surrounding businesses. The method can be used as a planning tool with the existing data presented in this thesis and can be customized to serve as a post-construction analysis tool after collecting historical site-specific data. The economic impact on surrounding communities is defined as the aggregate value of: i) user cost of passenger vehicle drivers and passengers, and ii) environmental cost from air pollution, water pollution, and climate change. Economic impact on surrounding businesses is quantified by calculating user cost for trucks, and business revenue changes from change in access to the business from road closure. The user cost contributes to economic impact on surrounding communities, and businesses. User cost is also a parameter which contributes to life cycle cost. Therefore, it is important to avoid duplication. A general community and a general business survey are also developed for the purposes of collecting site-specific data as well as of educating the public on ABC.

M-100 over CN Railroad bridge replacement project is the 3rd slide-in bridge construction (SIBC) project completed by MDOT. This project is used as the case study to demonstrate the application of economic impact analysis models and procedures. In order to perform a comparative analysis, SIBC is compared to bridge replacement with CC in terms of economic impact on surrounding communities which includes user cost from passenger vehicles and environmental cost. The most significant parameters affecting economic impact on surrounding communities through user cost from passenger vehicles and environmental cost are listed below;

- User cost from passenger vehicles are affected by the total duration of construction activities at the work zone (N), the mobility impact time (T_M) and the length of detour for passenger vehicles (L_{Dpv}).
- In addition to those parameters, the length of detour for trucks (L_{Dt}) and speed correction factors (SCF), and truck weight are other indicatives for environmental cost.

The economic impacts on surrounding communities by SIBC and CC are calculated as \$731,083 and \$5,242,411 respectively. Accordingly, the impact on communities with CC is 7.2 times greater than the impact with SIBC. Due to low contribution level, environmental cost can be eliminated from economic impact on surrounding communities for simplicity for rural networks. Nonetheless, it is credible to consider environmental cost for complicated road networks (such as high population cities) if traffic congestion is a possible problem.

SIBC is compared to bridge replacement with CC in terms of economic impact on surrounding businesses which includes user cost from trucks and business revenue change. The most significant parameters affecting economic impact on surrounding businesses through user cost from trucks and business revenue change are listed below;

- User cost from trucks are impacted the total duration of construction activities at the work zone (N), the mobility impact time (T_M) and the length of detour for trucks (L_{Dt}).

- Business revenue change is determined by six parameters such as the change in number of customer (ΔC), average expenditure per household (AE), mobility impact time (T_M) number of households without direct access (HWA) during mobility impact time, percent of households without direct access and avoiding the area influenced by the project (P), and the frequency of patronizing a specific business (F) which are all significantly contributing.

The economic impacts on surrounding businesses by SIBC and CC are calculated as $50,313 and $813,614 respectively. Hence, the impact on businesses by CC is about 16 times greater than the impact by SIBC. The overall economic impact due to CC is 7.8 times greater than SIBC. The contribution of user cost is more than business revenue change when economic impact analysis is conducted for SIBC, however the situation is reverse when it is conducted for CC. Therefore, it is necessary to consider both parameters in economic impact on surrounding businesses.

Due to lack of statistical accuracy, the deduction of aggregate unit daily cost for economic impact on surrounding communities and businesses is not feasible with the outcomes of this study.

Future Research

This study was performed to develop a model for quantification of economic impact on surrounding communities and businesses from a bridge construction project to be utilized in the planning stage. Hence, the existing data and posted speed limits are used in the model. If the model will be served as a post-construction analysis tool, historical data and site-specific data should be collected. Table 28 addresses the data needs and data collection methods.

