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ANALYSIS AND COMPARISON
OF TRAFFIC DISRUPTION USING OPEN-CUT
AND TRENCHLESS METHODS OF PIPE INSTALLATION

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ANALYSIS AND COMPARISON OF TRAFFIC DISRUPTION USING OPEN-CUT AND TRENCHLESS METHODS OF PIPE INSTALLATION

By

Bhavani Sripathi Gangavarapu

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ABSTRACT

ANALYSIS AND COMPARISON
OF TRAFFIC DISRUPTION USING OPEN-CUT
AND TRENCHLESS METHODS OF PIPE INSTALLATION

By

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The social costs are the deciding factor in pipe installation and renewal of utilities, the most important being the time and cost associated with traffic disruption. This paper aims at comparing traffic delays and costs involved during utility construction using open-cut and trenchless methods. Case study of two sites involving utility construction is chosen and the traffic flow rate is measured. Depending on the type of pipe installation method used, the time lost and costs for traffic jams are calculated. The same is repeated for the alternate method of pipe installation applying the same criteria.

A prediction model is designed from the available information to project the costs in using both the methods of utility construction. Data from the two case studies is used as an average measure in predicting the costs. Based on the data from the case studies and literature review of similar existing studies, the information can be applied to a range of applications in utility construction.

Dedicated to my Parents

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. Overview

The conventional method for construction, replacement and repair of underground utilities has been the traditional open-cut, or "dig and replace.' The traditional open-cut method includes direct installation of utility systems into open-cut trenches.

Advancements in technology and improvements in obtaining geo-technical data and development of new equipment led to improvements in utility pipe installation work. Alternative means of installing and renewing of underground utility pipes have been developed, which would facilitate utility construction with minimal surface disruption, called trenchless technology or trenchless solutions in pipe installation and renewal. Trenchless technology was accepted in America only after its initial success in Europe. According to North American cost indices for 1988 to1998, trenchless construction methods have gained a market share of around 20% by cost in pipe installation and renewal for utility services (Thomson et al, 1998).

Sterling[2] has indicated that 300,000 miles of underground utilities, including water, sewer and gas, electrical power, cable television and telephone, are constructed around the world each year, with an estimated market value of greater than $35 billion (Dukart, 2000).

[2] Dr. Ray Sterling is currently the chairman of International Society for Trenchless Technology (ISTT) and director of the Trenchless Technology Center at Louisiana Tech University.

Many techniques exist today using the trenchless solution for underground utility construction. Most of these methods are not appropriate for utility construction on urban roads, because of the unique characteristics of the urban roads (Bodocsi et al, 1995). Due to the high volume of traffic and various business places located in the urban areas, utility construction has to be assessed for cost effectiveness before construction. Municipalities and other official bodies are gradually becoming aware of the effectiveness of trenchless construction methods for urban roads.

1.2. Need Statement

Awareness of the cost advantages of constructing and renewing underground utilities using trenchless technology has increased the use of trenchless methods of pipe installation and renewals compared to traditional methods. There are three kinds of costs for any project and specifically for utility construction; direct cost, including labor, material and equipment; indirect cost, including overhead and profit; and social costs. In using an open-cut method for utility construction, direct cost would include the utility cut itself, including labor, materials, equipment and overhead necessary to cut, remove, replace and inspect pavements (NCMA, 2003). Social costs include user costs from possible traffic delays, detours and restraints on using roads due to repairs. Most of the traffic delays occur during lane closures and detour routes due to utility cuts made across the road. Table 1 provides information on the annual number of utility cuts for sample cities. The most important of the social costs associated with utility construction is cost of road repair and vehicular or traffic disruption (Bush, 2001). The need to protect the environment and a better quality of life has resulted in the need to identify and evaluate the social costs associated with utility service construction.

Table 1: Annual Number of Utility Cuts (Source: NMCA, 2003)

City	Number
Chicago, Illinois	120,000
San Francisco, California	14,000
Cincinnati, Ohio	10,000
Seattle, Washington	10-20,000
Boston, Massachusetts	25-30,000
Billings, Montana	650-730
Oakland California	500,000

A recently released study by the Texas Transportation Institute concluded that in 1999 the average person spent 36 hours a year sitting in traffic due to traffic jams as a result of accidents and other road blockages. Lane blockages due to open-cut construction add to this traffic disruption (Bush, 2001). Traffic congestion, according to the previously mentioned study, accounts for 6.8 billion gallons of fuel consumption and 4.5 billion hours of travel time, costing the nation $78 billion dollars per year. National Transportation Statistics (NTS, 2001) provides information on the average number of hours per person, spent on highways due to traffic delays. These data are summarized in Table 2. Delays include traffic accidents, lane blockage due to an emergency or accident, and delays in traffic movement due to construction.

