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IMPROVEMENT IN BENEFIT-COST ANALYSIS OF BRIDGES THROUGH ASSESSMENT OF SECONDARY BENEFITS AND DEFECT BASED MAINTENANCE COST

By

SHADMAN SAKIB

Presented to the Faculty of the Graduate School of

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of the Requirements

for the Degree of

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I express my gratitude to my advisor Dr. Nur Yazdani for his continuous support and guidance. His mentorship helped me culminate in my research and also in my academic career.I would also like to thank members of my committee, Dr. Raad Azzawi and Dr. Antonio Balderrema for consistently reviewing my work and providing me necessary support.

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Abstract

IMPROVEMENT IN BENEFIT-COST ANALYSIS OF BRIDGES THROUGH ASSESSMENT OF SECONDARY BENEFITS AND DEFECT BASED MAINTENANCE COST

Shadman Sakib, MS

The University of Texas at Arlington, 2024

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Benefit-cost Analysis (BCA) is conducted prior to federal grant allocation for bridge replacement and enhancement projects to prioritize decision-making. Benefits are measured based on total bridge closures, requiring vehicles to take alternate detour paths. Primary benefits are the direct user costs such as travel time saving or emission costs. However, there are more secondary benefits that are intangible and hard to monetize, but United States Department of Transportation (USDOT) guidelines suggest considering them wherever possible. There are lack of US based data and research also no set guideline by authority.

Apart from calculating primary benefits for a 95 sample of bridges in North Central Texas including 28 rated as Poor, 32 Fair, 35 Good Bridges, this study aimed to comprehensively assess and correlate existing research to develop methods and monetize secondary benefits for bridge closures, including noise reduction, emergency response, and detour pavement damage. Health damage resulting from road noise-induced diseases was determined using the affected population attribution factor and applied in a context based on the life years lost by that disease. Due to noise health damage, the total number of Disability Adjusted Life Years (DALYs) lost in Tarrant County is 4460 years. The study also found a 1.1% devaluation per $100000 property for increasing road traffic based on the hedonic pricing model and survey. Structural fire damage was evaluated for emergency response benefit by the FEMA calculation approach for monetizing emergency vehicles' temporary service. Emergency response delay for 5 minutes in Dallas County for reduced

61.4 real-time structure fire cases in Dallas County. Finally, the gas tax paid by detour-taking vehicles is considered a pavement damage benefit, as a portion of this money is used for road improvement. The total yearly primary benefits for 95 bridges amount to $2.3 billion. In comparison, the secondary benefits are as follows: pavement damage savings of $22.53 million, noise-related health benefits in Tarrant County worth $245.3 million, property devaluation of 1.1% per $100,000, and $738,584 in structure fire damage savings for Dallas County.

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1 Chapter 1

INTRODUCTION

1.1 Research Background

Benefit-cost Analysis (BCA) is an evaluation process to prioritize bridge project or take measures to reach alternate solutions if required. It is typically conducted before allocating federal grant to any bridge construction project or extension or enhancement. It involves comparing benefits that are projected to accumulate over a specific period to the project's predicted expenditures. Primary benefits are typically experienced directly by users of the improved facility. These are more direct and are meant to be calculated during the BCA of a bridge set by the USDOT guidelines include travel time saving, safety benefits, environmental benefits and so on. For instance, if a bridge is closed due to maintenance or replacement, vehicles have to take a detour and travel extra distance, which will cost them more time and money and add a negative impact on the environment due to emissions.

Apart from these mandatory primary benefits facility there are even more benefits to consider that are not easy to quantify known as secondary benefits. Which benefits are based on the situation with tertiary effect, such as noise reduction benefits, emergency response benefits, economic impact, etc. These benefits are generally not added to the BCA calculations because of uncertain nature and lack of calculation guideline. However, USDOT recommends that the applicant add them with proper connection to the project which may change the priority basis of the project. Adding those benefits and establishing the evaluation methods for those secondary benefits can highly improve the process of the BCA analysis and better understand the necessity of evaluating those benefits.

For example, traffic noise is not just a nuisance for vehicle passengers. It can significantly cost money. Added traffic noise not only harm the affected people healthwise and reduce productivity but also they can reduce adjacent property value. Furthermore, to reduce the road traffic noise building noise countermeasures such as noise barrier can cost a lot of dollars. In short traffic noise can be monetized into currency and considered as a secondary benefit.

Another secondary benefits is emergency response delays. The most important data point is to save human life or structural damage where longer emergency response time are associated with worse outcome in case of traumatic event or emergencies. The induced delay due to bridge closure for emergency vehicles may cause loss of life and valuable property damage which can also be monetized as benefits.

Typically, infrastructures like roadways and bridges are built for a certain capacity and lifetime. The capacity for a road pavement is dependent on the volume of traffic and the expected design load. However, when a bridge is closed, vehicles are bound to take alternative detour paths, which may not be designed to take the additional traffic for a long duration. Such detours will have a considerable impact on the rapid deterioration of the pavement, which will shorten the effective service life of the road. This phenomenon will be counted as another category of secondary benefit and add value to the total benefit.

Furthermore, the cost modeling based on the existing defects from the bridge inspection report and average low bid price is also a vital addition to the path of improving the BCA analysis. As they will give more practical idea about the maintenance cost budgeting and prioritize the ranking of the feasible intervention which can help the project to be more sustainable and effective throughout the service lifetime.

1.2 Problem Statement

Due to the intangible nature of secondary benefits, it is difficult to measure all the factors and convert them into currency. Therefore, still there is no set rule to monetize these difficult-to-quantify benefits, However, an applicant is allowed to calculate any foreseeable benefit that he may encounter and possibly to monetize. Hence there is still room for improvement for the BCA of bridge analysis. One of the major task in this study is to make the assessment as well as monetize some of these secondary benefits. Furthermore, establish some form of guideline based on the relevant data and rules to do the monetization in different locations and situations. The study includes general BCA of the primary benefits along with the secondary benefits to make improvements in the evaluation process.

Secondary benefits such as traffic noise may have multilateral impacts on various factors like health, property value, and cost of the measures to reduce the noise effect. The main challenge is to determine the multidimensional factors that are affected by this issue and set a logical rate according to the available data and research. The other challenging fact is there is lack of robust data and research for monetizing these benefits. Similarly, there is more difficult to quantify benefits such as emergency response which is even more uncertain in nature to evaluate because of all the variables that may arise during quantifying such a phenomenon. Emergency response can be correlated with many other benefits such as travel time saving, environmental impact, safety benefit, property damage cost, economic impact, etc. Meticulous assessment is required to set even a minimal standard for all these factors. Eventually, attempt to monetize them into US dollars. As the broad aspect of monetizing these benefits, guidelines allowed the applicants to consider any possible benefit but no fixed rate set by the regulatory institution USDOT [1] like common primary benefits, hence this is indeed a challenge to put these into monetization.

1.3 Scope and Objectives

The primary assignment of this thesis is to figure out the correlation of existing research data and come up with methods of monetization and quantification of secondary benefits. In such a way, this study will abridge the knowledge gap mentioned in the problem statement. Secondary benefit analysis ensures through assessment for a project that decision-makers have a complete picture of both direct and indirect effects. The scope and the objectives of the study are summarized below:

a) Assess secondary benefits and identify their intangible nature.

b) Establish methods to monetize for the secondary benefits.

c) Quantify the secondary benefits into currency (USD).

d) Calculate the benefit-cost analysis for Highway Bridge samples in North-Central Texas.

e) Show the importance of added secondary benefits with primary benefits to set the project priority while giving grants for any bridge project.

f) Make a comparison in the benefit-cost ratio (BCR).

g) Contribute to future research that attempts to monetize more of these secondary benefits.

h) Discuss difficulties associated with secondary benefits quantification and ways to overcome them.

i) Pave the way to discern intervention priority during bridge maintenance.

j) Contribute to the future guidelines set by the authority to monetize secondary benefits.

1.4 Outline of Thesis

Acknowledgement

Chapter 1- Introduction

- Background: It discusses the basis and general idea on which the study in conducted.
- Problem statement: State the problem and challenges that are needed to be addressed.
- Scope and objectives: Illustrates the extent of the study and required tasks to be performed to achieve the goal

Chapter 2 – Literature review: This chapter presents various relevant research on Benefit cost analysis, Additional benefit monetization related publications, regulatory guidelines.

Chapter 3 – Methodology: Methods and approaches of both primary and secondary benefit evaluation is conducted in this chapter.

Chapter 4 – Results and Discussion

Chapter 5 – conclusions and recommendations

The summary of research and conclusion and recommendation drawn from established methods and test results

References

Appendix

2 Chapter 2

LITERATURE REVIEW

2.1 Introduction

A functional and effective transportation network is essential to the economic welfare of country. Investment on infrastructural development underlies running system in an efficient manner in accordance with population growth and economic progression.

USDOT's discretionary grant programs have a BCA guideline to submit before any grant for various transportation projects. Where BCA is an evaluation process for the prospective benefits and cost of the project, this process gives the cumulative benefits accrue over the specific lifetime of the project compared with projected costs. These estimated benefits are meant to be monetized in currency. Which benefits are anticipated based on direct user or indirectly impacted facilities [1].

There is a standard data set provided by USDOT for specific types of benefits that are directly related to the user. Guideline also shows other types of benefits that applicants might find monetizing beneficial. Although there is no standard data provided for these other benefits, many of these are under research. As of yet, USDOT has not produced any guidelines about suggested methodology or parameter values. Decision makers are conscious of the resource limitations faced by applicants and the fact that it can occasionally be challenging to generate comprehensive forecasts and assessments. Transportation department's (DOTs) economists also provide seminars, websites, and website sources that might help come up with a monetization framework for challenging categories [1].

Lastly, the BCA plays a vital role in supporting funding decisions. The evaluation gives significant insight into the ultimate economic nationwide impact of the project.

2.2 Primary Benefits

Primary benefits outline appropriate methods for evaluating some of the most common benefit kinds; nevertheless, it is not meant to be a comprehensive inventory of all the pertinent advantages that could be anticipated to arise from all kinds of transportation enhancement projects. The baseline risk approach suggested by the guideline is to consider the worst-case scenario in a project. For instance, in the absence of the bridge, all kinds of traffic, both passenger and truck traffic, will be forced to take an alternative route. This significant rerouting will cause the traffic to increase on those alternate roads. Which roads might not hold all traffic efficiently and eventually cause substantial delays in travel time. This travel time delay is monetized as travel time saving and is considered a direct benefit. USDOT has its survey, economic analysis, and standard rate for different types of traffic hours costing and methods of monetization [2].

Due to the extra mileage traveling there will be cost associated in the vehicle operations as well. This Vehicle Operating Costs (VOC) are estimated based on the maintenance, tires, mileage-based depreciation, and insurance but made separate from fuel cost which is adjusted with the congested and noncongested traffic condition of the travel delays. This cost separation makes the calculation more precise and conservative..

Reducing the number or severity of crashes on the property to mitigate the risk of fatalities, injuries, and property damage is a major objective of many infrastructure improvements related to transportation. Applicants must explicitly state how their proposed project aims to improve safety outcomes and is expected to do so to calculate the project's safety benefits. It is the responsibility of the applicant to provide clear links and establish the reasoning for the enhancement project's contribution to safety. For example, any maintenance program, like patching deteriorated pavements or shoulder widening, can positively impact the long-term safety and functionality of the project.

Safety benefit is calculated in terms of the detour length taken by vehicles that are exposed on the road for a higher amount of time and have more chance of running into an accident. Additionally, a psychological factor is also imposed on the drivers for being unable to reach the destination in time due to the detour path, which is directly associated with the travel time delays. All the compensation rates for various accidents monetize the value of injuries according to the Maximum Abbreviated Injury Scale (MAIS). The KABCO level values shown result from multiplying the KABCO-level accident's associated MAIS-level probabilities [1].

So, one significant user advantage that results from modifications to transportation networks is increased safety. These benefits take the form of reductions in the rate of fatal, injury, and property damage-only (PDO) crashes. Crashes occur for integrated results and a combination of various factors, including heavily jam-packed, over-burdened roadways. With the progression of congestion, there is less margin for error and a more stressful driving situation. So avoiding the detours can improve this situation and result in more safety benefits [3].

Implementing the statewide crash data is not recommended, and more local county-based or crash data that can be exactly connected with the project should be applied to the calculation. There is a crash reduction factor (CRF) produced on the clearing house website based on location, severity, and impact of different countermeasures, and these values are estimated. Similarly, A crash modification factor (CMF) is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site. Through extensive research done by USDOT and partner organizations, there are individual CRFs for each type of countermeasure, but they can be combined based on clearinghouse data.

If a countermeasure reduces the accident by 25% then the CRF is .23 and CMF will be 1-.25= .75 so and applicant will reduce the crash data by 75% according to that specific countermeasure [4].

Environmental benefit is another primary benefit directly associated with the detour path taken by the vehicles. By reducing air pollution emissions from the production and burning of transportation fuels, transportation infrastructure projects may also reduce the environmental effect of the transportation system because society as a whole bears the consequences of air pollution exposure rather than the passengers and operators whose actions produce such emissions.

The most common local air pollutants generated by transportation activities include sulfur oxides (SOX), nitrogen oxides (NOX), and fine particulate matter (PM2.5). Recommended monetization values for reducing emissions of these pollutants including (CO2) Carbon dioxide is presented in guideline [1].

2.3 Secondary Benefits

Secondary benefits are the ones that are difficult to convert into currency. Because of their uncertain nature and sometimes appearing as intangible, these benefits are hard to monetize. The major task of this study is to assess some of these benefits and attempt monetization. There are examples of USDOT-suggested benefits given at the TRB conference, which are emergency response improvements, noise reduction, resilience, property value increases, and quality of life [6]. Furthermore, benefits like property damage saving, temporary job creation, and economic impacts are also included in the scope. However, the broadness of economic impact analysis keeps it out of context and should be avoided [1]. For instance, if there is job creation in one location due to some transportation project improvement and the companies relocate their business around that place, there is a chance that the other place where it is relocated is facing loss in jobs and less facility of business. Because of this, the total impact on the economy might be zero. Additionally, there might be a chance of double counting the benefits. So, even if there is a positive impact on the economy, a careful and cogent link should be established. It is the responsibility of the applicant, while monetizing secondary benefits, to quantify the timing and impacts wherever possible, as well as create a direct link with the project outcome.

Setting a link between the secondary benefits and the direct primary benefits can be done in many ways. Conflict between vehicles and trains causes a ripple effect on the region's road network, causing road congestion. Not only can traffic delays be considered as a quality of life benefit, but they can also lead to some more benefits. This road closure by the railway not only affected traffic delays but also delayed the emergency vehicles that were probably on the way to some rescue. Based on the type of rescue, it can be any property damage saving, lifesaving, environmental hazard response, and many more. From this kind of traffic, delays can be converted to other categories like safety benefits, environmental benefits, etc. [7]. These categories and subcategories of secondary benefits will be described more in the following parts.

2.3.1 Noise Reduction Benefits

Traffic noise is a significant source of nuisance that can be attributed to the creation of many problems such as health damage, Property value reduction, noise reduction countermeasure expenses, and so on. The degree and the overall impact noise has on us due to daily and constant exposure it cannot be overlooked. If these noise-related damages due to extra detour taking could be avoided, it would save a significant amount of loss that can be measured by different categories of monetization.

Life cycle cost analysis (LCA) chose to monetize impacts for another reason: monetary units can be used as a standard unit to evaluate different impacts. The EPS environmental accountability method monetizes health damages, ecosystem production capacity, biodiversity, and abiotic stock resources. The method uses different monetization methods, such as contingent valuation, market pricing, or hedonic pricing [8].

2.3.2 Benefits from Health Damages

Expressing health impacts, such as those caused by environmental noise, in monetary terms is a complex task. Various monetization approaches are used to quantify these impacts. For instance, we can consider the health impacts resulting from 1000 truck kilometers. However, this approach highlights the challenge of transferring health impacts assessed in disability adjusted life years (DALYs) into monetized health impacts [10].

Positive values in life are related to many aspects of human civilization, including fairness, love, and belief, diversity in nature, cultural heritage, and well-being. Generally speaking, those values can only be sufficiently articulated in monetary terms if one believes that the economic system is a superior structure to which all other forms of human interaction and existence are secondary [10].

An investigation of this kind is given in Muller-Wenk [10], which concludes that 38 more persons experience communication interferences in a year for every million additional truck kilometers driven throughout the day. The exact distance traveled at night would result in an extra 480 persons experiencing sleep disturbances over a year. A comparable link between transportation noises at night and sleep disruption was discovered 10].

The key results of the study on communication interference and sleep disturbance are significant. Communication difficulties at regular speech volume or listening disruption to radio or television are common, indicating a reduced ability to function in a general environment. Sleep disturbances are also prevalent, with symptoms including difficulty falling asleep, waking up during the night or getting up early in the morning, alterations to the nocturnal sleep cycle, and a reduction in the amount of Rapid Eye movement (REM) sleep, which is a more restful and restorative phase of sleep [10].

The study discovered statistically significant correlations between noise exposure and hypertension treatment, and odds ratios greater than one were discovered between noise exposure and treatments for elevated blood lipids, cancer, thyroid gland diseases, chronic bronchitis, bronchial asthma, and psychological disorders. How to assess these health impairments is now the question in order to make the impact of route analysis results meaningful and approachable for decision support. Mueller-Wenk [10].

Noise brings about economic loss and health-related damages, including medical costs, increased mortality, productivity loss, etc. Diseases linked to noise create two costs for society: the direct expense of medical care and the indirect cost of sick people's absence from work. Many jobs in urban locations involve high cognitive thinking and are likely to be exposed to traffic noise, which causes a loss in vital productivity [11].

The statistics by The World Health Organization shows that in the Western European countries, environmental noise causes a total loss of 1.0–1.6 million disability-adjusted years of life (DAYL), including 61,000 from increased ischaemic heart disease, 45,000 years for cognitive impairment of children, 903,000 years for sleep disturbance, 22,000 years for tinnitus, and 587,000 years for annoyance.54 Sleep disturbance and annoyance related to road traffic noise constitute most of the burden [12].

Effects of environmental noise on health: Not only can noise contribute to hearing loss, such as tinnitus, but it can also impact blood flow. Indeed, repeated exposure to excessive noise levels has been linked to hypertension, coronary heart disease, and myocardial infarctions. Environmental noise is said to cause almost 900,000 occurrences of hypertension annually, according to the EEA [15]. Moreover, 61 epidemiological research conducted in 2005 [10] had conclusively or subjectively linked transportation noise to myocardial infarction. The relationship between road traffic noise and myocardial infarction shows that regular exposure to louder noise levels raises the incidence and prevalence of myocardial infarction.