Table 28. Data Needs for Post-construction Analysis Tool

Data need	Data Acronym	Data Collection Method	Data Collection Location	Data Collection Time
Volume of passenger vehicle and truck traffic to be detoured	V_{pv} and V_t	Traffic count devices	Detour	Mobility impact time
Work zone speed	S_a	Speed measurement devices	Bridge	Onsite construction time
Normal speed of roadway	S_n	Speed measurement devices	Bridge	No construction
Accident rate per passenger vehicle-mile and truck-mile due to work zone	A_{apv} and A_{at}	Historical accident records	Bridge	Onsite construction
Normal accident rate for passenger vehicles and trucks;	A_{npv} and A_{nt}	Historical accident records	Detour and bridge	No construction
Average cost per accident	C_a	Historical accident cost records	Detour	Mobility impact time
Average cost per accident	C_a	Historical accident cost records	Bridge	Onsite construction
Percent of households without direct access and avoiding the area influenced by the project	P	Surveys	Households without direct access	Mobility impact time
The frequency of patronizing a specific business	F	Surveys	Households without direct access	Mobility impact time

Travel demand models can be employed to capture network-based impact depending on the complexity of the road network. More accurate values for percent of households without direct access and avoiding the area influenced by the project (P), and the frequency of patronizing a specific business (F) can be calculated through surveys included in Appendix A. In that respect, data collection tools can be upgraded from surveys to automated surveys utilizing mobile devices. Aggregate unit daily cost for economic impact on surrounding communities and businesses can be developed depending on the complexity of road network if large sample of case studies for statistical accuracy is achieved with the use of the model developed in this research.

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APPENDIX A

Surveys and Rationales
General Public Survey

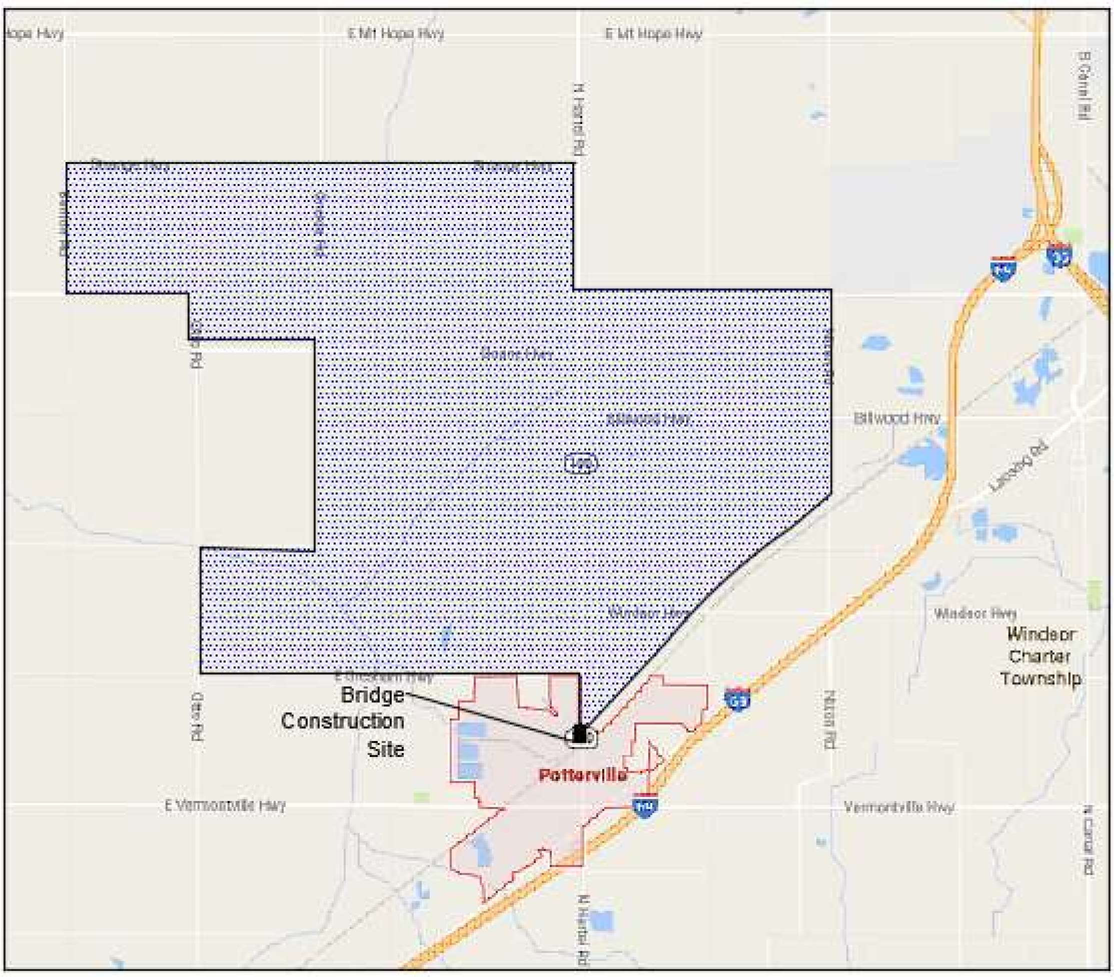
The purpose of this survey is to collect data in an effort to evaluate the economic impact of bridge construction projects on surrounding communities and businesses. Your responses are valuable to us. The information will be kept confidential. Where needed, the data will be used as summaries.