Table 2: Average Annual Person-Hours of Highway Traffic Delay Per Capita (in Hours) (Source: NTS, 2001)

Population Group	1995	1996	1997	1998	1999	Percent Change 1995-1999
Very Large Area (over 3 million population)	35	38	39	40	41	17
Large Area (over 1 million & less than 3 million)	28	29	31	32	34	21
Medium Area (over 500,000 & less than 1 million)	21	22	24	24	26	24
Small Area (less than 500,000 population)	6	7	8	9	10	67

Most of the local government bodies and contractors fail to realize the effect of the utility cuts made on the roads in urban areas in terms of the social costs. Some of the cities charge a utility cut fee to recover some of the costs involved in the actual construction of the utility work, such as the cost of cutting and cost of reinstating the pavement (NMCA, 2003). Various State and Federal laws were passed to compensate the utility cuts driven by construction (FHA, 2002). But these costs do not ease the money spent by an average person waiting in the traffic due to delays. The average cost spent by a person due to traffic delay come mostly from the money spent on gasoline or fuel wasted while waiting in traffic. Table 3 summarizes the fuel in gallons wasted in waiting during traffic delays. The information is organized according to the size of the urban area and as expected the results, as summarized by NTS, were higher in large population areas. The number of gallons wasted in turn amount to the cost spent on fuel by the user, which are not accounted for during the utility construction. The waiting time in traffic per person might increase due to utility cuts made in pavements for construction. The duration of such construction activity affects the amount of money spent on fuel per person while waiting in traffic.

Table 3: Average Wasted Fuel per Capita (in gallons)
(Source: NTS, 2001)

Population Group	'82	'85	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	% Change 1982-1999
Very Large Area	25	34	50	49	50	51	51	53	57	58	61	62	148
Large Area	12	18	30	31	33	36	38	40	43	45	46	49	326
Medium Area	8	12	22	22	24	26	28	30	32	36	36	39	362
Small Area	1	3	5	6	7	7	7	8	10	10	13	15	1142

Studies have shown that the traditional open-cut method, though considered as a reliable method, is a time consuming and inefficient method of pipe installation and renewal. Costs and the time associated with the traditional approach exceed the estimated or bid amount due to the addition of various social and environmental costs involved. If unaccounted in the project budget, these costs may show up during the maintenance by the public bodies such as municipalities, which in turn look for money from the general public as a tax.

It is important to understand the time and cost aspects in utility installation involved in using various methods of pipe installation. This can be better understood by comparing the cost and time aspects of the open-cut method and trenchless methods.

1.3. Research Goal

The main goal of this study is to analyze the costs in traffic and road disruption during utility construction using the open-cut method against the trenchless construction method.

1.4. Objectives

1. To present an overview of the various trenchless construction methods and parameters used in understanding social costs for utility construction.
2. To study and document the traffic flow rate and pattern during one or two utility construction projects and analyze the impact of utility construction on the traffic flow.
3. To estimate the cost of traffic delay using the information obtained from the traffic flow and other related studies.
4. Prepare a flow chart or model for estimating the costs due to traffic disruption.

1.5. Research Scope

- This study will be limited to the analysis of social costs due to traffic disruption in urban areas.
- Social costs due to damage to pavement, environmental safety issues, noise and dust, etc are not considered in this study.

1.6. Overview

This study consists of five chapters. The first chapter includes a brief overview of the topic and the proposal statement. The second chapter introduces the existing literature in the problem area and a breakdown of social costs, mainly costs due to traffic disruption, along with an introduction to the existing techniques in trenchless technology. The third chapter discusses the methodology and the expected deliverables or outcome of this research. This chapter discusses the process of collecting the required data and the method that would be utilized in collecting and estimating the required information to calculate the costs associated with traffic disruption due to utility construction. Fourth chapter presents the case studies as a part of the study and an analysis of the data collected during the case studies and the results of the study. The fifth and final chapter presents the conclusion and recommendations for future studies.

2. LITERATURE REVIEW

The last chapter briefly introduced the topic and the problem area. This chapter will emphasize the existing techniques in trenchless technology, and the various social costs associated with traditional utility construction. Most of the available techniques in estimating the social costs are discussed in this chapter.

2.1. Utility Construction Methods

There are many methods for constructing underground utility lines. Depending upon the availability and pertaining soil conditions along with the budget and logistic requirements the best among these methods should be implemented. Utility pipe installations are broadly classified into two methods, Open-Cut Method and Trenchless Method. Each of these methods is described briefly, since each of these methods is assessed for the cost due to traffic disruption for each of the case studies.