An estimated 61,000 disability-adjusted life years (DALYs) are lost as a result of ambient noise [16]. Although studies indicate that the expenses of noise-related health issues in the US are significant, a complete accounting of these expenditures has yet to be created. The annual cost of medical care for treating hearing loss is estimated to be between $3.3 billion and $12.8 billion[11]. The annual cost of lost productivity due to hearing loss ranges from $1.8 billion to $194 billion. According to a study by Neitzel and colleagues, preventing NIHL (Noise-Induced Hearing Loss) in just 20% of people who could be afflicted could save $123 billion in lost productivity, indicating that those costs may be higher [17]. Reducing the noise by just 5 decibels is expected to reduce the rate of hypertension by 1.4% and the prevalence of coronary heart disease by 1.8%, saving $3.9 billion in medical costs per year [18]. Other noise-related health impacts, such as ischemic heart disease and mental health issues, would further increase the cost estimates.

Another economic study in the USA from 2014 created a novel method to calculate the effect of noise pollution on the cost and prevalence of significant cardiovascular disease and hypertension components in the United States. The prevalence and associated costs of hypertension and coronary heart disease were assessed in response to hypothetical national-scale changes in environmental noise levels. Cost is associated with healthcare treatment and loss of productivity due to noise. For example, the relationship between the road traffic noise level and coronary heart disease CHD is 10 dB LDN. An increase in noise exposure increases the risk of CHD by 8% over a range of 52–77 dBA. According to the calculations, a 5-dB noise reduction scenario is predicted to lower the rate of coronary heart disease by 1.8% and hypertension by 1.4%. An estimated $3.9 billion was the yearly economic gain [13]. Additionally, 5.2 million (1.6%) and 7.9 million (2.4%) people were highly annoyed by rail and roadway noise, respectively, across the US; calculating the health damage caused by traffic noise and adding in the benefit-cost analysis is powerfully relevant [14].

2.3.3 Cost Effectiveness

There is a relationship between the effective treatment cost and clients' willingness to pay (WTP) for that treatment. The ultimate effectiveness of the cost selection for the yearly health damages is dependent on this relationship. Health economists analyze treatment costs and health outcomes to assess treatment techniques' efficacy and suggest cost-effective treatments. Health improvements are assessed in quality-adjusted life years (QALY), which is a very comparable metric to DALYs, with one extra QALY equating to nearly one DALY avoided.

The following table is a chart for the cost effectiveness of specific cost selection, which is related to the willingness to pay. The relationship of the intervention and cost-effectiveness is also represented in Table-1. Figure 2-1 shows a Diagram for WTP and cost difference vs. effectiveness.

Table 2-1: Cost vs Effectiveness per intervention

Intervention	**Cost**	**Effectiveness**
E	$55,000	5
D	$35,000	4
C	$25,000	3
B	$10,000	2
A	$12,000	1.5
Standard Care	$5,000	1

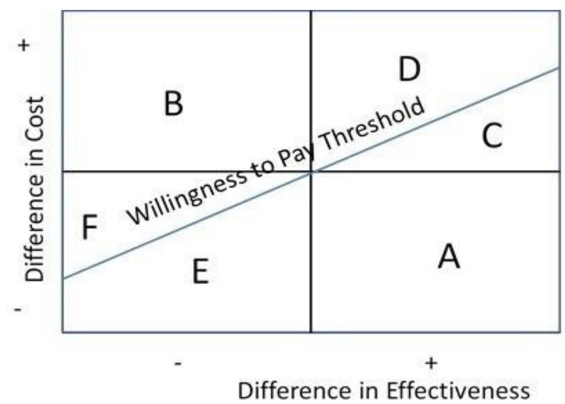

Figure 2-1 : Diagram for WTP and cost difference vs effectiveness

In the U.S. thresholds of $50,000/QALY or $100,000/QALY are often used. At points C and D, the intervention is more costly and more effective, but only point C is cost-effective. This is because the cost per unit increase in effectiveness is less than the willingness to pay threshold. Point D is not cost-effective, because it is too costly per unit gain in effectiveness.

At points E and F, the intervention is less costly and less effective. Only point E is cost-effective because the reduction in costs per unit reduction in effectiveness is sufficiently high [22].

2.3.4 Property Devaluation Benefits

Property devaluation is an imminent hazard caused the transportation noise increase due to detour taking extra vehicles. To measure this value reduction is a bit indirect as we cannot separately sell an environmental qualitative feature to the market. One probable solution is to employ a hedonic price method, such as the housing market. The method calculates how much people are willing to pay to live in a quieter location [19].

Hedonic pricing views a marketed good, typically a house, as a collection of discrete goods (characteristics or features) that cannot be sold separately on the market. The primary goal of a hedonic pricing model is to estimate the contribution of such traits or attributes to the price of the dwelling.

Hedonic pricing models are frequently used to calculate the quantitative values of ecosystem or environmental services that have an immediate impact on housing market prices. Where internal characteristics being sold for external impact. For instance one cannot sell the quietness of a house they have to sell the entire house but the quietness as an attribute does influence the total price [9].

2.3.5 Hedonic Pricing Approaches

Several measurement approaches are used to determine hedonic prices. Cohen and Coughlin measure the distance between each property and the airport to determine how close or accessible each property is to air transportation services and jobs at the airport.

For example, there were 67 houses in the 70–75 dB zone in 2003, down from 249 in 1995. Cohen and Coughlin took 727 households that moved between 1995 and 2003 out of the sample in an attempt to remedy this issue. A potential resolution could involve assigning a dummy variable to houses with zone shifts. They discover that homes in the 65 dB zone sell for 3.7% less than homes in the buffer zone, and homes in the 75 dB zone sell for 3.7% less using the smaller sample and a semi-log ordinary least squares (OLS) model [8].

Another approach involves a real-time survey. The subjective annoyance index for Geneva apartment buildings is created using information from a noise perception survey conducted in Switzerland. Annoyance caused by noise, especially traffic noise, is included in this index. The subjective noise index is then converted to a "perceived dB" index using the irritation index and the inverse of a Schultz curve. Consequently, three noise variables are available for an experiment in HP regressions by the researchers: (1) actual scientific traffic noise during the day, (2) actual scientific LDN for traffic noise, and (3) felt annoyance in dB for all noise sources The sample of apartment rent survey includes 2794 observations and hedonic property value study shows a reduction of rents by .15 to .18% per dB [9].

Finally, the hedonic property study aims to build a simulated market for environmental goods so that "consumers" can honestly and accurately express how much they are willing to pay (WTP) for more goods. When it comes to private goods, consumers in actual markets express their WTP by buying or not buying at various relative prices, assuming all other factors remain constant.Vehicle and Noise Threshold Interactions

There are studies related to certain noise threshold levels, which is directly dependent on the vehicle count, speed, and the vicinity of the noise source. Highway noise is caused by tire and pavement interaction. However, it is different in the case of trucks, where truck noise increases with vehicle speed. A good instance of increased density creating higher noise is two autos per mile at 50 mph, which gave less than a 40 dBA reading at 100 feet, but as the density increased, the noise climbed to around 65 dBA, resulting in a four-fold increase in noisiness. Whereas dBA is not directly proportional to noise. A combined traffic stream of 180 vehicles per mile density operating at 50 miles per hour and containing 5 percent heavy trucks would produce a mean noise level of 73 dBA with infrequent peak values of 90 dBA or more measured at a distance of 50 feet.

Traffic Rules of Thumb for Noise Doubling Traffic Volume = up to 3-decibel increase for same road geometry Noise of one heavy truck = as loud as ten passenger cars A 5 mph change in speed = 1-decibel change in noise level Halving the distance between traffic and a receiver = increase of 3 decibels [34]. Figure 2-2 shows the Automobile Density vs Speed based Noise level, Figure 2-3 shows Sound Pressure vs. level Of Noise Acceptability, and Figure 2-4 Speed vs Sound emission level [37] based on vehicle category..

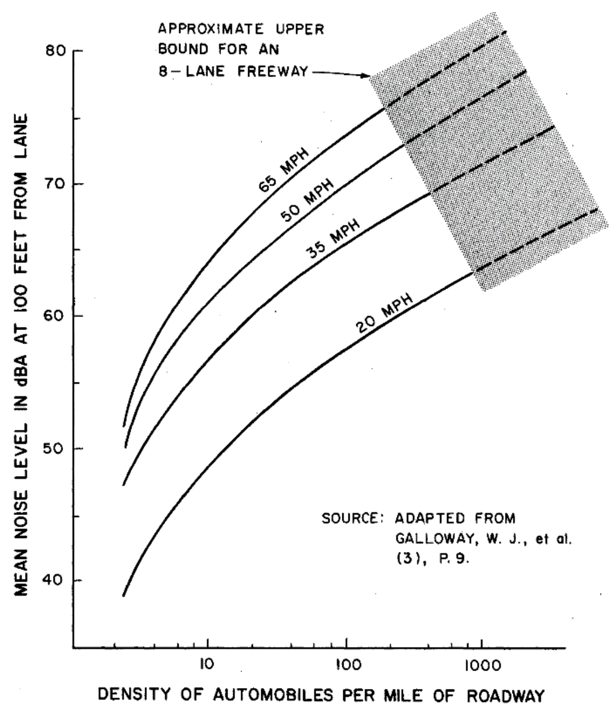

Figure 2-2: Automobile Densily vs Speed based Noise level

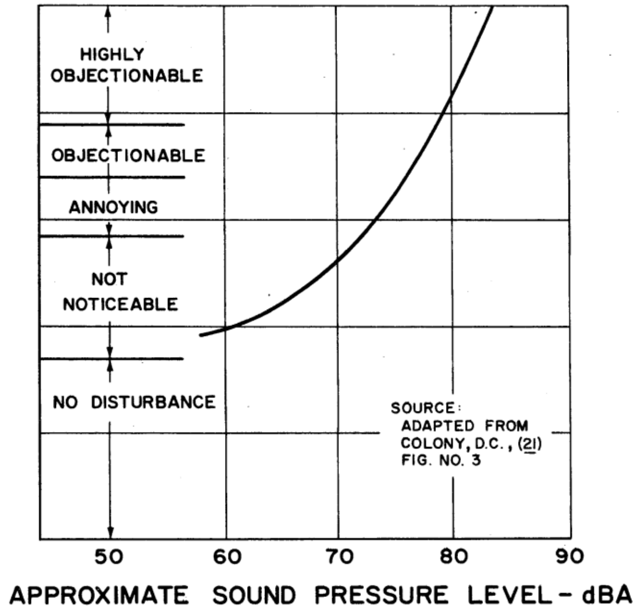

Figure 2-3 Sound Pressure Vs Level Of Noise Acceptability

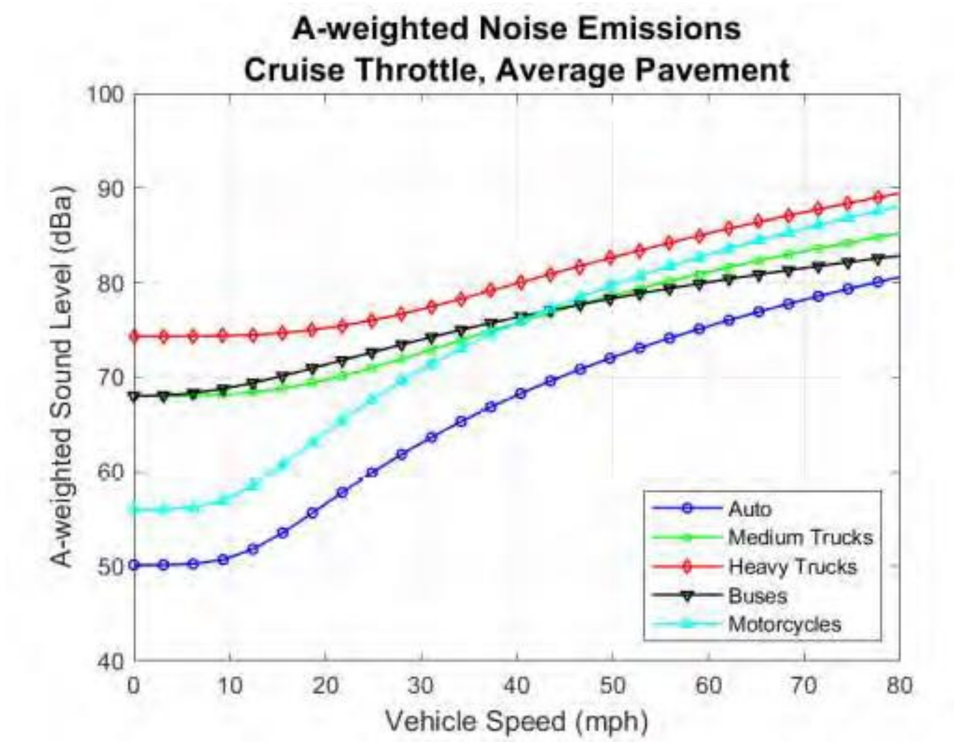

Figure 2-4 Speed vs Sound emission level based on vehicle category.

2.3.6 Benefits due to Noise Reduction Countermeasures Cost

The sound that is generated from the highway is basically from the tires, engine, and exhaust. There are range of frequencies generated from these traffic noise. Some sound are detectable by the human ears and some are not. Based on the count of the traffic and type of intensity these sounds vary and the common measure for sound is decibel dBA but the single measurement which is incorporated with the logarithmic time exposure of sound is expressed in Leq (equivalent continuous sound pressure level).

Apparently detour taking vehicles will increase this noise and countermeasures to reduce the noise impact is essential. According the importance and activity on the land there is specific guideline developed by the FHWA called noise abatement criteria (NAC). These criteria are used as one of two ways to evaluate when a traffic noise impact will occur. TxDOT has Adopted the federal NACs as its standard, as stated in their Guidance for Analysis and Abatement of Roadway Traffic Noise [23].

Traffic noise can be measured by the FHWA's traffic noise model software TNM 3.1 (latest version) and based on the land activity category given in NAC Table 2-2 different abatement measurements such as types of noise abatement receiver are proposed.

Table 2-2 FHWA Noise Abatement Criteria (NAC) [23]

Activity Category	FHWA dB(A) Leq	Activity Description
A	57 (exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 (exterior)	Residential
C	67 (exterior)	Active sports areas, amphitheaters, auditoriums, campgrounds, cemeteries, daycare centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or non-profit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools, television studios, trails, and trail crossings.
D	52 (interior)	Auditoriums, daycare centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios.

E	72 (exterior)	Hotels, motels, offices, restaurants/bars, and other developed lands, properties, or activities not included in A-D or F.
F	--	Agriculture, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing.
G	--	Undeveloped lands that are not permitted.

2.3.7 Emergency Response Benefits

Lifesaving: A well-maintained bridge is vital to Emergency Response Teams' attempts to save lives. It can be comprehended by looking at the statistics of the accidents that resulted in fatalities, serious injuries, and property damage. The arrival of an emergency vehicle at the right place at the right time is crucial to the action required. The Bridge's closing will obstruct victims' quick emergency assistance. If emergency personnel had not been able to respond in time by crossing the Bridge, any potentially lethal injuries might have turned fatal. Ambulance service delays have a reasonably predictable impact on the survival chances of patients with cardiac arrest [1]. The societal cost of the deaths that would follow if these lives were lost would be in the tens of millions of dollars [20].

Structural damage: This can happen for many different reasons, artificial or natural, on various infrastructure categories such as bridges and buildings. To minimize the loss, the rescue and intervention part has a vital role. Based on the effectiveness of the rescue operation, there are structural damage benefits; however, they can additionally include environmental, lifesaving, and more.

Accidents that lead to severe structural damage require quick emergency response. For instance, the fire on I-95 was started by a truck that overturned while carrying gasoline. Under the intense heat, the steel girders melted. There are significant economic and societal repercussions of this. I-95 is a significant interstate roadway along the East Coast [21].

The Federal Emergency Management Agency (FEMA) provides a methodology [26] that can help with the monetization of these advantages. This concept is based on the observation that delays in fire service might generate a generalizable increase in property damage when fires burn longer. The FEMA model [26] is based on the complete loss of a fire station or hospital, but it can also be used to account for delays in emergency vehicles. However, applicants using this methodology should be careful not to assume unreasonably excessive delays to emergency services in the baseline scenario. For example, assuming an ambulance will wait the entire time for a passing train at crossing gates when another grade-separated crossing is available nearby will result in an overestimation of the expected emergency service delay reduction. The methodology should not account for the traffic congestion situation, and emergency vehicles would be given priority over other vehicles [1].

2.3.8 Pavement Damage Benefits Due to Detour

When the highway bridge is closed for maintenance, highways or municipal streets are often used as detour roads. In most cases, these roads are not designed for extra traffic volume. Since detour vehicles will accelerate the damage to the the pavement and the DOTs must reconstruct the road to compensate for the damage, the cost associated with the damage can be accounted for as a secondary benefit. There are several methods for evaluating this user cost.

The Iowa DOT's current approach for measuring pavement damage caused by increasing traffic loading is based on the American Association of State Highway and Transportation Officials' (AASHTO) Road Test formulas for calculating a Present Serviceability Index (PSI), which were created in the 1950s. This method, while still in use, is based on subjective damage measurements (cracking and patching) acquired through a windshield survey. It also depends primarily on a functional assessment of the pavement surface [29].

The other approach is the traffic (gas tax) compensation method developed by Mn/DOT in 1991. The local agency receives revenue from traffic using the detour via the gas tax approach. However, because only a fraction of the state and federal gas taxes are designated for highway usage, the compensation granted to the local agency does not represent the whole gas tax revenue. The definition of the "highway" portion of the gas tax is one of the four essential components of the gas tax method. The other factors are vehicle miles traveled during the detour, fleet fuel economy, and state and federal gas tax rates [29].

2.4 Analysis Period

Selection of the analysis period is an essential step towards BCA. The benefits of transportation infrastructure improvements usually become apparent over the years when the new or enhanced asset is in use and are frequently associated with significant initial capital investments. A clear description of the analysis period is required, including the beginning and end of the benefit calculation duration. However, the calculation begins with a specific baseline year, from which year the benefits are projected with adjustment of inflation generally at a 7% discount rate [1].

The analysis period is generally connected with the service life of the enhancement project, and the duration is to be considered from the project's construction period. Where initial costs accrue during the project and benefits start after the end of the project. A more extended analysis period might help capture the full scenario, but due to market uncertainty, the analysis might lose its reliability. Furthermore, the discount rate increases even more in the subsequent years. Hence, guideline recommends that the analysis period capture up to 30 years while 20 years is a recommended duration [1].

2.5 Benefit-Cost Ratio

Among all the BCA measures, Net present value (NPV) is the most direct, where all the life cycle costs are discounted to the present. Benefits are estimated based on the present values. The value of the total benefit is placed as a numerator, and all costs become the denominator in the ratio. The majority of research suggests that an improvement is considered positive if its Benefit- Cost Ratio is 1.0 or above and harmful if it is less than 1.0 [4]. The general observation shows that this ratio is more than 20 in the case of newly constructed bridges, and the ratio might climb even higher in the case of extra added secondary benefits or proper consideration of all types of benefits. However, this parameter is solely to show the significance of the project in the case of bridges more than the cost-effectiveness since the benefit-cost ratio is generally high.