General Information:

Date: ________________________________

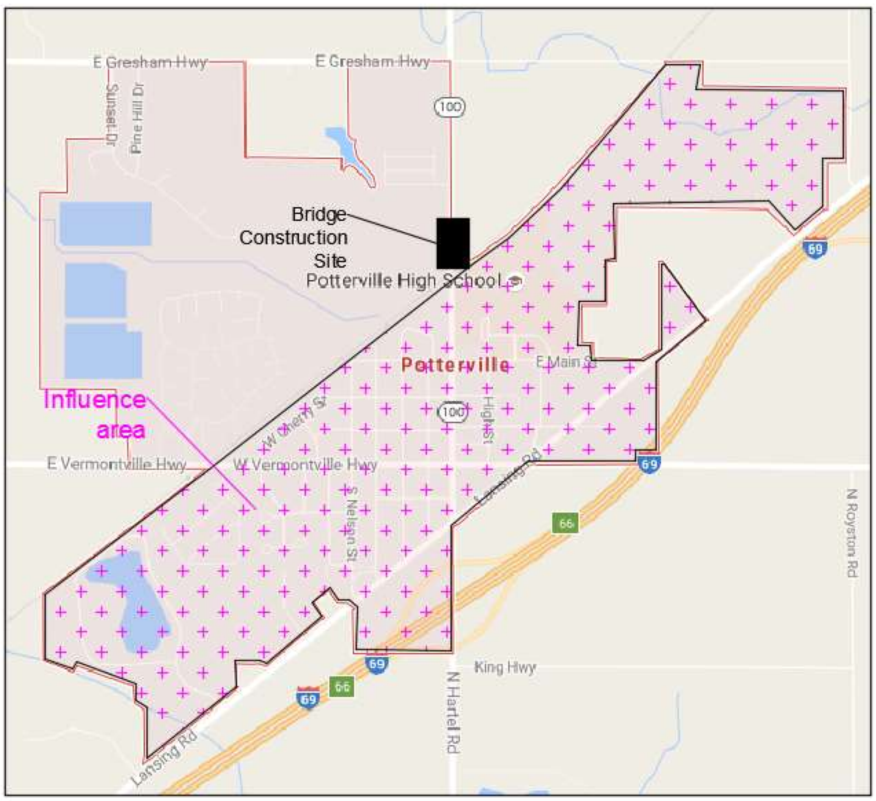
1. Is your residence located within the area shaded on the following map?

   Yes________ No ______



Bridge construction projects around communities impact the normal traffic flow. Usually, traffic is routed around the project with detour signs, requiring community members to use a different route. The extra traveling affects the amount of fuel you use; the additional time spent away from work or home; and your environment due to increased pollution. Accelerated Bridge Construction (ABC) projects keep the road open for as long as possible (even when work is being performed to construct the new bridge and foundation); therefore, reducing the impact of traffic interruption. However, the ABC project cost is (20%-40%) more than a conventional bridge construction project.

The following map shows a hatched area influenced by the construction and where a majority of the businesses are located at. Your understanding about this area is necessary to answer some of the questions listed below.



Impact on Daily Life:

Please circle your answer for the following questions.