2.1.1. Open-Cut Method of Pipe Installation

This is considered as the traditional method of installing utility lines under ground. Open-cut methods involve digging a trench along the length of the proposed pipeline, placing the pipe in the trench and then back filling with the soil. Most of the times, the surface pavement has to be redone after the installation to complete the project. This method of pipe installation is very time consuming and does not always yield the best results. In recent times, this method of installation is being discouraged due to understanding of the various social costs involved with underground utility construction.

2.1.2. Trenchless Technology Methods (TT Methods)

Trenchless technology methods can be defined as those methods or techniques used for utility or other installations, replacement, renovation, inspection, location, and leak detection, with minimum excavation from the ground surface (ASCE, 1996). These methods of installation are broadly divided into two categories: new installation methods and renewal methods.

2.1.2.1. New Installation Methods

New installation is further divided into the following family of methods: Horizontal Earth Boring, Pipe Jacking, and Utility Tunneling. Figure 1 classifies the various trenchless construction methods in practice. Horizontal Earth Boring does not require personnel entry into the borehole, while Pipe Jacking and Utility Tunneling require personnel to work inside the borehole (Iseley et al, 1999). Each of the methods is briefly discussed in this chapter.

Auger Boring

This method utilizes a process of simultaneously jacking casing through the earth while removing the spoil inside the encasement by means of a rotating flight auger. This method of pipe installation is very versatile and can be used in a wide variety of soil types. The auger method is traditionally classified into three types, Track Type, Cradle Type and Line & Grade Method.

Compaction Method

This method forms the borehole by compressing the earth immediately surrounding the compacting device, rather than removing it. The method is limited to relatively small diameter lines in compressible soil conditions. The compaction method is divided into three categories, the Push Rod Method, the Rotary Method and the Percussion Method.