3 Chapter 3

METHODOLOGY

3.1 Introduction:

This study estimates benefit analysis of 95 bridges as a sample of bridges of 16 counties in North Central Texas . The net present value (NVP) of 2023 for the benefits was calculated in the Microsoft Excel sheet. All the benefits were calculated based on the detour path taken by the vehiles due to bridge closure. Assuming the bridge closure as the worst-case scenario where passengers have to take a detour path to reach their destination. Here, “USDOT Benefit Cost Analysis Guidance for Discretionary Grant Programs 2023” is used as the primary reference for the calculation procedure.

Besides monetizing the primary benefits, this study attempts to monetize the secondary benefits such as traffic noise reduction, emergency response benefit, and the pavement damage cost due to detour-taking vehicles. Although mentioned by USDOT, the methods of monetizing these secondary benefits are vague; this study utilized existing research as references to establish the monetizing methods.

A major component of this study includes collection of the data related to bridge and doing proper analysis and observation of those data. There was several layers of required data for the BCR analysis. Types of data includes:

- NBI (National Bridge Inventory) Bridge inspection report
- Bridge sample selection
- Bridge category-wise sampling
- Detour length per bridge
- General Traffic volume (ADT)
- Truck traffic Volume
- Vehicle operating rates
- Environmental damage rates
- Crash data

- Roadway VMT per considered counties

3.1.1 Bridge Sampling:

The Federal Highway Administration (FHWA) pavement/bridge condition (PM2) measures for the national highway system bridges classify bridges as Good, Fair, and Poor based on a set numerical scale. These bridge condition ratings are based on the national bridge inventory (NBI) inspection ratings and the percentage of bridge deck areas. This study compiled 109 Good, Fair, and Poor bridges in the DFW area before continuing to categorize bridge defects. Among those bridges, 95 were subcategorized as having 35 Good, 32 Fair, and 28 Poor bridges based on the available data and defects. An NBI rating of 4 or less is considered a poor bridge, a 5-6 rating is fair, and a 7-9 rating is considered a Good bridge. Utilizing the Texas Department of Transportation (TxDOT) AssetWise database data, the bridges' defects were categorized based on elements (deck, superstructure, and substructure). A quantitative analysis of the previous inspection report was conducted to determine the defects most prevalent in poor and fair bridges.

Following is the sample picture for the inspection report ranking scale. Categorization was based on bridge components such as deck superstructure or substructure with an overall rating. If a bridge has any of the components Poor and the rest of the items Fair or Good, it will still be considered a Poor bridge, which means the lower ranks will dominate the overall scale. Tables 3-1 show the bridge inspection condition rating scale, and Tables 3-2 and 3-3 show examples of deck and substructure rating reports as Item condition ratings, respectively.

Table 3-2: Bridge inspection condition rating scale

Texas Department of Transportation	Structure Number	180570000911347	Inspector	Armendariz,Jesus
	Facility Carried	IH 45 NB Conn C	Inspection Date	03/11/2022
	Feature Intersected	IH 30	Maint. Section	08

Condition Rating	Description*
N	Not Applicable
9	Excellent Condition
8	Very Good Condition - no problems noted
7	Good Condition - some minor problems
6	Satisfactory Condition - minor deterioration of structural elements (limited)
5	Fair Condition - minor deterioration of structural elements (extensive)
4	Poor Condition - deterioration significantly affects structural capacity
3	Serious Condition - deterioration seriously affects structural capacity, local failures possible
2	Critical Condition - advance deterioration of primary elements, bridge should be closed until repaired
1	Failing Condition - bridge closed but repairable
0	Failed Condition - bridge closed and beyond repair

**These descriptions are for items 58, 59, 60 and 65. Code Items 61 and 62 according to the TxDOT Coding Guide.*

Seal:

Signature & Date:

Prime Firm Name & Number:

Sub Firm Name & Number:

Bridge Description:
4 Span Continuous Steel Beam Bridge on Concrete Bents

General Comments:
Southeast to Northwest: Spans (52'-87'-112'-64')

Table 3-1: Example of deck rating report as Item wise condition rating

DECK (ITEM 58)

Structure ID: 180570000911347 Inspection Date: 03/11/2022

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Component	Description	Min.	Rating	Comment
Deck - Component Rating		1	4	Deck is deteriorated. Top of concrete deck has light to moderate delamination, scaling and extensive map cracking. Transverse cracks and longitudinal cracks. Several small spalls (1sf each), some with exposed rebar. Deck has many repairs, most with concrete but some with asphalt, Some repairs are failing. Underside of deck has numerous minor map cracks, transverse and longitudinal cracks with efflorescence. Small spall (1sf) with exposed rebar in under deck in west span.
Wearing Surface	None	6	N	
Surfacing Thickness:	inches			
Fill Height:	inches			
Joints, Expansion, Open		6	7	Steel armor is warped and has moderate corrosion.
Joints, Expansion, Sealed		6	N	
Joints, Other		6	N	
Drainage System		6	8	
Curbs, Sidewalk & Parapets		6	N	
Median Barrier		6	N	
Railings	T4 (Alum.), H=31"	6	6	Parapet walls have extensive impact damage. Numerous vertical and diagonal cracks and small spalls (1sf each). Outside vertical face of parapet has several spalls about 1 sf each at aluminum guardrail posts due to impact. The aluminum railing has dents and a large tear. Several aluminum posts are missing, loose or damaged from impact.
Railing Type:	T4(A)			
Railing Protective Coating		7	N	
Delineation		7	N	
Other		-	N	

Table 3-3 Example of Substructure rating report as Item wise condition rating

SUBSTRUCTURE (ITEM 60) Structure ID: 180570000911347 Inspection Date: 03/11/2022

DO NOT DISCLOSE. THIS INFORMATION IS CONFIDENTIAL UNDER THE TEXAS HOMELAND SECURITY ACT & 23 U.S.C SECTION 409, SAFETY SENSITIVE INFORMATION.

Component	Description	Min.	Rating	Comment
Abutment Caps		0	7	Abutment caps have hairline vertical cracks.
Above Ground		0	N	
Below Ground or Foundation		0	8	
Backwalls & Wingwalls		0	6	Northeast corner of the northwest abutment backwall is breaking apart. Backwalls have vertical and diagonal cracks some with efflorescence and small to moderate spalls (2sf each). Excessive sand and debris around bearings.
Intermediate Supports:				
Caps - Concrete		-	7	Hairline vertical cracks in interior bent caps.
Caps - Steel		-	N	
Caps - Timber		-	N	
Above Ground - Concrete		-	7	Several columns have minor scrapes and small spalls (1sf each).
Above Ground - Steel		-	N	
Above Ground - Timber		-	N	
Above Ground - Masonry		-	N	
Below Ground or Foundation		-	8	
Collision Protection System		5	7	Concrete traffic barriers have hairline vertical cracks and minor scrapes under bridge.
Steel Protective Coating		6	N	
Overall Component Rating			6	

Table 3-4 shows element level data sample in the amount of defect with distinct code for different types of elements like Deck, superstructure, and substructure and Figure 3-1 shows visual picture of inspection showing defects addressing need for maintenance.

Table 3-4: Element Level Data in Bridge inspection Report

Element Inspection

Rollup

	Environment	Total Quantity	Units	Condition State 1	Condition State 2	Condition State 3	Condition State 4
12 - Reinforced Concrete Deck	3 - Mod.	11213	sq. ft.	4273	5540	1400	0
1080 - Delamination/Spall/Patched Area		140		0	140	0	0
1120 - Efflorescence/Rust Staining		600		0	600	0	0
1130 - Cracking (RC and Other)		1400		0	1400	500	0
1190 - Abrasion/Wear (PSC/RC)		4800		0	4800	0	0
107 - Steel Open Girder/Beam	3 - Mod.	1575	ft.	1560	15	0	0
1000 - Corrosion		10		0	10	0	0
515 - Steel Protective Coating		13781	sq. ft.	13693	88	0	0
3440 - Effectiveness (Steel Protective Coatings)		88		0	88	0	0
205 - Reinforced Concrete Column	3 - Mod.	9	each	7	2	0	0
1080 - Delamination/Spall/Patched Area		2		0	2	0	0
215 - Reinforced Concrete Abutment	3 - Mod.	120	ft.	108	12	0	0
1080 - Delamination/Spall/Patched Area		12		0	12	0	0
234 - Reinforced Concrete Pier Cap	3 - Mod.	146	ft.	146	0	0	0
304 - Open Expansion Joint	3 - Mod.	120	ft.	90	30	0	0
310 - Elastomeric Bearing	3 - Mod.	25	each	15	3	5	2
2230 - Bulging, Splitting, or Tearing		5		0	0	5	0
321 - Reinforced Concrete Approach Slab	3 - Mod.	1360	sq. ft.	360	1000	0	0
1130 - Cracking (RC and Other)		200		0	200	0	0
1190 - Abrasion/Wear (PSC/RC)		800		0	800	0	0
333 - Other Bridge Railing	3 - Mod.	630	ft.	435	170	25	0
1080 - Delamination/Spall/Patched Area		60		0	60	0	0
1130 - Cracking (RC and Other)		70		0	70	0	0
7000 - Damage		35		0	10	25	0

Description Most all prestressed concrete box beams have widespread longitudinal and diagonal cracks (up to 1/16" W) along the bottom flange soffit, most for the full length.

PHOTO 2 Recommended Maintenance Needs

Description Exterior box beams have moderate horizontal, diagonal and map cracking (up to 1/4" W) along the web and flanges, again for full length and some with efflorescence present.

Figure 3-1 Visual picture of inspection showing defects addressing need for maintenance

3.1.2 Data extraction from TXDOT Open data portal:

TxDOT's open data portal presents geospatial data on Texas bridges. This study extracted information from the portal, such as detour length, average daily traffic count ADT, year of the traffic survey, truck traffic, cost of the bridge construction, etc. Figure 3-2 shows TxDOT Open data portal geospatial data for bridges. Figures 3-3 and 3-4 represent detour length and ADT per bridge ID information, respectively.

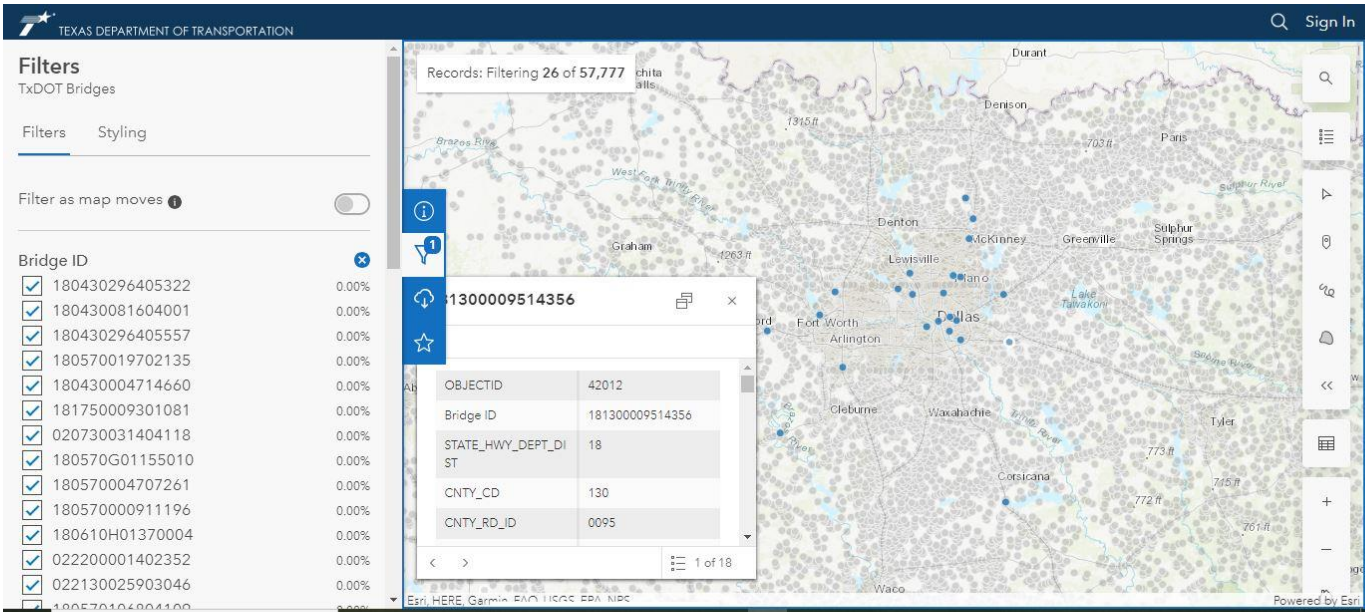


Figure 3-2: TxDOT Open data portal Geospatial data for bridges

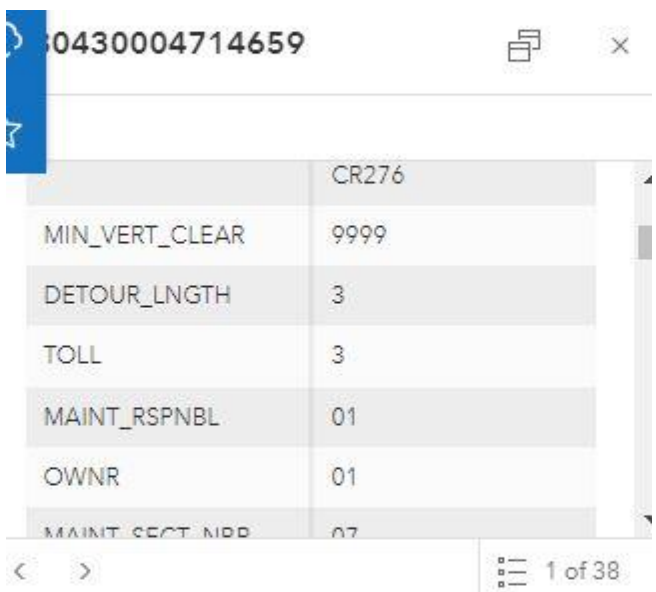
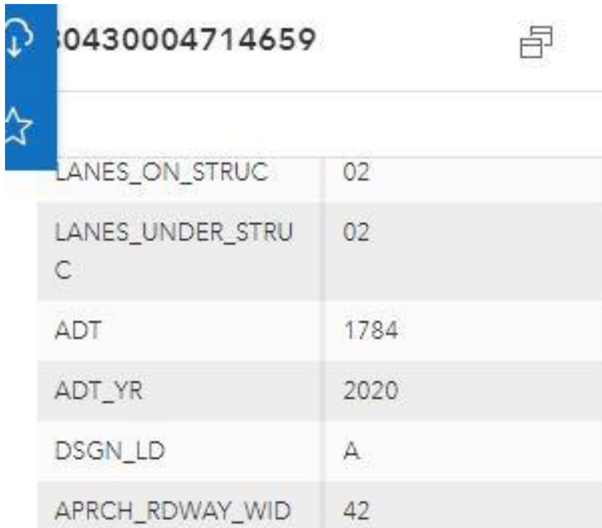


Figure 3-3: Per bridge ID information (Detour Length)



0430004714659

LANES_ON_STRUC	02
LANES_UNDER_STRUC	02
ADT	1784
ADT_YR	2020
DSGN_LD	A
APRCH_RDWAY_WID	42

Figure 3-4 Per Bridge ID information (ADT)

3.1.3 Detour Path:

The detour path's value in the BCA calculation of a bridge is heavily influenced by the traffic volume and location. Even for detour routes that may seem minor, if the bridge experiences high traffic volume and is closed for a prolonged period, it can have a significant impact on the benefit calculation. Furthermore, if the bridge is located in an area with limited alternatives, it leads to higher benefits, necessitating more attention. Figure 3-5 provides an example of a Detour Map for Walden Rd. 124. 69. Bridge closure.

For example, this study found that a bridge in Tarrant County in Lake Worth has a 37-mile detour path. This bridge, structure number 022200017105033, has a traffic volume 34,893 (2014), with 3% truck traffic. Since the structure shown in Figure 3-6 is situated on a water body and there is no nearby alternative, it has very high benefits, which make the bridge significant for keeping functional.

Figure 3-5: Detour Map. Walden Rd. 124. 69. Bridge closure

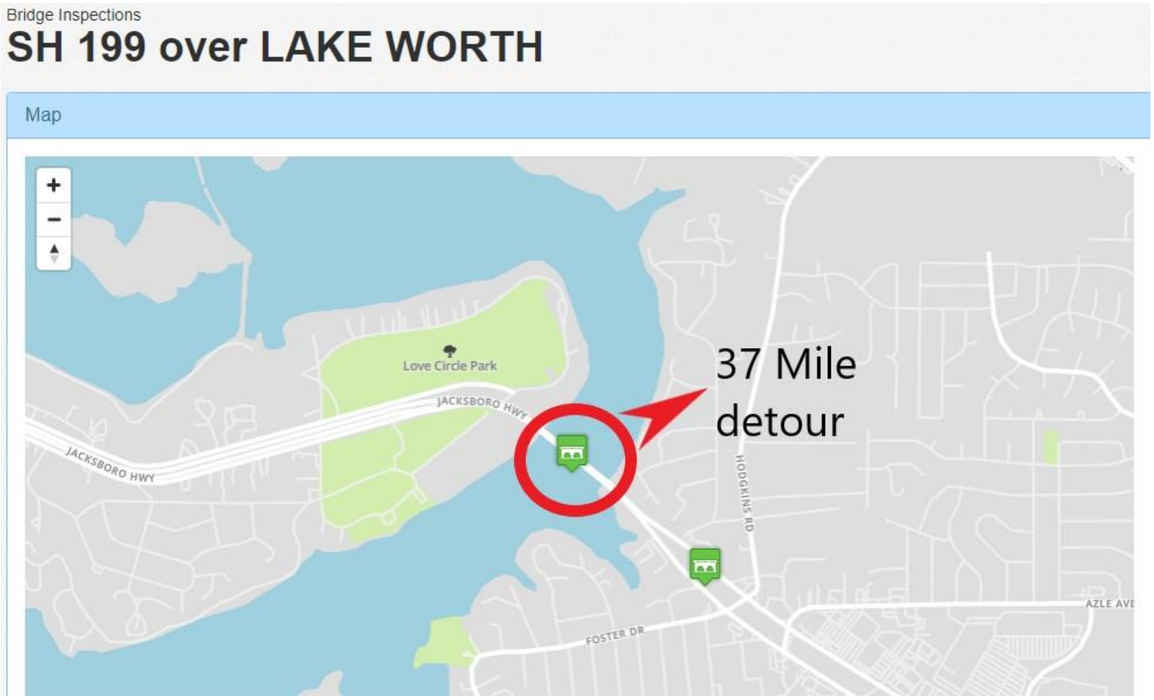


Figure 3-6; Lake worth Bridge with 37 mile detour path

3.1.4 Traffic Count:

Since Guideline has mentioned separate travel time-saving rates and vehicle operation rates for different types of vehicles, traffic count is considered according to that. Truck traffic is separated from the total traffic count to generate passenger-car traffic volume.