2. Did you use the designated detours around the construction site? (Yes) (No)
3. If yes, did the detour provide adequate access to your destination? (Yes) (No)
4. If yes, was the detour route in good condition? (Yes) (No)
5. Did the detour increased cost or time of your commute? (Yes) (No)

Please use √ mark to indicate your answers.

6. How often do you go to the following businesses/stores inside the influence area shown in the map?

	Before Construction					**During Construction**				
Number of trips	0	1-2	3-4	5-6	7 or more	0	1-2	3-4	5-6	7 or more
Restaurants (per week)										
Party/Liquor Store (per week)										
Grocery Store (per week)										
Gas Stations (per month)										
Clothing Stores (per month)										
Hardware Stores (per month)										
Pharmacy (per quarter)										
Auto Repair Shop (per quarter)										

7. What is the route you take during construction to access the businesses/stores located in the influence area shown in the map?

	Use designated detour	**Travel through the construction zone**	**Use alternate routes**
Restaurants			
Party/Liquor Store			
Grocery Store			
Gas Stations			
Clothing Stores			
Hardware Stores			
Pharmacy			
Auto Repair Shop			

8. If the bridge is closed to traffic for two days, would you still travel to the area influenced by the construction shown in the map and continue with your weekend routine (shopping, eating, etc.)?

(Yes) (No)

9. If the bridge is closed to traffic for an extended duration (four months or longer), would you still travel into the area influenced by the construction shown in the map through detours or alternate routes to continue your weekly routine (shopping, eating, etc.)?

(Yes) (No)

Traffic:

10. What is your primary mode of transportation?___________________________________
11. What is your commute duration per day?

    Without construction: ____________With bridge construction:_______________
12. What is your average commute distance per day?

    Without construction: ____________With bridge construction:_________

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
13. The current roads in my community handled rush hour traffic very well during construction.					

Accidents:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
14. There have been fewer accidents around the area affected by bridge construction.					
15. The average traveler is not at risk when driving through or by the bridge construction site.					
16. The posted speed allows for adequate access through the construction site.					

Public Opinion:

Please tell us your opinion in the following subjects:

17. Community needs to be better informed about upcoming bridge projects:_____________

    ____

    ____

18. Community needs to be informed about construction progress:____

19. Other subjects not covered above:____

General Public Survey – Rationale for Survey Questions

The purpose of the survey is to collect site-specific data for quantifying economic impact of the bridge construction project. A second purpose is to educate community on ABC versus conventional construction. Direct estimation and opinion questions asked in the survey mostly aim at the data collection purposes. Informative paragraphs included in the survey are for educational purposes.

The survey and its rationale are divided into sections both for participant and analyst to track the flow conveniently.

Section: General Information

Question 1. Is your residence located within the area shaded on the following map? Yes/No
Rationale 1. The map included in the survey is used to determine if the participant lives in the area where direct access to the commercial center is interrupted during bridge construction. Instead of asking participant's address directly, asking to indicate the location on the map reduces the survey time as well helps protect their privacy.

After an educational paragraph, the area indicated in the second map shows the commercial center affected by construction. The hatched area on the map is called the influence area. The economic impact on the surrounding businesses is calculated by considering the businesses located in the influence area.

Section: Impact on Daily Life

Question 2: Did you use the designated detours around the construction site? Yes/No
Rationale 2: The aim is to calculate the percentage of people who used the designated detour and bring a clarification to the user cost calculations.

Question 3: If yes, did the detour provide adequate access to your destination? Yes/No
Rationale 3: The data is used to evaluate the effectiveness of the detour for providing access to pertinent destinations.

Question 4: If yes, was the detour route in good condition? Yes/No
Rationale 4: When traffic is diverted from a designated route, the detour might have to carry additional traffic volume. This may lead to accelerated deterioration of the pavement. The data is used to evaluate the condition of the route based on the participant's perception.

Question 5: Did the detour increased the cost or time of your commute? Yes/No
Rationale 5: This question is rather educational since the participant needs to reflect on the effect of the project and the detours have in monetary terms.

Question 6: How often do you go to the following businesses/stores inside the influence area shown in the map?