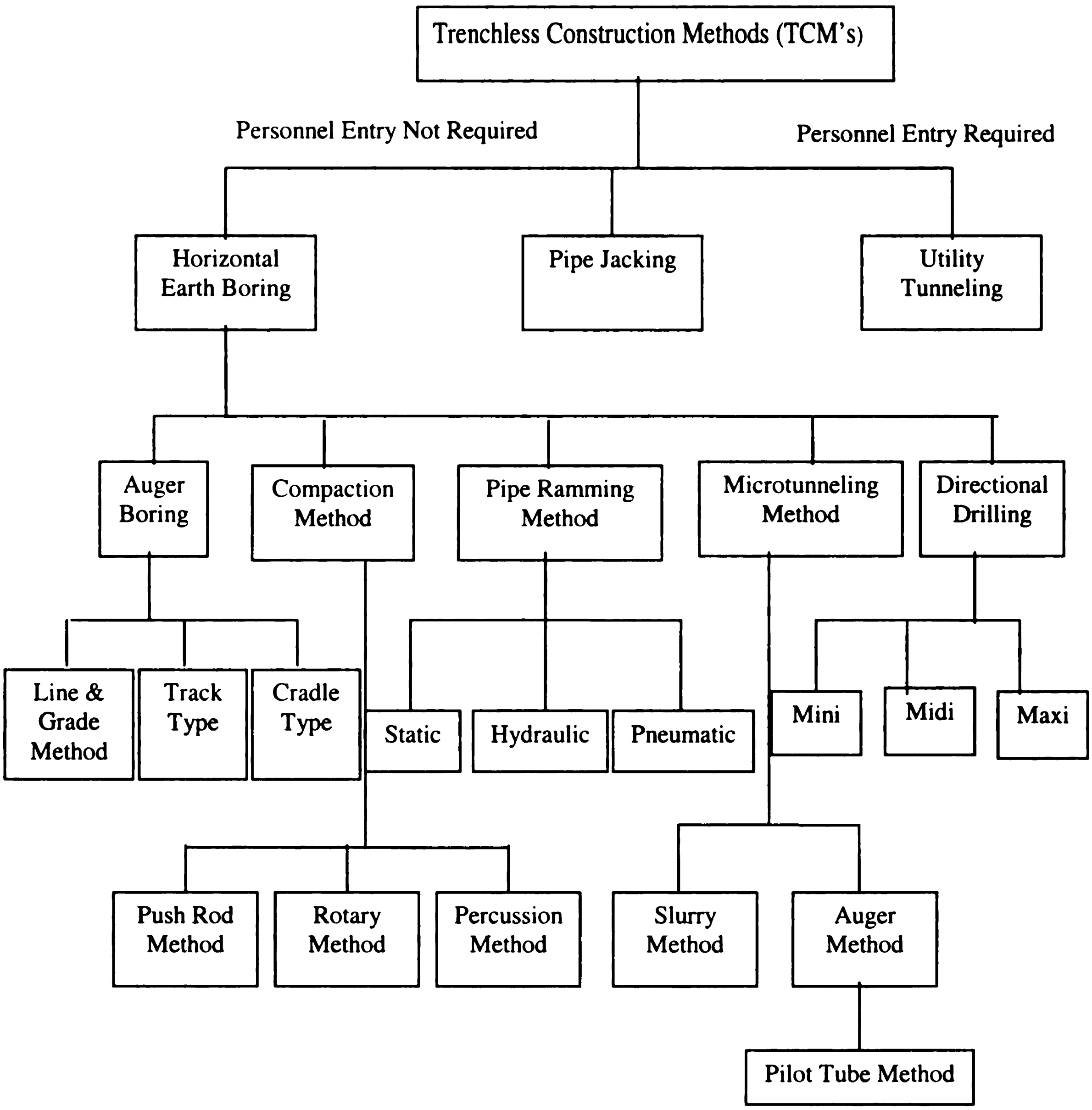

Figure 1: TCM- Classification System for New Installation

Pipe Ramming Method

The procedure consists of ramming a steel pipe through the soil by using a device, generally air powered, attached to the end of the pipe. In this method, the tool does not create a borehole; rather, it acts as a hammer to drive the pipe through the soil (Isleley et al, 1999).

Microtunneling Method

This is a remotely controlled pipe jacking process, which controls the applied pressure and provides continuous support at the excavation face. Microtunneling can be broadly divided into two categories, Slurry Microtunneling and Auger Microtunneling.

Directional or Horizontal Directional Drilling Method (HDD)

This method involves steering of boring systems in two stages. The first stage consists of drilling a small diameter pilot hole along the desired centerline of a proposed pipeline, and the second stage consists of enlarging the pilot hole to the desired diameter to accommodate the utility line and pulling the line through the enlarged hole. Based on size of the rig, torque and thrust capabilities and diameter, depth and length of installations, directional methods can be divided into three areas, Mini-HDD, Midi-HDD and Maxi-HDD.

Pipe Jacking and Utility Tunneling

Pipe jacking and utility tunneling are trenchless construction methods, which require workers inside the jacking pipe or tunnel. The excavation starts at an entry pit and can be done manually or by using machines.

2.1.2.2. Renewal Methods

Renewal methods are used to reinstate a pipeline to increase its life. Figure 2 presents a classification for trenchless renewal methods used for underground utility construction. These methods are mainly used for rehabilitation techniques for existing water, sewer or other sanitation pipelines.

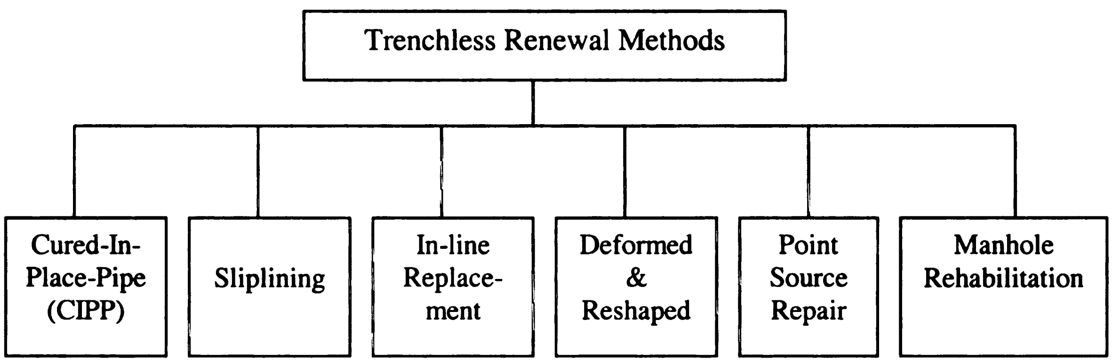

Figure 2: Classification System for Renewal Methods

2.2. Life-Cycle-Cost

Utility construction is often considered a risky business due to the many unforeseen factors involved in the construction of the project. To understand the total cost involved in the successful completion of the project, the life-cycle-costs have to be estimated. The life-cycle-cost of a project, from its design to its demolition after completion of its useful life, includes the following categories (Iseley et al, 1999):

2.2.1. Pre-Construction Cost

Pre-construction cost involves the design and planning stages of a project. Often these include the cost of appointing a designer or project manager and the cost of the design and procurement of various personnel required for the job. Major categories of pre-construction cost are Land acquisition, Easements, Permits, Design Fees, Planning, and Legal Fees.

2.2.2. Construction Cost

Construction cost is the original cost of constructing the project. This includes the direct costs such as labor, equipment and material; indirect costs such as overhead, contingency, profit and social costs. Most of the people involved in design and construction of underground utilities do not realize the importance of the third category, namely social costs. These are the unforeseen costs that influence, either directly or indirectly, the cost of the project.