3.1.5 Crash Data:

TXDOT has a List of crashes and injuries by county yearly. Table 3-6 shows a sample of crash data from the year 2022 used to calculate safety benefits. Terminologies in the table conform with the terminology given in the MAIS (Maximum Abbreviated Injury scale), except for "Incapacitating Injury" is referred to as "Suspected Serious Injury, and "Non-Incapacitating Injury" is referred to as "Suspected Minor Injury."

3.1.6 Roadway VMT Per County

NCTCOG has released total road way vehicle miles travel VMT for 10 counties for different years shown in Table 3 5 [38]. Total VMT is used to find out the exposure factor for the vehicles in each counties while calculating safety benefit which represents a fraction of time a vehicle might have chance to run into an accident. Table 3-6 shows crashes and injuries by counties.

Table 3-5 Roadway Vehicle Miles of Travel (VMT)

County	2023	2026	2036	2045
Collin	32,253,931	35,010,183	43,573,963	53,415,806
Dallas	92,882,433	99,191,371	110,446,841	122,447,539
Denton	26,727,961	28,845,410	35,417,635	45,243,069
Ellis	9,044,651	9,596,966	11,620,955	13,713,108
Johnson	5,717,034	6,076,868	6,976,306	8,130,319
Kaufman	7,736,090	8,194,899	9,373,918	11,295,787
Parker	6,146,925	6,559,382	7,774,531	9,064,871
Rockwall	3,281,624	3,698,824	4,399,846	5,522,099
Tarrant	61,540,586	66,185,544	77,646,292	87,927,607
Wise	4,115,586	4,326,852	4,901,751	5,596,590
10-County Total Daily VMT	**249,446,821**	**267,686,298**	**312,132,037**	**362,356,795**

Table 3-6 crashes and Injuries by counties (2022 update)

County	Fatal Crashes	Fatalities	Suspected Serious Crashes	Suspected Serious Injuries	Suspected Minor Crashes	Suspected Minor Injuries	Possible Injury Crashes	Possible Injuries	Non-Injury Crashes	Non-Injuries	Unknown Severity Crashes	Unknown Injuries	Total Crashes
Anderson	15	20	46	57	105	154	131	234	474	1,436	16	47	787
Andrews	10	19	10	16	52	69	45	72	275	682	6	15	398
Angelina	16	19	65	80	266	374	203	307	1,115	3,317	37	146	1,702
Aransas	6	6	17	21	49	77	35	57	183	486	8	26	298
Archer	1	2	11	12	13	20	18	25	74	149	4	5	121
Armstrong	5	12	4	5	6	9	2	2	27	73	2	3	46
Atascosa	12	13	35	55	91	134	65	92	694	1,787	26	64	923
Austin	9	10	18	28	83	104	59	93	388	1,328	10	38	567
Bailey	0	0	1	1	14	17	13	20	88	208	5	10	121
Bandera	5	6	32	39	51	63	27	35	171	394	8	17	294
Bastrop	24	28	95	138	223	308	283	452	1,225	4,167	64	173	1,914
Baylor	0	0	3	3	5	10	4	6	46	78	0	2	58
Bee	4	4	14	17	38	51	52	72	276	669	18	35	402
Bell	53	58	202	259	978	1,379	835	1,285	3,908	12,343	235	797	6,211
Bexar	232	250	728	854	5,730	7,657	6,990	11,350	30,740	85,127	3,052	13,886	47,472
Blanco	5	5	20	32	35	52	20	37	162	406	8	18	250
Borden	0	0	1	1	2	2	1	1	12	23	1	1	17
Bosque	6	9	7	7	19	28	33	44	109	211	3	9	177
Bowie	16	17	63	83	315	431	355	552	1,430	4,482	32	179	2,211
Brazoria	35	44	202	253	657	905	646	1,066	3,942	11,686	125	493	5,607
Brazos	17	17	92	110	666	903	492	841	2,163	7,144	66	321	3,496
Brewster	4	4	7	11	10	10	15	16	88	238	8	16	132
Briscoe	0	0	2	3	2	2	0	0	10	17	1	1	15
Brooks	4	5	3	3	22	35	24	59	95	267	3	15	151
Brown	7	8	34	46	66	93	84	143	452	1,281	11	29	654
Burleson	12	15	23	29	38	53	27	44	173	434	29	85	302

3.2 Primary Benefits Monetization :

The most obvious benefits because of a bridge closure and detour taking are the primary benefits such as travel time saving, vehicle operating cost etc. All the rates and the methods for any grant program are well researched and surveyed by USDOT based on the economic condition, income and several other guidelines.

3.2.1 Travel Time Saving benefit:

Transportation infrastructure enhancement projects may be designed to shorten travel times for system users. Enhancing traffic flow, boosting transit vehicle operating speeds or decreasing transit service headways, or providing additional, quicker links between destinations. For the bridge maintenance or replacement the lanes are assumed to be closed as a worst case scenario. Travel time-saving benefit is calculated based on that bridge closure requiring a passenger to travel an extra distance in a detour path from point A to Point B. Calculation concept is multiplying Vehicle Hourly Travel (VHT) with hourly rate provided in U.S.DOT guideline 2023. Values of travel time saving is referred in Table 3-7 and Average Occupancy of Passenger per Vehicle in Table 3-8. EQ. 1 provides the formula referring Excel calculation in Table 3-14 monetizes travel time saving benefit in dollars as currency.

$$\mathrm{I} = (\mathrm{E} * 1 * 32.4 + \mathrm{G} * 1.67 * 17 + \mathrm{H} * 1.67 * 31.9) * \left(\frac{\mathrm{D}}{75}\right) \qquad \ldots(1)$$

Where:

C= ADT; Average number of vehicles that moves through a road in a single day.

Total ADT and Truck ADT is given in TXDOT open data portal.

D= Detour Length (mi); alternate path distance in case of the bridge closure

E= ADT_TRK; Average number of trucks moves through a road in a single day.

F= ADT w/o TRK; ADT without Truck is the ADT of other vehicles except the trucks

F= (ADT w/o TRK) is separated into two more categories which are G & H. Personal purpose ADT (88.2% ADT w/o TRK) and Business purpose ADT (11.8% of ADT w/o TRK)

G= Personal purpose ADT

H= Business purpose ADT

I= $ Value of Travel Time Saving (VTTS)/Day

Assumed speed of vehicle is 75MPH (based on speed limit)

VHT = (ADT* Detour miles)/Speed

Vehicle Occupancy: number of people occupying the vehicle

Table 3-7: Value of Travel Time Saving

Personal purpose value of time/ hr.	Business purpose value of time/hr.	Commercial (Truck)
$17.00	$31.90	$32.40

Table 3-8: Average Occupancy of Passenger per Vehicle

passenger vehicle (People/Vehicle)	Truck occupancy (People/vehicle)
1.67	1

3.2.2 VOC Saving Benefit:

VOC saving is calculated based on the VMT and given per mile operating cost in USDOT Guideline. Total Vehicle operating cost is represented in Column J in Table 3-12 and EQ. 2 represents the formula for it. Vehicle operating cost per mile is given in Table 3-9.

Table 3-9: Vehicle Operating Cost per Mile

vehicle type for operation cost	$ cost / mile
Light duty	0.46
Commercial (TRK)	1.01

$$J = (E * 1.01 + F * 0.46) * D \qquad \ldots(2)$$

Where

J= Vehicle operating cost/ Day

3.2.3 Environmental Benefits:

Transportation projects that reduce overall fuel consumption, whether through increased fuel efficiency or a reduction in vehicle miles traveled, often reduce emissions and may result in climate and other environmental benefits. Projects that result in increased vehicle miles traveled, such as through stimulated demand, on the other hand, may result in a rise in emissions. The most common local air pollutants generated by transportation activities include sulfur oxides (SOX), nitrogen oxides (NOX), and fine particulate matter (PM2.5).

For the calculation of the Emission benefit, all the recommended emission type from USDOT guideline [1] and the compensation cost as a benefit for the year 2023 is considered. The emission rate in gram per mile cited in Table 3-10 is found on the Website of the U.S. Environmental Protection Agency (EPA). In addition, the Monetized Damage Costs for Various Emissions per Metric Ton in given in Table 3-11.

Table 3-10: Various emission rate from vehicles

Emissions Category	Rate gram/mile (E_r)
Exhaust NOx	0.143
PM2.5	0.008
C02	400
So2	0.0418

Table 3-11: Monetized damage costs for various emissions per metric ton

Emissions Type	Dollars per metric ton (P_m)
Exhaust NOx	$16,800
PM2.5	$810,500
C02	$57
So2	$45,100

Again from Table 3-14 column K is calculated using EQ. 3.

$$K = \sum(Er * Pm) * VMT \quad \text{-------} \quad (3)$$

Where,

K= Total vehicle emission reduction benefit per day

Er= Emission Rate

Pm = Recommended monetized value per metric ton

3.2.4 Safety Benefit

Safety benefit was calculated in terms of the detour length taken by vehicles that are exposed on the road for a higher amount of time and have more chance for running into an accident. Additionally, a psychological factor is also imposed on the drivers for being unable to reach the destination in time due to the detour path. As all the compensation rates for various category of accidents are mentioned in the KABCO scale suggested by USDOT Guideline [1].

Total vehicle miles traveled per counties were found from NCTCOG database and to avoid the overstatement of the accidents along the detour path an exposure factor is imposed to reduce the numbers of all type of accident considered and found from the data.

VMT for the detour path is calculated multiplying available ADT with respective detour length for that bridge. Dividing VMT for specific bridge ID by the total VMT of the county where the bridge is situated the exposure factor is calculated which is used to reduce the amount of accident for the whole county by multiplying with yearly accident rate of each different category found from TXDOT. Furthermore, compensation rates are multiplied with the amount of accident of each category and we figure out the safety benefit on a yearly basis. This total benefit on a yearly basis is again reduced by 51% crash reduction factor (CRF) as per the CMF clearing house. The CRF value is based on the Lane closure. Safety Benefits are separately calculated in another sheet and added to the Total calculation.

Table 3-12: Safety Benefit Calculation Table in Excel

County Name & Bridge ID	Bridge type	ADT	Detour Length	VMT/Day	Total VMT/day per county	Exposure Factor	Fatal Crashes	Suspected Serious Injuries	Suspected Minor Injuries	Possible Injuries	Non Injuries	Unknown Injuries	Total benefit/year	Final benefit with CRF/year
Collin							73	408	2808	3509	28,495	1,478		
180430081604001	Fair	1,477	11	16247	32,253,931	0.0005037215	0.036772	0.205518	1.41445	1.767559	14.35355	0.7445		
Safety Benefit							433906	115974	217401	138753	57414	159249	1122697	572575
180430004705083	Fair	18,700	1	18700	32,253,931	0.0005797743	0.042324	0.236548	1.628006	2.034428	16.52067	0.856906		
Safety Benefit							499418	133484	250225	159703	66083	183292	1292204	659024
180430296405322	Fair	28,475	2	56950	32,253,931	0.0017656763	0.128894	0.720396	4.958019	6.195758	50.31294	2.60967		
Safety Benefit							1520954	406519	762048	486367	201252	558208	3935348	2007027
180430004714660	Fair	22,343	2	44686	32,253,931	0.0013854435	0.101137	0.565261	3.890325	4.861521	39.47821	2.047686		
Safety Benefit							1193421	318977	597943	381629	157913	438000	3087883	1574820
180430296405557	Fair	75,154	1	75154	32,253,931	0.0023300726	0.170095	0.170095	6.542844	8.176225	66.39542	3.443847		

Table 3-13 Value of Reduced Fatalities and Injuries

KABCO or # Accidents Reported)	severity	Monetized value 2021 $
O	No injury	4,000
C	Possible Injury	78,500
B	Non-incapacitating	153,700
A	Incapacitating	564,300
K	Killed	11,800,000
U	Injured (Severity Unknown)	213,900
# Accidents Reported	Unknown if Injured	162,600

In the Table 3-12 for safety benefit calculation , the row for county name such as Collin represents multiple categories of accident data. EQ. 4 shows normalized number of accidents in the row of Bridge ID and EQ. 5 presents final safety benefit.

$$N = Q * X \qquad \text{------} \qquad 4$$

Where, N= Normalized number of accidents

Q= Number of accidents per county

R= VMT/day

T= Total VMT/day per county

X= R/T; Exposure factor

Again,

SB= the Final safety benefit

$$SB = N * Compansation\ rates * CRF \qquad \text{------} \qquad 5$$

CRF: Crash reduction factor for bridge lane closure (51%)

Compensation rates= Value of Reduced Fatalities and Injuries from Table: 3-13. Table 3-14 shows safety benefit caculations for sample of bridges.

Table 3-14: Benefit Calculation for Sample of Bridges

A	B	C	D	E	F	G	H	I	J	K	L	M
Bridge ID	County	ADT	Detour Length (mi)	ADT_TRK	ADT w/o TRK	Personal purpose ADT	Business purpose ADT	$ Value of Travel Time Saving (VTTS)/Day	Vehicle operating cost/ Day ($)	Emission reduction Costs/day($)	Safety Benefit/year	Total benefit/ year
180430081604001	Collin	1,477	11	7	1,470	1296.54	173.46	6787	7516	545	572575	5858677
180430004705083	Collin	18,700	1	6	18,694	16488.1	2205.892	7811	8605	628	659024	6726630
180430296405322	Collin	28,475	2	9	28,466	25107	3358.988	23787	26207	1912	2007027	20485593
180430004714660	Collin	22,343	2	12	22,331	19695.9	2635.058	18665	20569	1500	1574820	16076070
180430296405557	Collin	75,154	1	4	75,150	66282.3	8867.7	31391	34573	2523	2648571	27029820
180570019702167	Dallas	29,620	1	9	29,611	26116.9	3494.098	12372	13630	994	1851081	11461809
180570000911196	Dallas	121,720	1	8	121,712	107350	14362.016	50840	55996	4086	7606805	47095169
180570000902002	Dallas	16,405	1	7	16,398	14463	1934.964	6852	7550	551	1025219	6348513

3.3 Secondary Benefits:

For the quantification and monetization of the secondary benefits noise reduction and emergency response benefits are selected here. Although these benefits don't have any standard guideline but many researches has already been done in this field. Based on those surveys and researches this study attempted to integrate the relevant knowledge and mathematically quantify the desired benefits incorporating with avoided detour path.

3.3.1 Noise Reduction Benefit:

When a bridge is closed, vehicles will take possible detour paths, increasing the traffic in that alternate path. As noise intensity increases exponentially, doubling the traffic volume with an increase of 3 dB can double the intensity of the sound [34]. Undesirable traffic noise can have many different layers of impact that have financially negative consequences. Noise can damage health and reduce productivity, reduce property value, and can cost huge sums of money to install noise reduction countermeasures

3.3.1.1 Health damages benefits:

The cost related to treatment of the health damage is considered as the benefit. But the quantification is related to the life time a person loses due to specific amount of noise increase. The researchers employed a common internationally accepted metric known as Disability Adjusted Life Years (DALYs) to assess the health impact of noise. A DALY is the loss of one year of good health.

Our main measure of disease burden was the Disability Adjusted Life Year (DALY). The DALY simultaneously considers the reduced health state due to disability before death (Years of Life Lived with Disability (YLD)) and the decline in life expectancy due to death (Years of Life Lost =YLL). We estimated DALYs for represented as total DALYs as well as DALY rates per 100,000 people to adjust for local population sizes.

Disease type vs population attribution relation: This study extrapolates relation between the disease category and the number of population affected by that. An existing research of London [24] is adopted for this case where survey was conducted in England at local authority district with total population of n = 42,738,500. All the diseases and disturbances considered for the calculation has been proved to be responsible from road traffic noise. Table 3-15 and Table 3-16 shows DALYs with noise response for HA, HSD and IHD, Stroke Respectively.

Table 3-15: DALYs with noise response HA and HSD [24]

Factors	Highly annoyed (HA)	Highly Sleep Disturbed (HSD)
Percent of Population	3.9 %	0.9 %
Number of people	1,662,157	382,333
Total DALYs per year	33,243	26,763
DALYs per 100,000 people/yr	78	63

Table 3-16: DALYs With noise response for IHD and Stroke [24]

Factors	Ischemic heart disease (IHD)	Stroke
Population attribution factor (PAF)	1.5%	3.8%
Number of people	641077	1624063
Total DALYs per year	11,566	18592
DALYs per 100,000 people/yr.	27	44

We can find the rate of DALYs lost per person affected from the relation of number people and the Total DALYs lost per year. From which if we use the Local noise map to see the number of people affected by different noise level in different area we can set the value for the amount of DALYs

For instance

The rate of DALY's for highly annoyed (HA) per individual =Total DALYs per year/ Number of people

=33,243/1,662,157

=.01999

$\cong 2\%$

So we can say 2% DALYs lost from the number of highly annoyed people affected from total population. Hence use this individual rate for this specific category HA and apply it based on total population of considered area.

When the influence of population size was removed from the road traffic attributable DALYs by expressing them as rates per 100,000 people.

So if we want to use DALYs per 100,000 people/yr. formula is

= (Total DALYs per year/ Total Number of people)* 1000000

Similarly, deducing the each type of disease wise DALYs rate is given in the Table 3-17 .

Table 3-17: Type of disease vs DALYs rate

Type of Disease	Rate of DALYs
Highly annoyed (HA)	2%
Highly sleep disturbed (HSD)	7%
Ischemic heart disease (IHD)	1.8%
Stroke	1.14%

Health damage monetization on United States basis: The USDOT Bureau of Transportation Statistics data is obtained below, where the transportation noise map is developed using a 24-hr equivalent A-weighted sound level (denoted by 24-hr LAeq) noise metric. The results represent the approximate average noise energy due to transportation noise sources over 24 hours at the receptor locations where noise is computed, expressed in decibels. If the traffic count increases, the range of people affected by road noise can be changed. Table 3-18 for people potentially exposed to road noise in 2016 and 2018 in the United States.

Table 3-18: Population potentially exposed to road noise, 2016 and 2018

A-weighted 24-hour LAEQ (dBA)	Population exposed, 2016	Percent of total population, 2016	Population exposed, 2018	Percent of total population, 2018	Percent change 2016 to 2018
45 to 49	13999857	4.3	14310425	4.4	2.2
50 to 54	11985756	3.7	12144406	3.8	1.3
55 to 59	7942851	2.5	7961360	2.5	0.2
60 to 69	5981900	1.9	6367715	2	6.4
70 to 79	1569715	0.5	1654354	0.5	5.4
80 or more	291405	0.1	336381	0.1	15.4
Total road noise	41771484	12.9	42774641	13.2	2.4

3.3.1.2 Health damage in Tarrant county of Texas:

Tarrant County is located in the U.S. state of Texas, with a 2020 U.S. census population of 2,110,640. This county is the third most populous county in Texas and ranks number 15th in the United States. As a part of the Dallas-Forth Worth Metroplex, this county possesses all the urban features and faces a noise-related crisis as there is a large airport called DFW int. airport and highways. As a part of North Central Texas counties, it contains brides that are also covered in our 109 samples of bridges. This study conducts a sample test based on inferences discussed above on monetizing health damage due to road noise. Figures 3-7 and 3-8 show the physical and noise maps of Tarrant County, respectively.