Rationale 6: In the quantification of business revenue loss, one of the parameters is the frequency (F) of customers accessing the businesses within the influence area. This question aims to collect site-specific data on frequency and the change in customer access before and during construction. The type of retail sale establishments are subject to change according to the types of businesses located in the influence area, hence the content of the table needs to be customized based on the specific project for which the survey is conducted.

Question 7: What was the route you take during construction to access the businesses/stores located in the influence area shown in the map?

Rationale 7: This question is related with Question 2. If the participant did not use the designated detour, there are alternate ways to reach the destinations. The aim of the question is to see the percentage of participants choosing alternate ways to access different types of businesses.

Question 8: If the bridge is closed to traffic for two days, would you still travel to the area influenced by the construction shown in the map and continue with your weekend routine (shopping, eating, etc.)? Yes/No

Rationale 8: The data is used to calculate the percentage of people who would continue to use the same businesses during bridge closure. The result will be used in the quantification of business revenue loss due to ABC.

Question 9: If the bridge is closed to traffic for an extended duration (four months or longer), would you still travel into the area influenced by the construction shown in the map through detours or alternate routes to continue your weekly routine (shopping, eating, etc.)? Yes/No

Rationale 9: The data is used to calculate the percentage of people who are going to continue to use the same businesses during bridge closure. The result will be used in the quantification of business revenue loss due to CC.

Section: Traffic

Question 10: What is your primary mode of transportation?

Rationale 10: This question aims to relate all answers given to the questions by the participant with his/her mode of transportation. Since users of different transportation modes are not impacted at the same degree due to bridge construction, the participants' answers provided for the rest of the questions would be evaluated accordingly.

Question 11: What is your commute duration per day? Without construction/With bridge construction

Rationale 11: This question aims at educating the participant on bridge construction impact on travel duration.

Question 12: What is your average commute distance per day? Without construction/With bridge construction.
Rationale 12: This question aims at educating the participant on bridge construction impact on distance of travel.

Question 13: The current roads in my community handled rush hour traffic very well during construction.
Rationale 13: Bridge construction projects can have negative impact on rush hour traffic due to change in traffic flow patterns. The aim of this question is to determine if impact of congestion need to be included in the economic impact analysis.

Section: Accidents

Question 14: There have been fewer accidents around the area affected by bridge construction.
Rationale 14: Even though, users are more likely to be cautious while driving in construction zones, the number of crashes are higher because of other distractions. This question aims to measure the public opinion on crashes due to bridge construction.

Question 15: The average traveler is not at risk when driving through or by the bridge construction site.
Rationale 15: This question aims at evaluating work zone risks based on the public opinion.

Question 16: The posted speed allows for adequate access through the construction site and reduces the risk of accidents.
Rationale 16: The responses to this question can be utilized for quantifying user cost and environmental cost.

Section: Public Opinion

The following questions serve as an emotional outlet for the participant. If he/she can tell us what is his/her opinion (assuming that it is not being covered already in the survey), the feedback with this question can be incorporated in future studies.

Question 17: Community needs to be better informed about upcoming bridge projects.

Question 18: Community needs to be informed about construction progress.

Question 19: Other subjects not covered above.