2.2.3. Post Construction Cost

Post construction costs, as the name suggests, are the costs that come into play after the completion of the project. Usually, the contractor involved in the construction does not take care of this phase; these costs are the burden of the local bodies. Post construction costs involve Operation, Maintenance & Repairs.

For an effective estimate of the life-cycle-cost of the project, the social costs need to be considered carefully. As mentioned earlier, though often ignored and unaccounted for, these costs can show up either during or after construction and cannot be avoided unless alternative methods of construction are used.

2.3. Social Costs

According to Boyce and Bried (1994), the social costs include the following major categories:

- Road damage
- Damage to adjacent utilities
- Damage to adjacent structures
- Noise and Vibration
- Air pollution
- Vehicular traffic disruption
- Pedestrian safety
- Business and Trade loss
- Damage to detour roads
- Site safety
- Citizen complaints
- Environmental impacts.

The social costs can be a major element in calculating the life-cycle-cost of the project, since it depends mainly on the method of installation. Studies indicate that the social costs associated with the traditional open-cut method are more than that of trenchless technology.

2.3.1. Road Damage

Despite many precautions, utility cuts made in the pavements remains an expensive affair due to the huge costs and risk involved in cutting open a road. Often due to the poor restoration techniques used on the pavement by the contractor, the same work has to be repeated within a few years. This not only increases the cost of the work, but also reduces the life span of the pavement by 30 to 50 percent (Zeghal and Mohamed, 2001). Successive utility cuts and poor restoration techniques often render the pavement useless and usually require a new pavement construction.

2.3.2. Damage to Adjacent Utilities

The possibility of damaging any existing underground utilities is a major concern for any utility contractor. In case of any damage to the other adjacent utility, the cost of repairing the service adds to the cost of the project. Moreover, buried electrical cables, gas and oil pipelines, are a potential threat to the crew working on the site.

2.3.3. Damage to Adjacent Structures

Underground utility construction often tends to cause uneven settlements and disruption in adjacent structures. Most of these settlements are caused due to activities like dewatering, excess excavation and improper techniques used in shoring and underpinning.

2.3.4. Noise and Vibration

Noise and vibration are often associated with utility construction. To reach the buried utility lines, contractors have to cut open existing surfaces, such as pavements, using heavy machinery like drills and trenching machines. These machines produce vibrations and noises that often lead to citizen complaints.

2.3.5. Air Pollution

Utility construction tends to produce dusty conditions. The serious health concerns associated with the dusty conditions result in an obvious public nuisance. This problem is even more complicated in critical areas such as schools and hospitals, and in areas of heavy urbanization such as downtown areas and major business areas in big cities.

2.3.6. Vehicular Traffic Disruption

Surface excavations such as utility cuts made in pavements result in traffic delay and congestion. In areas of heavy traffic, such as business districts, surface excavation can prove critical to average commuters, due to the increased amount of time spent in waiting during traffic delays.

2.3.7. Pedestrian Safety

Additional traffic due to utility construction on secondary roads, used as a detour, is a potential risk to pedestrians and children. Pedestrians and children use these secondary roads, which are mostly associated with residential neighborhoods. In order to reduce costs of utility construction, these roads are often used instead of constructing a new detour road.

2.3.8. Business and Trade Loss

Construction in commercial areas is often associated with loss to the local business. It is obvious that people tend to avoid obstructed areas resulting in closure of shops and other business places for the duration of the construction.

2.3.9. Damage to Detour Roads

Using secondary roads not suited or designed to take heavy traffic, as detour roads during construction, result in damage to these roads. The heavy traffic decreases the life span of the roads and damages the pavement, which is an additional cost to the local government.

2.3.10. Site Safety

Site related accidents to construction workers and the general public tends to increase in open-cut utility construction. Collapse of trench walls, trench caving and other fall accidents are common in utility construction.

2.3.11. Citizen Complaints

Disruption to the normal life of residents and business often generates public outcry and complaints to the authorities. Dust and noise are a major concern of the public during a construction activity. Traffic delays and increased wait times due to lane closures often tend to frustrate people.

2.3.12. Environmental Impacts

Construction work in environmentally sensitive areas such as wetlands, rivers, streams, natural habitats, public parks and historic places requires special effort. Public criticism of surface disruption and administrative burdens tend to increase while working in these areas.

This research study is limited to estimating the cost of traffic disruption as part of estimating the social costs. The above discussion of cost item is included to provide a brief introduction and overview to understand that the cost of traffic disruption is only one among many social costs.