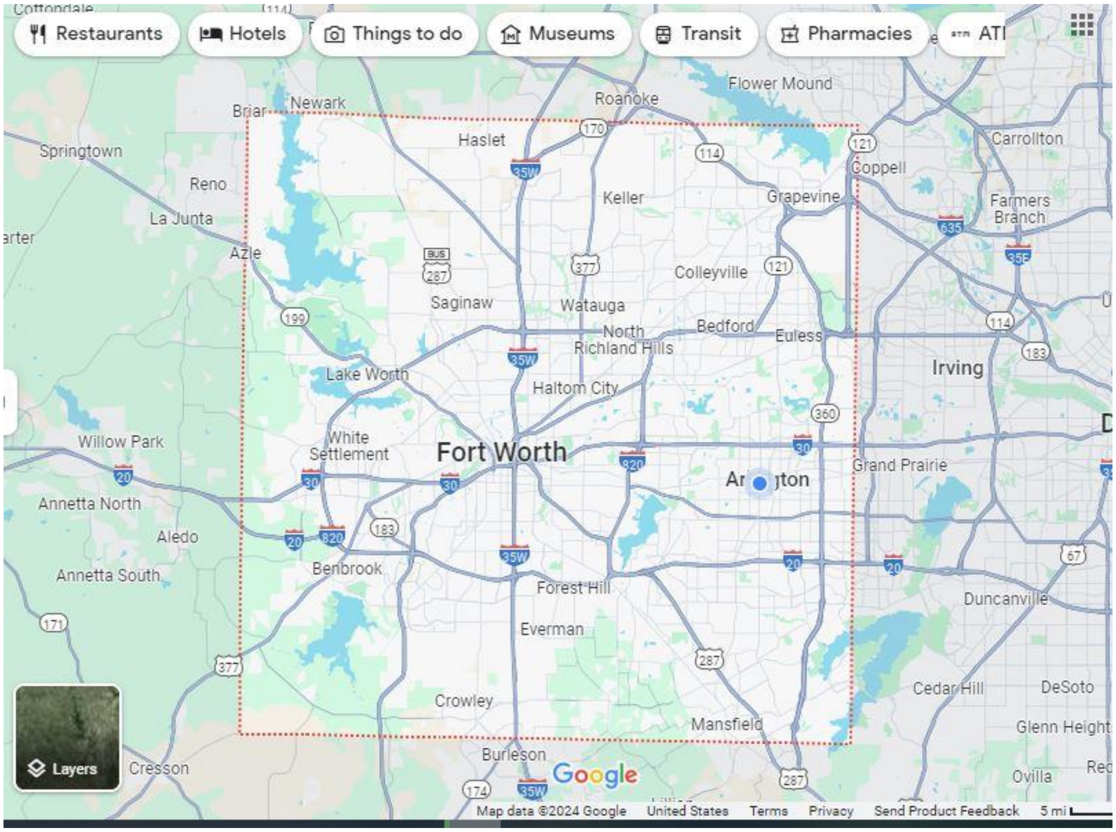


Figure 3-7: Map of Tarrant county in Texas, United States.

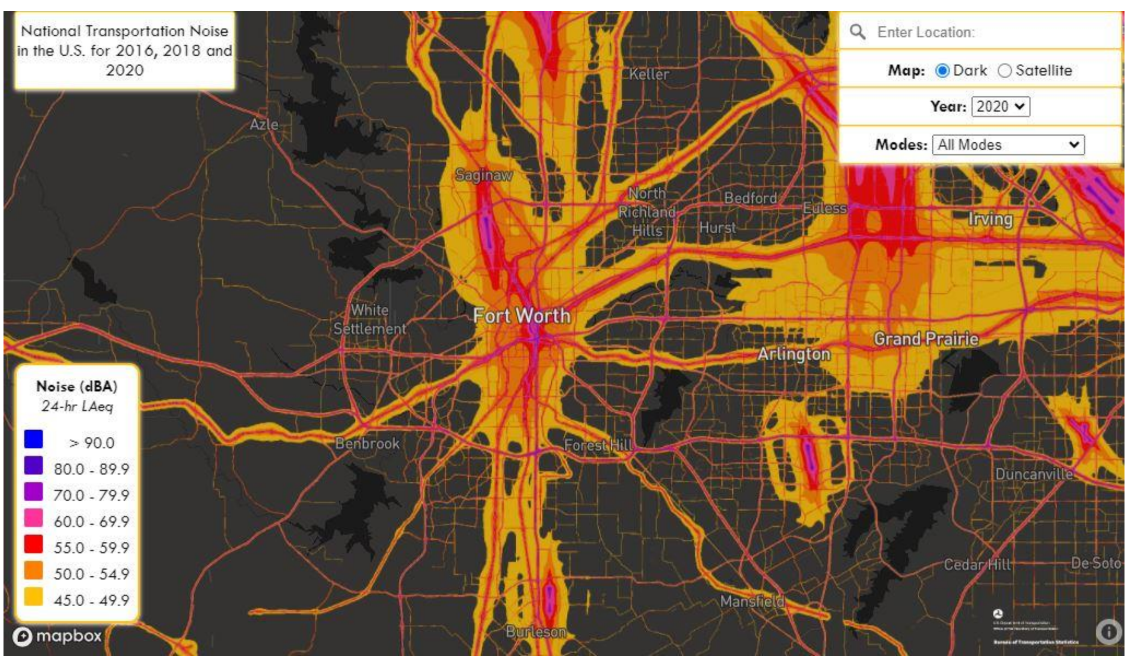


Figure 3-8: Noise map of Tarrant County in Texas, United states

Calculation for noise monetization of Tarrant County is presented as following:

Total number of people in Tarrant county N= 2,110,640

Highly annoyed percent of population 3.9%

Total number of people affected with highly annoyed is 3.9% of N = 82314

Daly factor 2%

Total DALYs per year in the whole county is 2% of number of affected

people 82314= 1646

DALYs per 100000 people/year= (1646/2110640)* 100000 = 78

Similarly, calculating for the other categories we find the results for noise health damage in Table 3-19.

Table 3-19: DALYs Calculation for Noise Health Damage

Factors	Highly annoyed (HA)	Highly sleep disturbed (HSD)	Ischemic heart disease (IHD)	Stroke
Percent of Population	3.9 %	0.9 %	1.5%	3.8%
Number of affected people	82314	18996	31660	80204
DALY factor	2%	7%	1.8%	1.14%
Total DALYs per year	1646	1330	570	914
DALYs per 100,000 people/yr	78	63	27	43

Health economists compare treatment costs and achieved health improvement in order to judge the efficiency of treatment methods or to make recommendations about cost-efficient treatment methods. The health improvements are measured in quality adjusted life years (QALY) which is a very similar metric to DALYs, whereby one more QALY equals roughly an avoided loss of one DALY. In the U.S. thresholds of $50,000/QALY or $100,000/QALY are often used. But the most cost effective point suggested is $55000/QALY.

Finally, the cost of the total DALYs for noise health damage showing in Table 3-20 for different categories of disease induced by noise to affected individuals.

Table 3-20: Cost of Total DALYs for Noise Health Damage

Factors	Highly annoyed (HA)	Highly sleep disturbed (HSD)	Ischemic heart disease (IHD)	Stroke	Total
Total DALYs per year	1646	1330	570	914	4460
Cost/QALY	$55,000	$55,000	$55,000	$55,000	
Total Cost of DALYs	$90,530,000	$73,150,000	$31,350,000	$50,270,000	245300000

3.3.1.3 Property Value Reduction Benefits

When vehicles take detour paths, they add to the road noise based on the added traffic volume. As a result, added traffic noise will lower the pertaining hedonic price of the property value more.

The traffic noise estimation is derived from FHWA's TNM 3.1, and the external cost estimation methodology is similar to that used in the 1997 Federal Highway Cost Allocation Study (HCAS), with updated data inputs and parameter values. The approach [35] relies on changes in housing values to monetize noise impacts. The estimation of noise damage costs consists of three major steps:

- estimation of traffic noise levels above a threshold of 55 dBA,
- estimation of number of housing units affected, and
- estimation of changes in property values.

These steps are summarized in EQ. 6:

Noise Damage = (Noise_Level_dBA−Noise_Threshold_dBA) × Nb_Housing_Units × Change_Property_Values_per_dBA …. (6)

Where,

Noise Damage = noise pollution cost because of road traffic,

Noise Level dBA = noise level in dBA,

Noise Threshold dBA = noise threshold level in dBA,

Nb Housing Units = number of housing units affected, and

Change Property Values per dBA = change in property values per dBA, in U.S. dollars.

Hence, Noise Damage due to Hedonic price is stated below

So change in noise due to increased traffic: 3dBA

Number of Housing units 1000

Change in Property value per unit per decibel $21 annually as Lee estimated in 1992 if inflated today (aier.org) is $43.80

Noise Damage= Change in Level_dBA* Nb_Housing_Units* Property_Values_per_dBA

= 3*1000* 43.80

=131400

Average noise threshold for household is 55db and if it increased to 80db difference is 25db

Then,

Noise Damage= (25+3)*1000*43.80=$1182600/year

However other research criticized this model. Bein interprets Sælensminde's research to imply that hedonic noise surveys identify only about 1/6th of total motor vehicle noise costs

Study finds that traffic volume increases of a few hundred motor vehicles per day reduced adjacent residential property values by 5-25%. Assuming 150 residences per mile of urban residential street, with average values of $100,000 per residence, this represents an annualized cost of approximately $1 million (5% discount rate over 25 years). Assuming 500 additional vehicles per day cause average property values to decline by 10%, and that noise represents one-third of this cost (reduced safety and privacy are other possible costs), such traffic noise costs average 18¢ per vehicle mile.

- Property cost depreciation based on distance covered for 2 mile
- Traffic volume ADT= 10000 (assumed)
- Cost = 10000*2*.18= $3600/Day
- And 365*3600=$1314000/year.

The other method according to investment calculator [36] shows the newly adjusted price assuming the housing price and noise level jump as following

- Current Home Value = 100000
- Ldn, Median Home is about 55 Ldn.
- The Ldn is the average equivalent sound level over a 24 hour period
- New Ldn, Busy Streets raise this to about 75 Ldn
- New Price 92296.83
- Which shows 7.703% devaluation
- New price for added 3Ldn sound level which is doubling the effect is 91193.69
- This price shows 8.806% devaluation in property.

3.3.1.4 Noise Abatement Cost Benefits:

Increasing traffic count will increase the existing usual noise on the road. When this increased noise will cross certain threshold of guideline it will initiate noise abatement projects both on roadside and on other public and private infrastructures. The most popular method of noise abatement is to install noise barriers. A noise barrier is a physical barrier that separates the roadway noise source from the noise-sensitive receptor(s). It is important to note that noise barriers do not totally prevent all noise; rather, they lessen overall noise levels.

TxDOT has certain guideline and criterias to initiate these noise abatement projects. If these noise abatement countermeasures could be avoided which is resulting from the detour taking traffic it would be a benefit considered for the specific bridge that is causing this hazard.

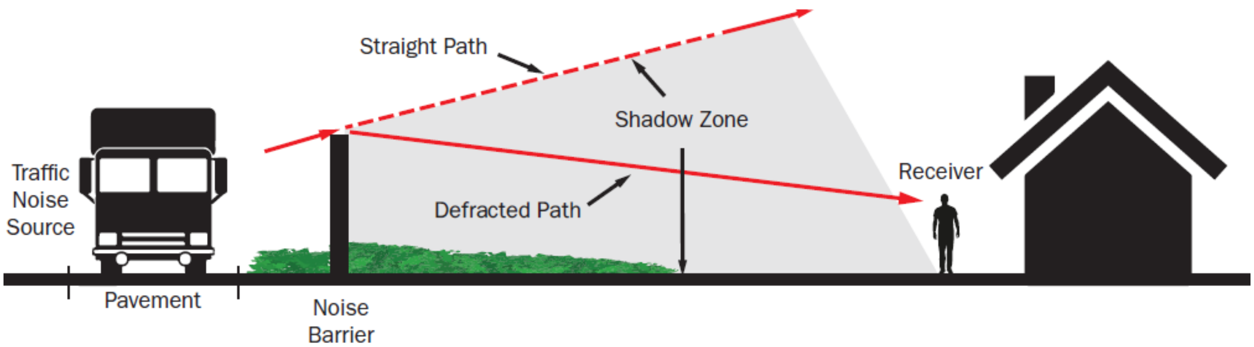


Figure 3-9: Noise barrier placement (courtesy: TxDOT)

3.3.1.5 Considerations for Implementing Noise Barrier:

Based on the feasibility and cost effectiveness, noise abatement barrier projects have been launched. Typically, the maximum constructible barrier height in Texas is 20 feet, though individual wall portions may be taller if necessary. In certain situations, walls have been built up to 24 feet tall. For aesthetic and public perceptions, it is desirable to optimize barriers to a consistent height within a single neighborhood or for adjacent neighborhoods; however, effectiveness must not be sacrificed to achieve this.

3.3.1.6 TxDOT noise abatement evaluation criteria:

For a feasible case, it provides at least a 5 dBA reduction (“benefit”) for a majority of impacted first-row receptors and benefits a minimum of two impacted receptors. In a reasonable case, the barrier should provide a substantial noise reduction consisting of a predicted reduction of at least 7 dBA for at least one receptor. Does not exceed 1,500 square feet per benefited receptor (Standard Barrier Cost analysis).

Cost Assessment for noise barrier: FHWA has set the max cost per benefited receiver which are as following:

- Current FHWA-approved cost $35 per square foot
- Current FHWA-approved square footage per benefited receiver 1500
- Current FHWA-approved cost per benefited receiver $52,500

Assuming a project is as following

- Total Length of Proposed Barrier 566 ft
- Average Height of Proposed Barrier 16 ft
- Benefited Receivers 8
- Standard Barrier Cost Total $316,960
- Square Footage per Benefiter 1132
- Cost Per Benefited Receiver $39,620
- As final cost is below $52500 so Project is feasible.

Assessment from Survey report:

The preliminary survey of Dallas County has shown that at 50 meters outside the highway right-of way, noise levels usually exceed 66 dBA but seldom exceed 75 dBA. Cost effectiveness comparison that will govern the implementation priority between two noise abatement project A and Project B is shown on Table 3-21.

Table 3-21 : Cost Effectiveness Comparison Between Project A And Project

Project A	Project B
Present noise level 70 dBA	present noise level 68 dBA
Noise reduction achieved 6 dBA	Noise reduction achieved 5 dBA
Cost/benefited receiver $23,000	Cost/benefited receiver $18,000
Cost-effectiveness factor 2.17	Cost-effectiveness factor 1.85

As Project A has higer cost-effectiveness it will govern the priority for the implementation.

3.3.2 Emergency Response Benefits:

Structural fire damage Benefit: is an obvious factor that can be related to emergency vehicle delay. If a bridge is closed emergency vehicle service will not be closed rather there will be temporary service loss. The FEMA calculation [26] approach assume the total service outage of in case of monetizing the fire loss however, USDOT suggested the applicant to adjust with the total outage as it is less likely to happen [1].

Table 3-22 is the calculation approach for monetizing emergency vehicle's temporary service loss for structural fire damage with an example case in Dallas County, Texas:

Table 3-22 : Calculation Approach for Structural Fire Damage

Assumptions	Amount
Average loss per structure fire (2023 dollars, adjusted for inflation per year) [39]	$ 26378
90th percentile fire response time (US Fire Administration) [40]	8 minute
Average loss per response minute	$ 2398
Total fire incident by DH717 Irving FD (fire department)	537
Building fire incident	154
By 60% incident reduction factor	61.6
Delay per 5 mile Detour	5 minute

In Table 3-22 we get the average loss per response minute by dividing loss per structure fire with response time. The total fire incident includes building fire, vehicle fire, and other fire. However, only building fire incident is considered here. As it it less likely that all the incident will be impeded by a closed bridge 60% reduction factor is assumed. Delay occurs when nearest fire station can not response due to road blockage for bridge closure.

The total cost for for extra delay = Lost time* Average loss per response minute* Reduced Incident

= 5* 2398* 61.6

= $ 738584

We can apply this method of monetizing structural fire damage on basis of distance between nearest fire station and response time delay due to one station not being able to respond in time due to detour miles. For that we will require the local data of structural fire damage. Traffic congestion do not apply in this case as recommended by the USDOT guideline 2023 [1].

3.3.3 Pavement Damage Benefits Due to Detour:

This study adopted the Gas tax method, which offers an uncomplicated and consistent solution to compensate for the usage of detours. This process allows more realistic traffic-based compensation determination. The gas tax paid by detour-taking vehicles is considered a pavement damage benefit. This study conducted the implementation of this method in the state of Texas, USA.

The method involves determining the gas tax paid per mile by the detoured traffic, which is then added to the total vehicle miles traveled over the length and duration of the detour.

The First step is to define all the data element of the determination process.

a) Detour VMT : The required elements for determining vehicle miles travel (VMT) for detour are Length of detour, duration of detour and traffic volume along the. All three of these elements are already present for calculating the primary

VMT = Detour Length (mi) * Detour Duration (days) * Traffic Volume

b) Fleet Fuel Economy: Fuel consumption vary according to the type of the vehicle. A passenger car and commercial truck will have different type of consumption. Though separate passenger vehicle traffic volume and and truck traffic volume is present it is suggested to use a average fuel consumption for the whole fleet of traffic. Federal Highway Administration FHWA, Highway Statistics 2021 has an evaluation for Average fuel economy for the major vehicle category shown in Figure 3-10 [30].