General Business Survey

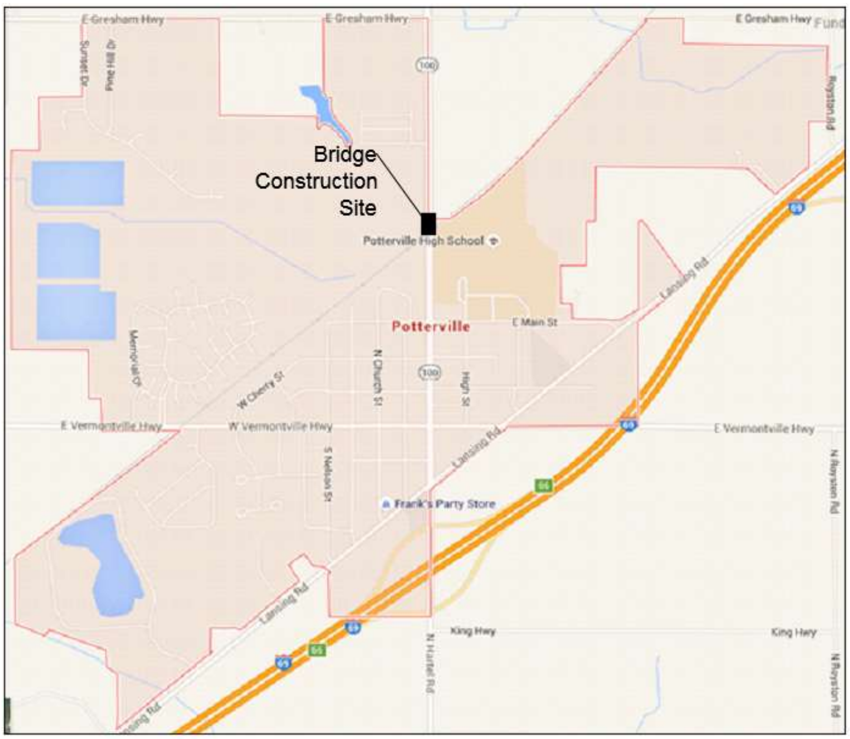
The purpose of this survey is to collect data in an effort to evaluate the economic impact on businesses within the vicinity of a bridge construction project. Your responses are very valuable to us. Also, the information will be kept confidential. Where needed, your data will only be used as summaries without referencing your business.

Date: ____

General Information:

1. Business Type:____

Please mark the location of your business on the map given below



2. State the number of employees: ____
3. Do you pay employees' travel expenses? (Yes) (No)
4. Did you notice an increase in employee travel expenses during the construction?

   (Yes) (No)

   If yes, please provide an estimate of the total additional expenses during construction? (Circle the most appropriate answer)

Less than $100	$100-$200	$200-$300	$300-$400	$400-$500	$500 or more

5. Does your business own vehicles other than commercial trucks?

   (Yes) (No)

   If yes, please provide an estimate of the total additional expenses during construction? (Circle the most appropriate answer)

$0	Less than $100	$100-$200	$200-$300	$300-$400	$400-$500	$500 or more

Impact on Business Performance

In general, businesses are affected by the road closure for bridge construction activities. The economic impact on businesses that require direct customer access such as retail and grocery stores, restaurants, gas stations, etc., can be high. During a conventional bridge construction project (CC), road closure can last more than four months. With Accelerated Bridge Construction (ABC), roads are kept open most of the time and traffic disruption is limited to one or two days up to perhaps two weeks. Therefore, ABC is expected to reduce the impact of construction on your business. However, the ABC project cost is (20%-40%) more than a conventional bridge construction project.

6. How would you describe the impact of loss of access to your business during construction?_____(Circle the most appropriate answer)

Closed during the entire construction duration	Closed for a couple of days	Closed for several hours	No impact

7. In your opinion, what percentage of customers are from the local community? (Circle the most appropriate answer)

During construction				
0%	25%	50%	75%	100%
After construction				
0%	25%	50%	75%	100%

8. In your opinion, compared to the sales before construction, what was the percent change of your gross sales?

During construction (Increase / Decrease)				
0%	25%	50%	75%	100%
After construction (Increase / Decrease)				
0%	25%	50%	75%	100%

9. In your opinion, what has been the overall impact to the other businesses around you?

During construction (Increase / Decrease)				
0%	25%	50%	75%	100%
After construction (Increase / Decrease)				
0%	25%	50%	75%	100%

10. In your opinion what could be the impact on your gross sales if road closure lasted for four months or more?

During construction (Increase / Decrease)				
0%	25%	50%	75%	100%
After construction (Increase / Decrease)				
0%	25%	50%	75%	100%

11. In your opinion, what could be the overall impact to the other businesses around you, if road closure lasted for four months or more?

During construction (Increase / Decrease)				
0%	25%	50%	75%	100%
After construction (Increase / Decrease)				
0%	25%	50%	75%	100%

12. Knowing the impact to your business during the ABC projects is important to us. Is there anything else that you would like us to know in regard to how these construction projects affect your business?