2.4. Cost of Vehicular Traffic Disruption

The most important of the social costs associated with utility construction is the road and vehicular (or traffic) disruption (Bush, 2001). These costs are often not estimated in preparing the initial estimate, and are ignored, due to the poor understanding of their influence on the successful completion of the project. In most cases, the contractor is least concerned in understanding these costs. The end user of the road or the public body is the most affected by these costs. If these costs are not considered in the initial estimate of the cost, the public bodies often face stiff resistance from public or users during or after the construction. Resistance from the public during the construction of the project might lead to delays in completing the work. An analysis of the expenditure after completion of construction will sometimes discover extra spending on the part of the public body, which must collect these funds from the public in terms of a tax or a special assessment. Contractors and public officials need to better understand the various factors affecting the cost of traffic disruption for a successful completion of the project. The following are major categories under traffic and road disruption (Bush, 2001):

- Duration of the project
- Cost of fuel
- Cost of travel time
- Road damage
- Vehicular wear
- Loss of revenue
- Sales tax

In addition to the above, a direct influence of the construction activity can be estimated for Loss of Productivity, Dust and Dirt Control (Boyce & Bried, 1994). All of the above mentioned costs have to be assessed to give a correct perspective of the advantages in using trenchless technology. Initial studies have shown that these costs are minimized in using the trenchless methods of pipe installation compared to the traditional open-cut method.

2.4.1. Duration of the Project

The duration of the project and the time of the year play an important role in estimating the social costs involved in utility construction. Most of the utility companies either close the lanes or allow one lane for traffic during construction. The lane closure procedure often continues for the entire duration of the project, resulting in congestion and delays for daily commuters.

The cost of delay and congestion are significantly less for projects of short duration. But with an increase in time, the cost of travel time and other related costs increase. For example, a lane closure on a road for a few hours for utility service would not have a major affect on the cost of travel time, because of the small increment of time for which the traffic is disrupted. But the same cost would be very high if the lane was closed for over a month for construction. Also, the place and location of the lane closure for utility construction affects the social costs for the project. For example, a lane closure for a couple of hours on a city street would not be the same as a lane closure on a highway or a busy road. The time of the day for carrying out the work also affects the social costs. For example, a lane closure during an urban peak hour can add significantly to the social costs, compared to a closure during off-peak hours. The time of the construction, such as winters, holiday seasons and music concert times, also off balance the social costs.

2.4.2. Cost of Fuel

Utility construction often results in lane closures and traffic congestion. The amount of time spent in traffic delays is directly related to the cost of fuel wasted. Initial studies showed that these costs are significant in calculating the social costs for utility construction. Table 2 and 3 on pages 4 and 5; provide information on the time spent in waiting in traffic and the amount of fuel wasted during such delays. The cost of fuel is estimated based on the number of gallons wasted per car in waiting during traffic delays. The average fuel consumption of a car is used in calculating the amount of fuel wasted in traffic. The cost of fuel per gallon is multiplied by the number of gallons wasted per car to obtain the cost of fuel. Table 4 gives information on the average consumption of fuel and travel for passenger cars and motorcycles. Table 5 provides information on the fuel consumption by mode of transport. For a generic estimate on the amount of money wasted in waiting per person, the above-mentioned tables can be incorporated into the following formula as suggested by Victoria Transport Policy Institute (VTPI):

Cost of Fuel = (gallon/mile) x (additional miles) x (cost of fuel/gallon) *[1]*

Table 4: Passenger Car and Motorcycle Fuel Consumption and Travel (Source: NTS, 2001)

Category	1995	1996	1997	1998	1999	2000
Vehicles registered (thousands)						
Passenger cars	128,387	129,728	129,749	131,839	132,432	133,621
Motorcycles	3,897	3,872	3,826	3,879	4,152	4,346
Vehicle-miles traveled (millions)						
Passenger cars	1,438,000	1,470,000	1,502,556	1,549,577	1,569,100	1,601,914
Motorcycles	9,800	9,900	10,081	10,283	10,584	10,479
Fuel consumed (million gallons)						
Passenger cars	68,072	69,221	69,892	71,695	73,283	72,916
Motorcycles	196	198	202	206	212	210
Average miles traveled per vehicle (thousands)						
Passenger cars	11.2	11.3	11.6	11.7	11.8	12.0
Motorcycles	2.5	2.6	2.6	2.6	2.5	2.4
Average miles traveled per gallon						
Passenger cars	21.1	21.2	21.5	21.6	21.4	22
Motorcycles	50	50	50	50	50	50
Average fuel consumed per vehicle (gallons)						
Passenger cars	530	534	539	544	553	546
Motorcycles	50	51	53	53	51	48

Table 5: Fuel Consumption by Mode of Transportation in gallons (Source: NTS, 2001)