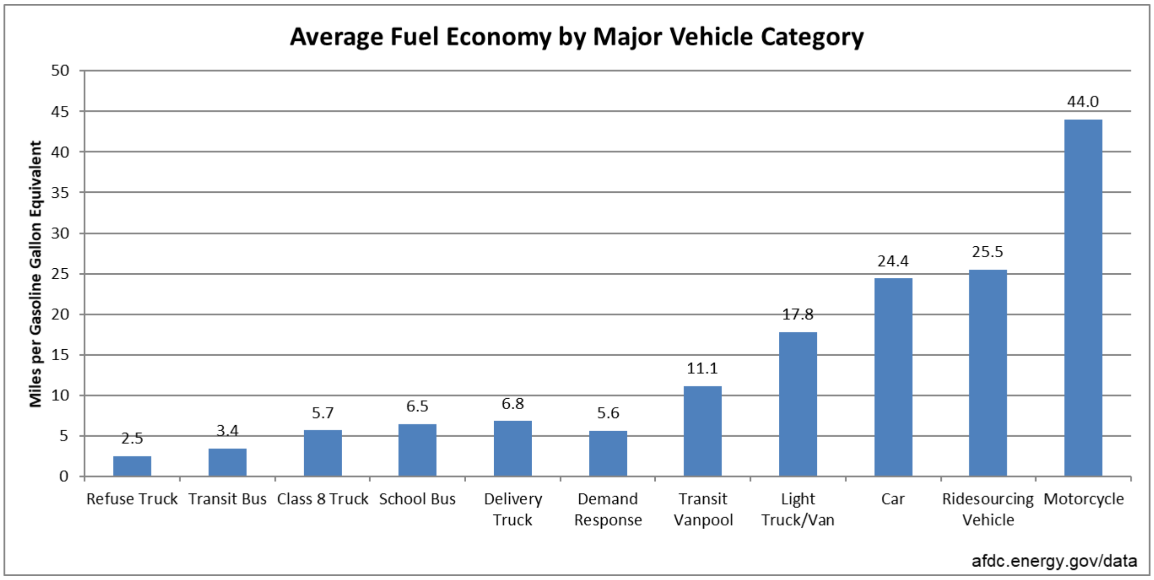


Figure 3-10: Average Fuel Economy by Major Vehicle Category.

It is required to apply fleet fuel economy which is total average of this major vehicle category also vary state to state. For texas The average fleet fuel economy in 19.8 MPG (Miles per Gallon) obtained from U.S Department of Energy, Vehicle Technologies Office [31].

c) Gas Tax Rate: Although gas tax rate are readily available There are two type of approach for this rate 1) a single, average gas tax for all fuel types can be defined, or 2) the standard tax rate for a single fuel type can be used. This strudy utilized the 1st approach of single average tax for all fuel Where,

i. Texas state gas tax: 20 cents per gallon

ii. Federal gas tax: gasoline is 18.4 cent/gallon and diesel 24.40 with cent/gallon; for 74% gasoline and 24% diesel consumption rate in Texas The Weighed average is 19.47 cent/gallon

d) Gas Tax portion Usage on highway: Texas state use 15 cent of state gas tax for the road and 5 cent goes to school [33] . 5 cent/gallon of federal gas tax is assumed on the road improvements. Finally a combined rate of 20 cent/gallon is implemented calculation.

3.3.4 Pavement Damage Cost For Detour Equivalent Gas Tax Income

Pavement damage costs equal to gas tax income generated by detour-taking vehicles are calculated by detour parameters such as length, traffic volume, and duration. As the combined gas tax and fleet fuel economy of Texas are constant, only the detour parameters for different bridge closures apply as the variables. Here, EQ. 7 is for Gas tax income generated by the detour-taking vehicles which is equivalent to the pavement damage cost

$$I = (ADT * D * T * CT)/F \text{ ......7}$$

Where:

I= Gas tax income in dollars generated by detour

ADT= Average Daily Traffic (Traffic volume)

D = Detour Length (Miles)

T= Detour Duration (Days)

CT= .20; Combined Tax (dollars)

F= 19.8 mpg, Fleet wide fuel consumption

Calculation of pavement damage for sample of poor bridges in Dallas county conducted in excel is presented in Table 3-23.

Table 3-23: Pavement Damage Benefit By Equivalent Gas Tax Income For Sample Of Poor Bridges

Bridge ID	County name	ADT	Detour Length (mi)	Detour Pavement Damage/ year ($)
180570009201048	Dallas	8615	6	190574
180570000911383	Dallas	141993	10	5235095
180570009502332	Dallas	6730	4	99251
180570043001012	Dallas	7032	1	25926

4 Chapter 4

RESULTS AND DISCUSSIONS

4.1 Primary Benefits:

The primary benefits present VTTS, VOC, emission cost, and safety were provided in Tables 4-1, 4-2, 4-3, and 4-4, respectively. Tables 4-1 and 4-2 both showed benefits for the Poor bridges, whereas Table 4-2 was calculated for lower average speed as an alternative for municipal detours. Bridges in Table 4-2 resulted in 9.7% increased total benefits due to more travel delay compared to the same bridges with higher detour speeds in Table 4-1. Benefits depend on higher VMT, which is the result of multiplying ADT by the detour length. A zero detour distance resulted in zero benefits for any bridge, which implies that all traffic had readily available alternate paths less than a mile away. Although most detour lengths range from 1 to 6 miles, there are outliers primarily because they are located on large rivers. Some of these outliers had higher VMT and consequently accrued massive yearly benefits, indicating their significance for staying functional. In Table 4-1, for Poor bridges, the minimum useful detour length is 1 mile, and the maximum is 24 miles. However, the maximum benefit of $549,398,129 resulted in a bridge with a 10-mile detour having more traffic volume and consequently accruing more VMT. Similarly, for fair bridges in Table 4-3, one bridge exhibits a 37-mile detour path, which is located on a river, accruing a total of $481,581,837 yearly benefit for ADT of 34893 vehicles. In Table 4-1, the maximum total yearly benefits of $979.7 million were achieved for Poor bridges when the detour speed was unadjusted. Conversely, Table 4-4 shows the minimum total yearly benefits of $413.7 million for good bridges, with no significant outliers in detour miles.

Safety benefits were dependent on both VMT and accident rate in the specific county. Due to the higher compensation rate for safety benefits, utilizing robust accident data along the detour path for specific bridges was crucial. Although the study imposed an exposure factor to mitigate the risk of overstating this benefit, the accuracy of this factor was uncertain. The accident rate might have increased on specific roads due to additional detour vehicles. Therefore, even obtaining historical data might not have been entirely accurate.However, the limitation of this benefit was traditionally conducted in this way.was based on the overall accident rate in a county. Though safety benefits were already presented along with the other primary benefits, detailed calculations of the safety benefits were conducted separately and are shown in the appendix.

Though BCA is generally done for any specific bridge construction maintenance or enhancement project, this study dealt with a larger sample for observation of the result. This study conducted overall analysis to observe the holistic nature of such bulk analysis aligned in a single streak. Such observation would have helped the counsel to determine if the Poor bridges that had a rating of 4 or lower were to be replaced or not according to the allocated budget they had or other decisions of maintenance operation in case of a fair or good bridges. This phenomenon made this study unique in lining up many samples under similar analysis. However, case-by-case analysis would have given more accurate results as there would be more localized data in case of accident rate and traffic congestion or any other relevant benefit that could be added for that particular project.

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Table 4-1 Benefits for Sample of Poor Bridges

Bridge ID	ADT	Detour Length (mi)	(VTTS)/Day ($)	VOC/ Day ($	Emission Costs/Day ($)	Safety benefit/year($)	Total benefit/ year ($)
180570237402340	16420	2	13,717	15,121	1,102	2,052,312	12,711,045
180570019603101	194462	1	81,224	89,458	6,528	12,152,764	75,239,507
180570237402444	76110	2	63,580	70,036	5,110	9,512,881	58,899,259
180570009201048	8615	6	21,590	23,791	1,735	3,230,330	20,003,722
180570000911357	680	1	284	317	23	42,496	264,700
180570009202315	26991	1	11,274	12,429	906	1,686,783	10,447,459
180570000911383	141993	10	593,082	653,239	47,669	88,737,515	549,398,129
180570009202063	68837	0	-	-	-	-	-
180570009214204	14240	1	5,948	6,559	478	889,919	5,512,480
180570000911347	192770	0	-	-	-	-	-
180570237402341	7000	1	2,924	3,220	235	437,460	2,708,305
180570009502332	6730	4	11,245	12,405	904	1,682,346	10,423,405
180570043001012	7032	1	2,937	3,238	236	439,460	2,721,892
180570058102010	58703	1	24,519	27,007	1,971	3,668,602	22,713,642
180570009207165	22259	6	55,785	61,488	4,484	8,346,362	51,691,432
180570000911353	81504	1	34,043	37,496	2,736	5,093,534	31,535,568
180610035302006	23777	6	59,588	65,648	4,789	4,487,360	50,776,276
180610019502053	33174	2	27,713	30,549	2,227	2,086,942	23,621,110
180610019503134	52260	0	-	-	-	-	-
181300009504025	8713	1	3,639	4,013	293	304,083	3,132,445
181300AA0347001	100	3	125	138	10	10,470	107,792
21820000710057	3180	24	31,881	35,239	2,562	-	24,806,918
21840031401006	1160	0	-	-	-	-	-
181990000912132	26134	1	10,916	12,037	877	798,636	9,282,300
22200017206067	34052	0	-	-	-	-	-
22200001416192	69770	0	-	-	-	-	-
022200ZS4528003	5269	7	15,406	16,974	1,238	1,792,310	13,760,207
22200000813122	42650	0	-	-	-	-	-
Total/Day	1224585	82	1,071,420	1,180,400	86,115		
Total Annually	446973525	29930	391,068,291	430,846,058	31,432,096		979,757,593

Table 4-2: Benefits for Sample of Poor Bridges with adjusted detour speed

Bridge ID	ADT	Detour Length (mi)	(VTTS)/Day ($)	VOC/ Day ($)	Emission Costs/Day ($)	Safety benefit/year($)	Total benefit/ year ($)
180570237402340	16420	2	17146	15121	1102	2,052,312	13,931,864
180570019603101	194462	1	101529	89458	6528	12,152,764	82,468,401
180570237402444	76110	2	79475	70036	5110	9,512,881	64,557,880
180570009201048	8615	6	26988	23791	1735	3,230,330	21,925,264
180570000911357	680	1	355	317	23	42,496	289,988
180570009202315	26991	1	14092	12429	906	1,686,783	11,450,845
180570000911383	141993	10	741352	653239	47669	88,737,515	602,182,418
180570009202063	68837	0	0	0	0	-	-
180570009214204	14240	1	7435	6559	478	889,919	6,041,854
180570000911347	192770	0	0	0	0	-	-
180570237402341	7000	1	3655	3220	235	437,460	2,968,522
180570009502332	6730	4	14056	12405	904	1,682,346	11,424,173
180570043001012	7032	1	3672	3238	236	439,460	2,983,305
180570058102010	58703	1	30649	27007	1971	3,668,602	24,895,862
180570009207165	22259	6	69731	61488	4484	8,346,362	56,656,257
180570000911353	81504	1	42554	37496	2736	5,093,534	34,565,387
180610035302006	23777	6	74485	65648	4789	4,487,360	56,079,611
180610019502053	33174	2	34641	30549	2227	2,086,942	26,087,581
180610019503134	52260	0	0	0	0	-	-
181300009504025	8713	1	4549	4013	293	304,083	3,456,351
181300AA0347001	100	3	157	138	10	10,470	118,944
21820000710057	3180	24	39851	35239	2562	-	27,644,325
21840031401006	1160	0	0	0	0	-	-
181990000912132	26134	1	13645	12037	877	798,636	10,253,834
22200017206067	34052	0	0	0	0	-	-
22200001416192	69770	0	0	0	0	-	-
022200ZS4528003	5269	7	19257	16974	1238	1,792,310	15,131,304
22200000813122	42650	0	0	0	0	-	-
Total/Day	1224585	82	1339275	1180400	86115		
Total Annually	446973525	29930	488835363	430846058	31432096		1,075,113,971

Table 4-3: Benefits for Sample of Fair Bridges

Bridge ID	ADT	Detour Length (mi)	(VTTS)/Day ($)	VOC/ Day ($)	Emission Costs/Day ($)	Safety benefit/year($)	Total benefit/ year ($)
180430081604001	1,477	11	6,787	7,516	545	572,575	5,858,677
180430004705083	18,700	1	7,811	8,605	628	659,024	6,726,630
180430296405322	28,475	2	23,787	26,207	1,912	2,007,027	20,485,593
180430004714660	22,343	2	18,665	20,569	1,500	1,574,820	16,076,070
180430296405557	75,154	1	31,391	34,573	2,523	2,648,571	27,029,820
180570019702167	29,620	1	12,372	13,630	994	1,851,081	11,461,809
180570000911196	121,720	1	50,840	55,996	4,086	7,606,805	47,095,169
180570000902002	16,405	1	6,852	7,550	551	1,025,219	6,348,513
180570106804109	117,986	2	98,562	108,559	7,922	14,746,902	91,302,169
180570237401476	23,200	0	-	-	-	-	-
180570G01155010	18,238	1	7,618	8,391	612	1,139,771	7,056,899
180570004707261	31,040	1	12,965	14,282	1,042	1,939,823	12,010,806
180570237407347	47,751	1	19,945	21,970	1,603	2,984,165	18,476,707
180610H01370004	2,750	1	1,149	1,271	92	86,500	980,627
020730031404118	13,386	1	5,591	6,172	449		4,347,929
020730007905039	18,925	1	7,905	8,717	635		6,143,612
021270001403194	12,590	0	-	-	-	-	-
181300009514356	14,353	0	-	-	-	-	-
181750009301081	20,267	1	8,466	9,338	680		6,580,371
021820031402095	9,760	1	4,077	4,506	328		3,172,234
021840031407044	36,274	1	15,151	16,696	1,218	1,162,940	12,934,278
181990000912476	33,095	0	-	-	-	-	-
22130025903046	8,519	1	3,558	3,924	286		2,765,427
022200001415331	22,913	1	9,571	10,549	769	1,113,445	8,549,986
022200017105033	34,893	37	539,247	593,940	43,342	62,737,467	481,581,837
022200001402352	102,340	0	-	-	-	-	-
022200008112077	45,300	1	18,921	20,838	1,521	2,201,330	16,896,944
022200009402068	8,219	25	85,828	94,684	6,898	9,984,951	76,702,642
22200000813132	7,500	3	9,398	10,350	755	1,093,376	8,392,522
022200000813423	2,945	1	1,230	1,357	99		956,382
022490013411075	1,800	2	1,504	1,656	121	163,963	1,331,826
Total/Day	947,938	102	1,009,190	1,111,848	81,114		
Total Annually	345997370	37230	368,354,280	405,824,348	29,606,453		901,265,477

Table 4-4: Benefits for Sample of Good Bridges

Bridge ID	ADT	Detour Length (mi)	(VTTS)/Day ($)	VOC/ Day ($)	Emission Costs/Day ($)	Safety benefit/year($)	Total benefit/ year ($)
180430004706428	92786	0	-	-	-	-	-
180430009105055	33476	4	55,929	61,598	4,495	4,318,780	47,758,909
180430296405556	87129	1	36,392	40,082	2,925	2,810,155	31,076,171
180570237401482	23200	0	-	-	-	-	-
180570237401561	5000	0	-	-	-	-	-
180570058102013	32122	6	80,501	88,663	6,470	12,044,649	74,570,570
180570009202297	26991	1	11,274	12,429	906	1,686,783	10,447,459
180570296401499	7240	1	3,024	3,330	243	452,459	2,801,162
180570004801160	7685	1	3,210	3,538	258	480,269	2,974,337
180570237403169	52500	0	-	-	-	-	-
180570004707418	15000	0	-	-	-	-	-
180610019503149	91450	1	38,197	42,073	3,070	2,876,513	32,545,495
180610019602026	74860	1	31,268	34,439	2,513	2,354,683	26,641,159
180710004808179	33458	2	27,951	30,822	2,246	2,455,875	24,178,725
180710004808174	33458	1	13,975	15,411	1,123	1,227,937	12,089,363
021120B00370001	1150	1	480	529	39		373,067
21120008004058	12688	0	-	-	-		-
21270050405518	7684	1	3,209	3,535	258		2,492,940
181300049501197	24868	1	10,387	11,448	835	867,892	8,938,246
181300019705249	7824	1	3,268	3,603	263	273,057	2,812,821
181750016203123	2842	1	1,187	1,318	95		925,780
21820031403145	9710	0	-	-	-		-
21840008006063	11775	1	4,918	5,419	395	377,505	4,198,396
181990101403390	2291	5	4,785	5,278	385		3,719,090
22130025903085	8519	1	3,558	3,926	286		2,766,230
22130025902021	5687	6	14,254	15,749	1,146		11,088,684
22200226602012	42990	1	17,956	19,776	1,443	2,089,077	16,035,512
022200ZN7350002	20140	2	16,825	18,551	1,352	1,957,386	15,032,515
022200ZB2880001	26369	1	11,014	12,130	885	1,281,388	9,835,662
22200001416458	75760	1	31,644	34,857	2,543	3,681,518	28,261,366
22200000805048	14823	1	6,191	6,821	498	720,316	5,529,998
022200C03572001	9981	2	8,338	9,188	670	970,043	7,447,854
22200001415383	12640	1	5,280	5,834	424	614,234	4,721,764
22490013407097	8281	8	27,672	30,518	2,224	3,017,277	24,524,629
22490001308331	25465	0	-	-	-	-	-
Total/Day	947842	54	472,689	520,864	37,992		
Total/Annualy	345962330	19710	172,531,481	190,115,400	13,867,135		413,787,904

Figure 4-1, 4-2, 4-3 and 4-4 shows the bar chart comparison for VTTS, VOC and emission benefits per day basis for the Poor, Fair and Good bridges. In the Figure 4-1, we could see graphically the variations in the trend of various benefit results. The VOC was the maximum, and the emission cost was placed as the minimum. However, travel time saving could be more significant in different cases if the detour path was along some municipal road where the speed limit fell down, and the assumed average speed was 60 mph rather than the 75mph on the highway. The travel time would have increased which influences all other benefits as well. However, VTTS would have become the maximum benefit among all three categories, as shown in Figure 4-2 that represented the same set of samples with adjusted speed for the detour distance.