____

____

____

____

____

____

Thank you for your time. Your responses are valuable to us and we will incorporate them in our future work.

General Business Survey – Rationale for Survey Questions

The purpose of the survey is to collect site-specific data for quantifying economic impact of the bridge construction project. A second purpose is to educate the business community on ABC versus conventional construction. Direct estimation and opinion questions mostly aim at the data collection purposes. Informative paragraphs included in the survey are for educating the businesses on accelerated bridge construction.

The survey and its rationale are divided into sections both for participant and analyst to track the flow conveniently.

Section: General Information

Question 1: State the type of business:
Rationale 1: This question defines the type of business since business revenue loss varies with the type of establishment.
The map shown is intended to find out whether the business is located in the influence area of a bridge construction. Instead of asking participant's address directly, asking to indicate the location on the map reduces the survey analysis time as well helps protect privacy.

Question 2: State the number of employees:
Rationale 2: The number of employees is used to determine the size of the business.

Question 3: Do you pay the employees' travel expenses? Yes/No
Rationale 3: If the business pays its employees' travel expenses, the data collected for this question and Question 4 together can be used as an indicator of the user cost, which is a parameter of the economic impact on the surrounding businesses.

Question 4: Did you notice an increase in employee travel expenses during the construction? Yes/No
If yes, please provide an estimate of the total additional expenses during construction?
Rationale 4: Data retrieved from this question is used to obtain a monetary value estimation which can be used directly in economic impact on surrounding businesses.

Question 5: Does your business own vehicles other than commercial trucks? Yes/No
If yes, please provide an estimate of the total additional expenses during construction?
Rationale 5: Data retrieved from this question is used to obtain a monetary value estimation which can be used directly in economic impact on surrounding businesses.

Section: Impact on Business Performance

Question 6: How would you describe the impact of loss of access to your business during construction?
Rationale 6: The data is used to measure the impact of the loss of access to the business, hence the loss of customers.

Question 7: In your opinion, what percentage of customers are from the local community? During/After construction

Rationale 7: The data is used to calculate the percentage of the local customer base of the business. The result, in conjunction with the local expenditure data, is used to calculate business revenue loss.

Question 8: In your opinion, compared to the sales before construction, what was the percent change of your gross sales? During/After construction

Rationale 8: The data is used to verify and compare the calculated change in the business revenue due to ABC.

Question 9: In your opinion, what has been the overall impact to the other businesses around you?

Rationale 9: The aim is to obtain an estimation of the overall impact of the ABC project on the surrounding businesses in participant's point of view.

Question.10: In your opinion what could be the impact on your gross sales if road closure lasted for four months or more?

Rationale 10: The aim is to verify the change in business revenue due to CC.

Question 11: In your opinion, what could be the overall impact to the other businesses around you, if road closure lasted for four months or more?

Rationale 11: The data is used to calculate the overall impact of the CC project on the surrounding businesses in participant's point of view.

APPENDIX B

Abbreviations

Abbreviations used in the text explained in this section.

A_{apv}	Accident rate per vehicle mile due to work zone
A_{at}	Accident rate per truck mile due to work zone
AAA	The American Automobile Association
ABC	Accelerated bridge construction
AC	Accident cost
ADT_{pv}	Average daily passenger vehicle traffic
ADTT	Average daily truck traffic
AE	Average expenditure per household
A_{npv}	Normal accident rate for passenger vehicles
A_{nt}	Normal accident rate for trucks
ARE	the Swiss Federal Office for Spatial Development
ASTM	the American Society for Testing and Materials
ATRI	the American Transportation Research Institute
AVO	Average vehicle occupancy
C_a	Average cost per accident
C_{ap}	Average medical cost per accident per person
CALTRANS	the California Department of Transportation