Highway	1995	1996	1997	1998	1999	2000
Gasoline, diesel and other fuels (million gallons)						
Passenger car and motorcycle	68,268	69,419	70,094	71,901	73,495	73,125
Other 2-axle 4-tire vehicle	45,605	47,354	49,388	50,462	52,859	52,832
Single-unit 2-axle 6-tire or more truck	9,216	9,409	9,576	6,817	9,372	9,548
Combination truck	19,777	20,193	20,302	25,158	24,537	25,645
Bus	968	990	1,027	1040	1,148	1,110

The number of miles traveled per gallon can be used to calculate the number of gallons per mile and can be incorporated in formula [1]. If more specific data on the type of vehicle is available, the data from table 4 can be used, otherwise the data from table 5 provides generic information. Data from the table would be used in estimating the cost of fuel for the additional miles traveled by each vehicle due to traffic disruption. Data collected during case studies for traffic disruption represents a fraction of the total fuel consumption or the average miles traveled by vehicles as mentioned in the above tables. The fraction or percentage of those additional miles is calculated and the information is used in predicting the cost of traffic disruption for the number of vehicles given in the table. The prediction model developed during this research would be used in projecting such costs.

2.4.3. Cost of Travel Time

Travel time refers to the time spent in travel, which includes the costs to business of time by their employees, vehicles and goods, and costs to consumers of personal (unpaid) time spent on travel (VTPI, 2003).

Travel time costs vary widely depending on factors such as type of trip, distance of travel, traveler and travel condition. For example, the delay cost during an emergency or crisis, rushing to a hospital or airport, may exceed a dollar per minute. While on the other hand, a pleasant drive along a riverside might be considered as a benefit rather than a cost. Per-minute travel time costs tend to be higher for passengers during uncomfortable and congested conditions. Based on earlier studies, Victoria Transport Policy Institute (VTPI) summarized the various factors affecting travel costs as follows:

- Commercial vehicle costs include drivers' wages and overhead costs, vehicle costs, costs for the value of the freight, and delays beyond a critical delivery time.
- Personal travel time is usually estimated at one-quarter to one-half of prevailing wage rates.
- Travel time costs tend to be higher for driving under congested conditions, under crowded or uncomfortable conditions.
- Travel time costs per minute tend to increase for longer commutes of more than about 20 minutes.
- People with full-time jobs tend to have more demands on their time, than people who are retired or unemployed.

While calculating the cost of travel time, VTPI valued the drivers' time at $6.00 per hour (50% of $12.00 average wage) and passengers at $4.20 per hour (35% of $12.00). These values were used for automobiles and motorcycles. Urban peak speeds were estimated to average 30 mph with a 16.5% congestion cost premium (VTPI, 2003), and off-peak speeds were estimated at 35 mph with no congestion premium. Table 6 summarizes the travel time cost per user.

Table 6: User Travel Time Costs per Passenger Mile in US dollars (Source: VTPI, 2003)

Vehicle Class	Urban Peak	Urban Off-Peak	Rural	Average
Average Car	$ 0.230	$ 0.170	$ 0.150	$ 0.174
Compact Car	$ 0.230	$ 0.170	$ 0.150	$ 0.174
Electric Car	$ 0.230	$ 0.170	$ 0.150	$ 0.174
Van/Light Truck	$ 0.230	$ 0.170	$ 0.150	$ 0.174
Rideshare Passenger	$ 0.180	$ 0.154	$ 0.135	$ 0.152
Diesel Bus	$ 0.350	$ 0.280	$ 0.233	$ 0.275
Electric Bus/Trolley	$ 0.350	$ 0.280	$ 0.233	$ 0.275
Motorcycle	$ 0.230	$ 0.170	$ 0.150	$ 0.174
Bicycle	$ 0.350	$ 0.300	$ 0.300	$ 0.310
Walk	$ 1.000	$ 1.000	$ 1.000	$ 1.000
Telework	$ 0.000	$ 0.000	$ 0.000	$ 0.000

As mentioned earlier in chapter 1, the cost of traffic delay due to utility cuts adds to the cost of travel time. When the cost of delay is determined from the case studies and is generalized using the prediction model, the total cost of travel time can be derived for the specific number of vehicles by adding the cost of delay to the cost of travel time from Table 5. Boyce & Bried (1994) and VTPI suggested using the following formula in determining the cost of delay for detour.