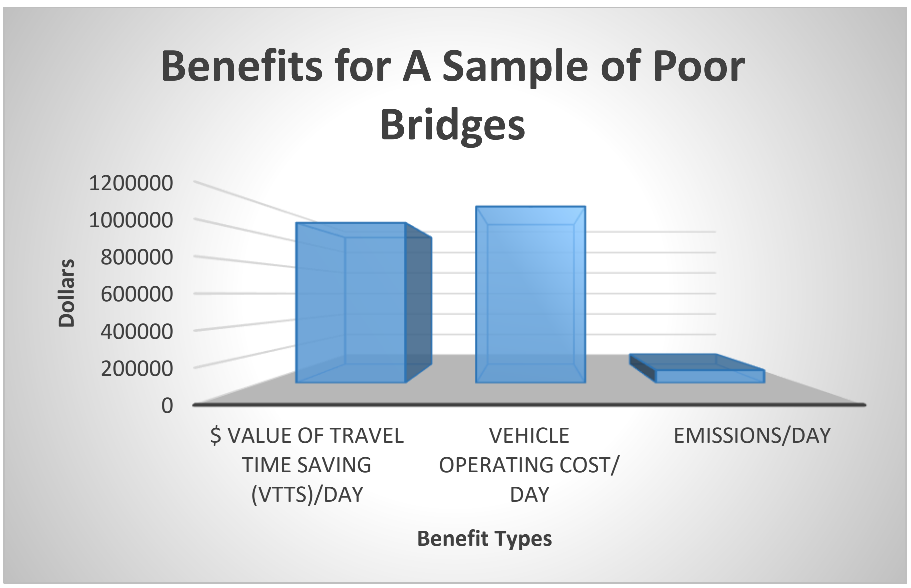

Figure 4-1: graphical representations for benefits of Poor Bridges

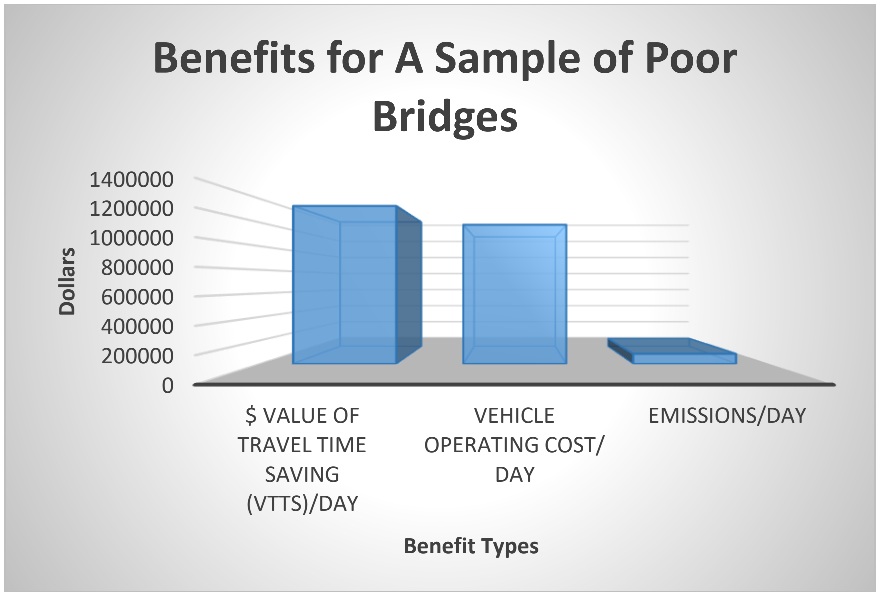

Figure 4-2 graphical representations for benefits of Poor Bridges with municipal detour speed

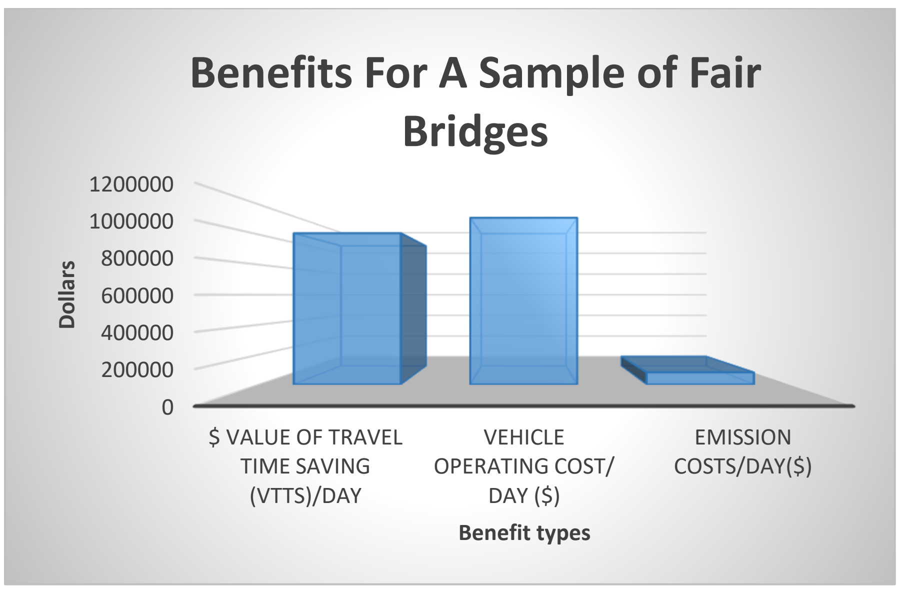

Figure 4-3: graphical representations for benefits of Fair Bridges

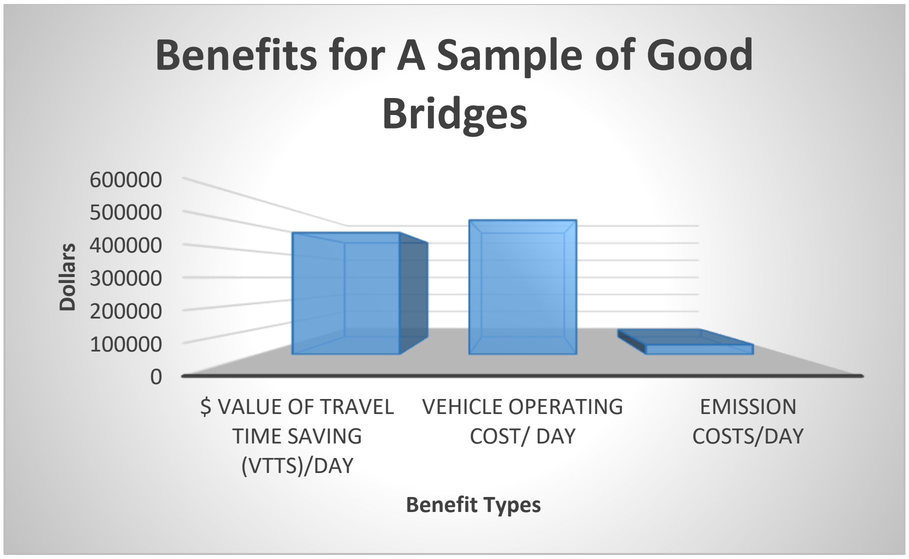

Figure 4-4: graphical representations for benefits of Good Bridges

Figures 4-3 and 4-4 showed the results for Fair and Good bridges. The fair bridge exhibited VTTS and VOC benefits of nearly 1 million and 1.1 million dollars per day, respectively. On the other hand, the Good bridge showed VTTS and VOC benefits of less than half a million dollars per day. Although these benefits were not related to the category of the bridges but were dependent on traffic volume and detour distance, a pattern was observed: the Poor bridges had the highest benefits, while the Good bridges had the least.

The benefit-cost ratio (BCR) represented the viability of the project. This study precalculated the defect-based maintenance cost for the bridges according to the TxDOT low bid average cost for particular defect interventions such as cracking, delamination, wearing surface, and so on. Table 4-5 showed the BCR for a sample of fair bridges with defect-based maintenance costs. While the total construction cost is compared with the benefit over a 20-year analysis period using a 7% discount rate, which accumulates a larger benefit and usually results in the project being beneficial, here only a one-year net present value was considered to align with the ballpark closure period for maintenance project. In Table 4-5, the BCR for three samples remained consistent in the 40 to 50 range, and two samples were more than 300. This projected the attractiveness of the maintenance project and illustrated its significance.

Table 4-5 BCR for Sample of Fair Bridges with Maintenance Cost

Bridge ID	Primary Benefit	Maintenance Cost	BCR
180430081604001	5858677	16469	355.7
180430004705083	6726630	114122	58.9
180430004714660	16076070	1330026	12.1
180570019702167	11461809	269813	42.5
180570000902002	6348513	18559	342.1
180570G01155010	7056899	156544	45.1

4.2 Secondary benefits:

This section presents all the results for different categories of the secondary benefits, such as noise health damage, noise property devaluation, emergency response benefits, and pavement damage due to detours. We can speculate on the results of the secondary benefits added to this study's BCA analysis. These were the hardest to convert them into the currency. The task had become even harder due to insufficient data and direct guidelines to monetize these benefits. However, from the existing research and data, this assessment provided estimates and results of secondary benefits for noise damage, emergency response benefits, and pavement damage due to detour-taking vehicles. Adding secondary benefits in individual cases of BCA analysis will make the analysis more robust and add value to prioritizing the project and grant allocation. The applicant will be able to discern if there are any significant changes due to any of the secondary benefits.

4.2.1 Noise Health Damage:

Table 4-6 showed the result of health damages due to road traffic noise among 2,110,640 people in Tarrant county in Texas, United States.

Table 4-6: Road Noise Health Damage Tarrant County, Texas

Factors	Highly annoyed (HA)	Highly sleep disturbed (HSD)	Ischemic heart disease (IHD)	Stroke	Total
Number of affected people	82314	18996	31660	80204	213174
Total DALYs per year	1646	1330	570	914	4460
Cost/QALY	$55,000	$55,000	$55,000	$55,000	
Total Cost of DALYs	$90,530,000	$73,150,000	$31,350,000	$50,270,000	245300000

The Table 4-6 showed different categories of diseases caused by road noise, and the number of people affected by these diseases is a certain percentage of the total population of Tarrant County. The study obtained the total cost by multiplying the total daily per year with the cost per QALY, $55000.

The Detour taking vehicles would be adding the road traffic noise resulting in damage of public health. The above analysis was similar to a study conducted in Europe [24], and this study took reference from research conducted in England. The study implemented US-based data of the number of populations and the number of people exhibiting certain types of diseases induced by noise. The results complied with the cost of the study done in other research. However, there was a lack of US-based survey research that could show a solid relation between the number of DALY lost for a specific type of disease. For example, the lifespan of people in Europe and a specific area of the USA should not be the same, which affects the rate of DALYs lost from affected people. Despite this limitation of not having more local data, this assessment provided valuable knowledge and an approximate idea of how much road noise could affect the BCA analysis for health damage.

4.2.2 Property value reduction due to noise

Table 4-6 showed the results for property devaluation due to noise. The results were based on estimating traffic noise levels above 55 Ldn, the number of housing units impacted by the noise, and the reduction in property values in currency and percentage. As observed in Table 4-7, an extra 3dB increase in noise level, related to increased traffic from detours, further reduced property values. Additionally, there was a third-degree impact of road traffic noise, adding a 1.1% devaluation per $100,000 of property value. When this value was calculated for a whole neighborhood affected by road noise, the consequence was significant and could not be ignored.

Table 4-7 Property Devaluation Due to Noise

Noise Level	Home value
Home value with 55Ldn	$100000
Home value decrease for 75 Ldn	$92296
Devaluation percentage	7.703%
Home value decrease for 78 Ldn with 3 db increase	$91193
Percentage devaluation due to added noise	8.806%

4.2.3 Emergecy Response Benefit

Table 4-8 presenting the structural fire damage benefit in Dallas county. In case of a briddge closure a fire service might face that bridge as a deterant to reach the destination of a fire incident. So, there will be delay to to respond in such emergency situation. This study estimated the delay time based on the nationwide average of fire response time and monetized the delay according to the average loss per structure fire. Not all the fire incident turns into structural fire damage there are false call as well and other type of damage. This study only considered the building fire incident which is 154 in dallas county in the latest data of year 2023. It is also less likely that all the incident will be obstructed by a single bridge of the county so to avoid the overstatement 60% reduction factor is used to consider the number of the incident. Emergency response delay for 5 minutes in Dallas County costs $ 738584 for reduced 61.4 realtime structure fire cases in Dallas county.

Besides adding value to BCA, the emergency response benefit for structural fire damage represents a critical aspect of disaster management and recovery efforts, as well as societal benefits. This benefit plays a pivotal role in providing immediate assistance to individuals, families, and communities affected by fire incidents. Through analyzing the effectiveness, challenges, and potential improvements of this benefit, a comprehensive understanding of its significance in mitigating the impact of structural fires can be gained.

Table 4-8: Structural Fire Damage Benefit in Dallas County

Assumptions	Amount
Average loss per structure fire (2023 dollars, adjusted for inflation per	$ 26378
90th percentile fire response time (US Fire Administration)	8 minute
Average loss per response minute	$ 2398
Total fire incident by DH717 Irving FD (fire department)	537
Building fire incident	154
By 60% incident reduction factor	61.6
Delay per 5 mile Detour	5 minute
Total cost for extra Detour delay	$738584

4.2.4 Pavement damage benefit:

Tables 4-9, 4-10, and 4-11 show the detour pavement damage cost per year for Poor, Fair, and Good bridges, respectively. There is no separate cost variation in the results according to the bridge category because its cost depends on the length of the detour and traffic volume, which is independent of the rating of the bridges.

According to the gas tax method, this pavement damage cost is equivalent to the gas tax paid by all these detour-taking vehicles. The logic behind this is a portion of the gas tax is being used by the transportation department to maintain the damage to the road. As TxDOT did not have any guidelines to measure the pavement damage benefit due to detours, the study incorporated the gas tax method, which a few departments of transportation also adopted. This study tried to utilize all the available data, such as traffic volume, average gas consumption by vehicles, Texas gas tax rate, and state and federal reimbursement of the tax in road damage maintenance.

The gas tax method, as demonstrated by its adoption in Iowa and MnDOT, is not only simple but also highly convenient to implement. While the condition-based approach may offer more accurate and consistent evaluations, its lack of cost-effectiveness due to existing data collection techniques (2 year cycle) and logistical challenges is a clear disadvantage.

Table 4-9: Detour Pavement damage cost per year for Poor bridges

Bridge ID	County name	ADT	Detour Length (mi)	Detour Pavement Damage cost/ year ($)
180570237402340	Dallas	16420	2	121077
180570019603101	Dallas	194462	1	716956
180570237402444	Dallas	76110	2	561215
180570009201048	Dallas	8615	6	190574
180570000911357	Dallas	680	1	2507
180570009202315	Dallas	26991	1	99512
180570000911383	Dallas	141993	10	5235095
180570009202063	Dallas	68837	0	0
180570009214204	Dallas	14240	1	52501
180570000911347	Dallas	192770	0	0
180570237402341	Dallas	7000	1	25808
180570009502332	Dallas	6730	4	99251
180570043001012	Dallas	7032	1	25926
180570058102010	Dallas	58703	1	216430
180570009207165	Dallas	22259	6	492396
180570000911353	Dallas	81504	1	300495
180610035302006	Denton	23777	6	525976
180610019502053	Denton	33174	2	244616
180610019503134	Denton	52260	0	0
181300009504025	Kaufman	8713	1	32124
181300AA0347001	Kaufman	100	3	1106
21820000710057	Palo Pinto	3180	24	281382
21840031401006	Parker	1160	0	0
181990000912132	Rockwall	26134	1	96353
22200017206067	Tarrant	34052	0	0
22200001416192	Tarrant	69770	0	0
022200ZS4528003	Tarrant	5269	7	135983
22200000813122	Tarrant	42650	0	0
Total Damage cost / Year				9457283

Table 4-10: Detour Pavement damage cost per year for fair bridges

Bridge ID	county	ADT	Detour Length (mi)	Detour Pavement Damage cost/ year ($)
180430081604001	Collin	1,477	11	59901
180430004705083	Collin	18,700	1	68944
180430296405322	Collin	28,475	2	209967
180430004714660	Collin	22,343	2	164751
180430296405557	Collin	75,154	1	277083
180570019702167	Dallas	29,620	1	109205
180570000911196	Dallas	121,720	1	448766
180570000902002	Dallas	16,405	1	60483
180570106804109	Dallas	117,986	2	869998
180570237401476	Dallas	23,200	0	0
180570G01155010	Dallas	18,238	1	67241
180570004707261	Dallas	31,040	1	114440
180570237407347	Dallas	47,751	1	176052
180610H01370004	Denton	2,750	1	10139
020730031404118	Erath	13,386	1	49352
020730007905039	Erath	18,925	1	69774
021270001403194	Johnson	12,590	0	0
181300009514356	Kaufman	14,353	0	0
181750009301081		20,267	1	74722
021820031402095		9,760	1	35984
021840031407044	Parker	36,274	1	133737
181990000912476	Rockwall	33,095	0	0
22130025903046		8,519	1	31408
022200001415331	Tarrant	22,913	1	84477
022200017105033	Tarrant	34,893	37	4759899
022200001402352	Tarrant	102,340	0	0
022200008112077	Tarrant	45,300	1	167015
022200009402068	Tarrant	8,219	25	757559
22200000813132	Tarrant	7,500	3	82955
022200000813423	Tarrant	2,945	1	10858
022490013411075	Wise	1,800	2	13273
Total Damage cost / Year				8907984

Table 4-11: Detour Pavement damage cost per year for Good bridges

Bridge ID	County Name	ADT	Detour Length (mi)	Detour Pavement Damage/ year ($)
180430004706428	Collin	92786	0	
180430009105055	Collin	33476	4	493686
180430296405556	Collin	87129	1	321233
180570237401482	Dallas	23200	0	0
180570237401561	Dallas	5000	0	0
180570058102013	Dallas	32122	6	710578
180570009202297	Dallas	26991	1	99512
180570296401499	Dallas	7240	1	26693
180570004801160	Dallas	7685	1	28334
180570237403169	Dallas	52500	0	0
180570004707418	Dallas	15000	0	0
180610019503149	Denton	91450	1	337164
180610019602026	Denton	74860	1	275999
180710004808179	Ellis	33458	2	246711
180710004808174	Ellis	33458	1	123355
021120B00370001		1150	1	4240
21120008004058		12688	0	0
21270050405518		7684	1	28330
181300049501197	Kaufman	24868	1	91685
181300019705249	Kaufman	7824	1	28846
181750016203123		2842	1	10478
21820031403145		9710	0	0
21840008006063	Parker	11775	1	43413
181990101403390	Rockwall	2291	5	42233
22130025903085		8519	1	31408
22130025902021		5687	6	125803
22200226602012	Tarrant	42990	1	158498
022200ZN7350002	Tarrant	20140	2	148507
022200ZB2880001	Tarrant	26369	1	97219
22200001416458	Tarrant	75760	1	279317
22200000805048	Tarrant	14823	1	54650
022200C03572001	Tarrant	9981	2	73597
22200001415383	Tarrant	12640	1	46602
22490013407097	Wise	8281	8	244248
22490001308331	Wise	25465	0	0
Total Damage cost / Year				4172341

5 Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 Research Conclusion:

In conclusion, this thesis presented a comprehensive assessment of BCA of both primary and secondary benefits. It provided a primary benefit analysis of 95 bridges over North Central Texas and investigated the methods for determining several secondary benefits. It shows that considering secondary benefits in addition to primary benefits can provide a more complete picture of the costs and benefits of infrastructure projects and quantify previously overlooked aspects of infrastructure projects. The following conclusions can be made based on the results of this study:

- The primary benefits are the results of a large volume of bridge samples exhibiting a pattern in benefit, with Poor being the highest and Good being the most minor benefit. Benefit results imply that Poor bridges require more attention in case of maintenance or replacement.
- Due to noise health damage, the total number of DALYs lost in Tarrant County is 4460 years, and the damage cost is $245.3 million. Noise can further reduce a property's value by around 1.1% per $100,000. So calculating the noise health damage on a case-by-case basis, using a BCA analysis of a bridge, can give greater insight and a stronger result.
- Emergency response delay for 5 minutes in Dallas County costs $ 738584 for reduced 61.4 realtime structure fire cases in Dallas county. If more precise data can be obtained, an emergeny response should give a significant additional benefit for bridge closure.
- The pavement damage caused by the detour taking vehicle for total 95 bridges is $22.53 million dollars. By examining the pavement damage from detour-taking vehicles, this research provides crucial insights for

transportation planners and engineers to mitigate such impacts effectively highlighting the urgent need for proactive management strategies.