CARB	the California Air Source Board
CC	Conventional construction
CC	Impact to climate change
CC_{pv}	Impact to climate change from passenger vehicles
CC_t	Impact to climate change from trucks
CFC	Chlorofluorocarbon compound
CH_4	Methane
CMF	Crash modification factor
CO	Carbon monoxide
CO_2	Carbon dioxide
CP	Health care costs from pollutant
CPI	Consumer price index
CPM	Capital preventive maintenance
CSM	Capital scheduled maintenance
DDC	Driver delay cost
DOE	the Department of Energy
DOT	the Department of Transportation
E_{pv}	Emission of a pollutant from passenger vehicles
E_t	Emission of a pollutant from trucks
EPA	The Environmental Protection Agency

F	The frequency of patronizing a specific business
FC	Facility carried
FHWA	the Federal Highway Administration
FI	Future intersected
GHG	Greenhouse gases
GWP	Global warming potential
HC	Total health care cost
HC_{pv}	Total health care cost from passenger vehicles
HC_t	Total health care cost from trucks
HWA	Number of houses without direct access
L	Length of the affected roadway due to bridge construction
L_{Dpv}	Length of detour for passenger vehicles
L_{Dt}	Length of detour for trucks
L_{WZpv}	Length of the road segment closed to passenger vehicles during construction
L_{WZt}	Length of the road segment closed to trucks during construction
MDOT	the Michigan Department of Transportation
Mi-ABCD	Michigan Accelerated Bridge Construction Decision Tool
MMT	Millions of Metric Tons
MOHSP	the Michigan office of Highway Safety and Planning
N	Construction duration in days affecting the work zone

N_2O	Nitrous oxide
NCHRP	the National Cooperative Highway Research Program
NHTSA	the National Highway Traffic Safety Administration
NJDOT	the New Jersey Department of Transportation
NO_2	Nitrogen dioxide
O_3	Ozone
OQI	Office of Quality Improvement
P	The percent of households without direct access avoiding the area influenced by the project
PAC	Passenger accident cost
PDC	Passenger delay cost
PM_{10}	Particulate matter between 2.5 and 10 microns in aerodynamic diameter
$PM_{2.5}$	Particulate matter less than 2.5 microns in aerodynamic diameter
r_{pv}	Average hourly vehicle operating cost for passenger vehicles
r_t	Average hourly vehicle operating cost for trucks
S_a	Work zone speed limit
SC_{CO2}	Social cost of carbon dioxide
SCF	Speed correction factor
SCF_{Dpv}	The detour speed correction factors for passenger vehicles
SCF_{Dt}	The detour speed correction factors for trucks

SCF_{NSpv} The speed correction factor for normal speed limit within the road segment with no construction for passenger vehicles

SCF_{NSt} The speed correction factor for normal speed limit within the road segment with no construction for trucks

SCF_{WZ} The work zone speed correction factor

SIBC S lide-in bridge construction

S_n Normal speed limit of the roadway

SUV Sport utility vehicle

T_{Dpv} Time to travel via detour for passenger vehicles

T_{Dt} Time to travel via detour for trucks

T_M Mobility impact time

TMP Traffic Management Plan

TTC Trenchless Technology Center

T_{WZpv} Time to travel along a distance equal to the road segment that is closed due to construction at the normal posted speed for passenger vehicles

T_{WZt} Time to travel along a distance equal to the road segment that is closed due to construction at the normal posted speed for trucks

UC_p Unit cost of a pollutant

UC_{wpv} Unit cost of water pollution from per mile travel of passenger vehicles

UC_{wt} Unit cost of water pollution from per ton-mile travel of trucks

USDOE the U.S. Department of Energy

USDOT the U.S. Department of Transportation

VOC Vehicle operating cost

VOC Volatile organic compound

V_{pv} Volume of passenger vehicle traffic on the roadway to be closed during construction

V_t Volume of truck traffic on the roadway to be closed during construction

w_{pvd} Hourly rate for passenger vehicle drivers

WIM Weigh-in Motion

WisDOT the Wisconsin Department of Transportation

WMU Western Michigan University

w_p Hourly rate for a passenger

WP_{pv} Water pollution damage from passenger vehicles

WP_t Water pollution damage from trucks

WP Total water pollution damage

w_t Hourly rate for truck drivers

ΔC Change in number of customers

ΔR Business revenue change