- The assessment of secondary benefits, such as various noise damage costs, emergency response costs, and pavement damage costs due to detours, not only added value to a thorough analysis but also provided the societal significance of conducting this secondary analysis.
- In conclusion, this thesis enhances understanding in economics, engineering, and related fields through secondary benefit analysis. The findings inform strategic infrastructure investments and policy development, fostering better societal outcomes through informed decision-making.

5.2 Limitations

After calculating the primary benefits for a sample of bridges, there is a need for research to quantify the secondary benefits. Though plenty of research is available, there is a need for more data due to location. For example, most noise monetization data and research are available from Europe. Unfortunately, there is a lack of US-based data. As these data require extensive surveys from authentic research institutes to validate the result, it is also challenging to extrapolate anything without fully understanding the variable's nature and unpredictability. So, the difficulty in setting up the rates in different geolocations based on health-related compensation, the hedonic pricing model for property devaluation, human longevity, income level, and willingness to pay should vary. This study will add noise reduction benefits.

For pavement damage benefit, there is no set guideline for Texas, although the condition-based method considers cracking, wearing surfaces, and various existing defects. Due to a lack of data, this study could not assess a more accurate method. Additionally, the federal return for the road maintenance was assumed based on other transportation departments' recommendations, but no definitive return amount for Texas was found.

5.3 Recommendations and Future Research

Monetizing secondary benefits can help justify the costs of the bridge project by demonstrating its broader positive impacts beyond the primary objectives. This strengthens the case for investment and increases the likelihood of funding approval.The extent this study has explored can be significantly helpful for establishing guideline for secondary benefit analysis. Follwing are the recommendations for the future research:

e) Future researchers should look at the overall BCA pattern for a higher volume of samples and enable the analysis of the correlation between categories of bridges.

f) Guideline should be adopted for the secondary benefit analysis and add more benefits for the bridges.

g) More surveys and research should be conducted to generate US-based data for noise health damage and emergency response costs. Further more local data are recommended for individual case basis analysis.

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Appendix

County Name & Bridge ID	Bridge type	ADT	Detour Length	VMT/Day	Total VMT/day per county	Exposure Factor	Fatal Crashes	Suspected Serious Injuries	Suspected Minor Injuries	Possible Injuries	Non Injuries	Unknown Injuries	Total benefit/year	Final benefit with CRF/year
Dallas							323	1816	9555	14,541	98,350	16,559		
180570237402340	Poor	16420	2	32840	92,882,433	0.0003535652	0.11420157	0.64207448	3.3783159	5.1411922	34.7731417	5.85468686		
Safety Benefit							1347579	362323	519247	403584	139093	1252318	4024142	2052312
180570019603101	Poor	194462	1	194462	92,882,433	0.0020936359	0.67624441	3.80204287	20.0046914	30.4435602	205.909095	34.6685175		
Safety Benefit							7979684	2145493	3074721	2389819	823636	7415596	23828950	12152764
180570237402444	Poor	76110	2	152220	92,882,433	0.0016388460	0.52934724	2.97614426	15.6591731	23.8304591	161.1805	27.1376502		
Safety Benefit							6246297	1679438	2406815	1870691	644722	5804743	18652707	9512881
180570009201048	Poor	8615	6	51690	92,882,433	0.0005565100	0.17975272	1.01062211	5.31745276	8.09221147	54.7327555	9.21524859		
Safety Benefit							2121082	570294	817292	635239	218931	1971142	6333980	3230330
180570000911357	Poor	680	1	680	92,882,433	0.0000073211	0.00236471	0.01329509	0.06995295	0.10645587	0.72002851	0.12122981		
Safety Benefit							27904	7502	10752	8357	2880	25931	83326	42496
180570009202315	Poor	26991	1	26991	92,882,433	0.0002905932	0.09386159	0.52771718	2.77661767	4.22551518	28.5798376	4.81193219		
Safety Benefit							1107567	297791	426766	331703	114319	1029272	3307418	1686783
180570000911383	Poor	141993	10	1419930	92,882,433	0.0152873902	4.93782705	27.7619007	146.071014	222.293942	1503.51483	253.143895		
Safety Benefit							58266359	15666041	22451115	17450074	6014059	54147479	173995127	88737515
180570009202063	Poor	68837	0	0	92,882,433	0.0000000000	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
180570009214204	Poor	14240	1	14240	92,882,433	0.0001533121	0.04951981	0.27841476	1.46489703	2.22931111	15.0782441	2.53869491		
Safety Benefit							584334	157109	225155	175001	60313	543027	1744939	889919
180570000911347	Poor	192770	0	0	92,882,433	0.0000000000	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
180570237402341	Poor	7000	1	7000	92,882,433	0.0000753641	0.0243426	0.13686119	0.72010388	1.09586923	7.41205821	1.24795396		
Safety Benefit							287243	77231	110680	86026	29648	266937	857765	437460
180570009502332	Poor	6730	4	26920	92,882,433	0.0002898288	0.09361469	0.52632902	2.76931376	4.21439994	28.5046581	4.79927437		
Safety Benefit							1104653	297007	425644	330830	114019	1026565	3298718	1682346
180570043001012	Poor	7032	1	7032	92,882,433	0.0000757086	0.02445388	0.13748684	0.72339578	1.10087891	7.4459419	1.25365889		
Safety Benefit							288556	77584	111186	86419	29784	268158	861686	439460
180570058102010	Poor	58703	1	58703	92,882,433	0.0006320140	0.20414053	1.14773746	6.03889397	9.19011589	62.158579	10.4655202		
Safety Benefit							2408858	647668	928178	721424	248634	2238575	7193338	3668602
180570009207165	Poor	22259	6	133554	92,882,433	0.0014378822	0.46443596	2.61119413	13.7389647	20.9082455	141.415717	23.8098919		
Safety Benefit							5480344	1473497	2111679	1641297	565663	5092936	16365416	8346362
180570000911353	Poor	81504	1	81504	92,882,433	0.0008774964	0.28343134	1.59353345	8.38447804	12.7596751	86.3017703	14.5304628		
Safety Benefit							3344490	899231	1288694	1001634	345207	3108066	9987323	5093534
180570019702135	Fair	31210	3	93630	92,882,433	0.0010080485	0.32559968	1.83061613	9.6319037	14.6580337	99.1415729	16.6922756		
Safety Benefit							3842076	1033017	1480424	1150656	396566	3570478	11473216	5851340
180570019702167	Fair	29,620	1	29620	92,882,433	0.0003188978	0.10300398	0.57911834	3.04706811	4.63709236	31.3635949	5.28062804		
Safety Benefit							1215447	326796	468334	364012	125454	1129526	3629570	1851081
180570000911196	Fair	121,720	1	121720	92,882,433	0.0013104739	0.42328306	2.37982052	12.5215777	19.0556003	128.885104	21.7001366		
Safety Benefit							4994740	1342933	1924566	1495865	515540	4641659	14915304	7606805
180570000902002	Fair	16,405	1	16405	92,882,433	0.0001766211	0.05704862	0.32074397	1.68761487	2.56824781	17.3706878	2.92466924		
Safety Benefit							673174	180996	259386	201607	69483	625587	2010233	1025219
180570106804109	Fair	117,986	2	235972	92,882,433	0.0025405450	0.82059603	4.61362971	24.2749074	36.9420647	249.8626	42.0688845		
Safety Benefit							9683033	2603471	3731053	2899952	999450	8998534	28915495	14746902

180570237401476	Fair	23,200	0	0	92,882,433	0.0000000000	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
180570G01155010	Fair	18,238	1	18238	92,882,433	0.0001963558	0.06342291	0.35658205	1.87617921	2.85520899	19.3115882	3.2514549		
Safety Benefit							748390	201219	288369	224134	77246	695486	2234845	1139771
180570004707261	Fair	31,040	1	31040	92,882,433	0.0003341859	0.10794205	0.6068816	3.19314633	4.85939726	32.8671838	5.53378441		
Safety Benefit							1273716	342463	490787	381463	131469	1183676	3803574	1939823
180570237407347	Fair	47,751	1	47751	92,882,433	0.0005141015	0.16605479	0.93360836	4.91224002	7.4755502	50.5618845	8.51300707		
Safety Benefit							1959447	526835	755011	586831	202248	1820932	5851303	2984165
180570237401482	Good	23200	0	0	92,882,433	0.0000000000	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
180570237401561	Good	5000	0	0	92,882,433	0.0000000000	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
180570058102013	Good	32122	6	192732	92,882,433	0.0020750102	0.67022831	3.7682186	19.8267229	30.172724	204.077258	34.3600946		
Safety Benefit							7908694	2126406	3047367	2368559	816309	7349624	23616959	12044649
180570009202297	Good	26991	1	26991	92,882,433	0.0002905932	0.09386159	0.52771718	2.77661767	4.22551518	28.5798376	4.81193219		
Safety Benefit							1107567	297791	426766	331703	114319	1029272	3307418	1686783
180570296401499	Good	7240	1	7240	92,882,433	0.0000779480	0.0251772	0.14155357	0.74479315	1.13344189	7.66618592	1.29074095		
Safety Benefit							297091	79879	114475	88975	30665	276089	887174	452459
180570004801160	Good	7685	1	7685	92,882,433	0.0000827390	0.0267247	0.15025403	0.79057118	1.20310786	8.13738105	1.37007517		
Safety Benefit							315351	84788	121511	94444	32550	293059	941703	480269
180570237403169	Good	52500	0	0	92,882,433	0.0000000000	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
180570004707418	Good	15000	0	0	92,882,433	0.0000000000	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
Denton					26,727,961		49	319	1817	2540	25304	1451		
180610035302006	Poor	23777	6	142662	26,727,961	0.005337556	0.26154026	1.7026805	9.69834003	13.5573933	135.061528	7.74479437		
Safety Benefit							3086175	960823	1490635	1064255	540246	1656612	8798746	4487360
180610019502053	Poor	33174	2	66348	26,727,961	0.0024823442	0.12163487	0.79186781	4.51041948	6.30515437	62.8132386	3.60188149		
Safety Benefit							1435291	446851	693251	494955	251253	770442	4092044	2086942
180610019503134	Poor	52260	0	0	26,727,961	0.0000000000	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
180610H01370004	Fair	2750	1	2750	26,727,961	0.0001028885	0.00504154	0.03282143	0.18694842	0.26133681	2.60349078	0.14929122		
Safety Benefit							59490	18521	28734	20515	10414	31933	169608	86500
180610019503149	Good	91450	1	91450	26,727,961	0.0034215105	0.16765402	1.09146186	6.21688463	8.69063675	86.5779024	4.96461178		
Safety Benefit							1978317	615912	955535	682215	346312	1061930	5640222	2876513
180610019602026	Good	74860	1	74860	26,727,961	0.0028008122	0.1372398	0.8934591	5.08907582	7.11406306	70.8717526	4.06397854		
Safety Benefit							1619430	504179	782191	558454	283487	869285	4617026	2354683
Ellis					9,044,651		28	169	537	631	6308	317		
180710004808179	Good	33458	2	66916	9,044,651	0.007398406	0.20715537	1.25033061	3.97294401	4.66839417	46.6691449	2.34529469		
Safety Benefit							2444433	705562	610641	366469	186677	501659	4815440	2455875
180710004808174	Good	33458	1	33458	9044651	0.003699203	0.10357768	0.6251653	1.986472	2.33419709	23.3345724	1.17264735		

Safety Benefit							1222217	352781	305321	183234	93338	250829	2407720	1227937
Erath					No data		17	38	120	120	1380	18		
20730031404118	Fair	13386	1											
20730007905039	Fair	18925	1											
Hood							9	43	166	215	1501	32		
Hunt							14	113	360	356	3054	152		
Johnson					5,717,034		33	155	458	538	5536	189		
Kaufman					7,736,090		20	175	388	488	4067	376		
181300009504025	Poor	8713	1	8713	7,736,090	0.00112628	0.02252559	0.19709892	0.43699647	0.54962442	4.58057895	0.42348111		
Safety Benefit							265802	111223	67166	43146	18322	90583	596242	304083
181300AA0347001	Poor	100	3	300	7,736,090	3.87793E-05	0.00077559	0.00678637	0.01504636	0.01892429	0.15771533	0.01458101		
Safety Benefit							9152	3830	2313	1486	631	3119	20529	10470
181300009514356	Fair	14353	0	0	7,736,090	0	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
181300049501197	Good	24868	1	24868	7,736,090	0.003214544	0.06429088	0.56254516	1.24724299	1.56869737	13.0735496	1.20866846		
Safety Benefit							758632	317444	191701	123143	52294	258534	1701749	867892
181300019705249	Good	7824	1	7824	7,736,090	0.001011364	0.02022727	0.17698863	0.39240909	0.49354545	4.11321585	0.38027272		
Safety Benefit							238682	99875	60313	38743	16453	81340	535406	273057
Navarro							8	62	149	233	2683	118		
Palo Pinto							5	31	121	48	1117	36		
Parker					6,146,925		15	108	379	352	5111	197		
21840031407044	Fair	36274	1	36274	6,146,925	0.005901162	0.08851743	0.63732549	2.23654038	2.07720901	30.1608388	1.16252891		
Safety Benefit							1044506	359643	343756	163061	120643	248665	2280274	1162940
21840031401006	Poor	1160	0	0	6,146,925	0	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
21840008006063	Good	11775	1	11775	6,146,925	0.001915592	0.02873388	0.20688393	0.72600935	0.67428836	9.79059042	0.37737161		
Safety Benefit							339060	116745	111588	52932	39162	80720	740206	377505
Rockwall					3,281,624		6	55	208	325	4356	93		
181990000912132	Poor	26134	1	26134	3,281,624	0.00796374	0.04778244	0.43800569	1.6564579	2.58821547	34.690051	0.74062781		
Safety Benefit							563833	247167	254598	203175	138760	158420	1565952	798636
181990000912476	Fair	33095	0	0	3,281,624	0	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
181990101403390	Good	2291	5	11455	3,281,624	0.00349065	0.0209439	0.19198574	0.72605515	1.13446117	15.2052703	0.32463043		
Safety Benefit							247138	108338	111595	89055	60821	69438	686385	350056
Somervell							3	13	28	20	294	7		
Tarrant					61,540,586		208	1061	6387	8362	56034	4434		
22200017206067	Poor	34052	0	0	61,540,586	0	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
22200001416192	Poor	69770	0	0	61,540,586	0	0	0	0	0	0	0		

Safety Benefit							0	0	0	0	0	0	0	0
022200ZS4528003	Poor	5269	7	36883	61,540,586	0.000599328	0.12466024	0.63588707	3.82790832	5.01158124	33.5827485	2.65742062		
Safety Benefit							1470991	358831	588350	393409	134331	568422	3514334	1792310
22200000813122	Poor	42650	0	0	61,540,586	0	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
22200001415331	Fair	22913	1	22913	61,540,586	0.000372323	0.07744327	0.39503512	2.37802953	3.11336824	20.8627692	1.65088194		
Safety Benefit							913831	222918	365503	244399	83451	353124	2183226	1113445
22200017105033	Fair	34893	37	1291041	61,540,586	0.020978692	4.36356794	22.2583922	133.990906	175.423823	1175.52003	93.0195204		
Safety Benefit							51490102	12560411	20594402	13770770	4702080	19896875	123014640	62737467
22200001402352	Fair	102340	0	0	61,540,586	0	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0
22200008112077	Fair	45300	1	45300	61,540,586	0.0007361	0.15310871	0.78100166	4.70146807	6.15526475	41.2466043	3.26386557		
Safety Benefit							1806683	440719	722616	483188	164986	698141	4316333	2201330
22200009402068	Fair	8219	25	205475	61,540,586	0.003338853	0.69448152	3.54252355	21.3252572	27.9194928	187.089316	14.8044763		
Safety Benefit							8194882	1999046	3277692	2191680	748357	3166677	19578335	9984951
22200000813132	Fair	7500	3	22500	61,540,586	0.000365612	0.07604737	0.38791473	2.33516626	3.05725071	20.486724	1.62112528		
Safety Benefit							897359	218900	358915	239994	81947	346759	2143874	1093376
22200226602012	Good	42990	1	42990	61,540,586	0.000698563	0.14530118	0.74117575	4.46172433	5.84138702	39.1433007	3.09743004		
Safety Benefit							1714554	418245	685767	458549	156573	662540	4096229	2089077
022200ZN7350002	Good	20140	2	40280	61,540,586	0.000654527	0.1361417	0.69445358	4.18046653	5.47315815	36.6757886	2.90217451		
Safety Benefit							1606472	391880	642538	429643	146703	620775	3838011	1957386
022200ZB2880001	Good	26369	1	26369	61,540,586	0.000428481	0.08912414	0.45461883	2.73671107	3.58296195	24.00953	1.89988678		
Safety Benefit							1051665	256541	420632	281263	96038	406386	2512525	1281388
22200001416458	Good	75760	1	75760	61,540,586	0.001231058	0.25605996	1.30615201	7.86276426	10.2941028	68.981076	5.45850896		
Safety Benefit							3021508	737062	1208507	808087	275924	1167575	7218662	3681518
22200000805048	Good	14823	1	14823	61,540,586	0.000240865	0.05010001	0.25555823	1.53840753	2.01411677	13.4966538	1.06799734		
Safety Benefit							591180	144212	236453	158108	53987	228445	1412384	720316
022200C03572001	Good	9981	2	19962	61,540,586	0.000324371	0.06746923	0.34415795	2.07175951	2.71239283	18.1758215	1.43826235		
Safety Benefit							796137	194208	318429	212923	72703	307644	1902045	970043
22200001415383	Good	12640	1	12640	61,540,586	0.000205393	0.04272173	0.21792188	1.31184451	1.71749551	11.5089863	0.91071216		
Safety Benefit							504116	122973	201631	134823	46036	194801	1204381	614234
wise					4,115,586		22	93	158	163	2135	46		
22490013411075	Fair	1800	2	3600	4,115,586	0.000874724	0.01924392	0.08134929	0.13820632	0.14257994	1.86753478	0.04023728		
Safety Benefit							227078	45905	21242	11193	7470	8607	321495	163963
22490013407097	Good	8281	8	66248	4,115,586	0.016096857	0.35413086	1.49700772	2.54330343	2.62378772	34.3667901	0.74045543		
Safety Benefit							4178744	844761	390906	205967	137467	158383	5916229	3017277
22490001308331	Good	25465	0	0	4,115,586	0	0	0	0	0	0	0		
Safety Benefit							0	0	0	0	0	0	0	0