Cost of Detour Delay= (Time/mile) x (Additional miles to travel) x (Value of time in dollars) [2]

Table 6 provides information about the means of transportation used by individuals. Most of the people prefer to use personal means of transportation, such as cars, for getting to work. With the increase in the number of vehicles on the roads and the congestion thereafter, a few individuals are inclined to use other means of getting to work. Some of these individuals car pool to get to work, and a few, use public transportation. There are also individual who work at home, also called telework, and play an insignificant role in calculating the costs of travel time and congestion. In estimating the general cost of traffic delay or disruption, knowledge of the type or mode of transport preferred by a large section of the population has to be considered. Also, the other means of transport such as bus and train transit has to be considered to derive an accurate and consistent formula to generalize the cost of traffic disruption. This data can be useful in places where suitable data is not available.

Table 7: Principal Means of Transportation to Work (Thousands) (Source: NTS, 2001)

Category	Number	Percent
All workers	118,041	100.0
Automobile	103,466	87.7
Drives self	92,363	78.2
Carpool	11,103	9.4
2 person	8,705	7.4
3 person	1,454	1.2
4+ person	945	0.8
Public transportation	5,779	4.9
Taxicab	144	0.1
Bicycle or motorcycle	749	0.6
Walks	3,627	3.1
Other means	987	0.8
Works at home	3,288	2.8

Information from Table 7 can be used to project the average cost of traffic disruption. The number of vehicles measured during the case studies is assumed to represent a certain percentage of the average vehicles used for commuting as laid out in Table 7.

Each of these categories is used in projecting the cost of traffic delay using the prediction model.

2.4.4. Road Damage

Road damage due to utility construction can be in two forms. One is the damage to the actual construction, including the utility cuts and the following reinstating procedure used on the pavement. Many times, damages can be in the form of potholes and cracks in the road due to the poor techniques used in resurfacing the pavement. The second cost is the damage to the detour roads, due to the additional traffic during construction. These damages do not show up readily and take a significant amount of time to develop.

Potholes form due to the differential settlement of the soil below the pavement. Also, poor drainage of storm water washes out the sub grade under the pavement that eventually leads to the collapse of the pavement around the utility cut. Potholes and cracks on the pavement take time to develop and should be considered in the life-cycle-cost of the project for an effective estimate of the cost of the construction. Often, the local bodies have to come back after a couple of years after the completion of project and repair the pavement. The contractors could get away with incomplete work of reinstating the pavement, and the additional costs for repairing become a burden to the local government bodies.

Damage to the detour roads also add to the social cost for utility construction. The secondary roads are often used as detour roads during construction on a main road. Since these roads are not designed specifically to take on the heavy traffic, they tend to get damaged. This sort of damage can be in the form of wearing of asphalt, potholes, and pavement collapse. For short duration of projects, like a day or two, these costs are insignificant. But for longer durations, these damages have to be added to the total estimate of the project costs.

The cost of restoring a pavement per foot has to be collected from the public entity overseeing the work at the particular locality. Most of the time such costs cannot be easily recognized as this kind of work is done as an emergency, and would not be a part of a regular routine or periodic restoration of pavement. The following formula can be used in estimating the cost of pavement restoration:

$$\textit{Pavement Restoration Cost} = (\textit{Restoration cost/foot}^2) \times (\textit{Number of feet})^2 \qquad [3]$$

This cost pertains to the cost of restoration some years after the original completion of the utility work, and is not the same as the cost included in the bid proposal or the initial estimate of the utility construction work. In the absence of relevant data for estimating this cost, a relative positive trend could be associated with the trenchless method of pipe installation (Boyce & Bried, 1994).

2.4.5. Vehicular Wear

Additional social costs can be in the form of vehicle wear and tear, such as damage to the engine, transmission, and tire wear, due to the detour roads. Improper techniques used in restoring the pavements often result in potholes, which damage the shocks, muffler, tires, axle and chassis of the vehicles. According to a 1997 report by the Environmental Working Group and the Surface Transportation Policy Project, nearly $4.8 billion is spent each year to repair damage to Americans' cars resulting from run-ins with potholes, utility cuts and other dangerous road conditions (Soucy Insurance, 2001).

Cost of the potholes cannot be readily estimated, as they are not visible for a significant period of time. One way of estimating the cost of repair due to potholes is to contact the insurance companies and acquire the total amount of claims paid by the company for minor damages during the period of construction. A detailed analysis of the claims, if available, might yield significant data in the number of claims that originate from damage to the chassis due to potholes or other related defects in the surface pavement. If such data were available these costs could be used in calculating the cost of damage and repair due to potholes.

Cost of Damage due to Potholes[2] = (Average amount of claim) x (Number of claims)[4]

Vehicular wear can be estimated using the depreciation value of the additional miles traveled by the vehicle. Also the cost for repairing the damages in the vehicle due to the potholes, reported for the duration of the project, can also be accounted in the estimate to

[2] During the time of writing this proposal no significant amount of information was available in calculating damages due to potholes. An interview and discussion with Mr. P. R. Swaroop of CIDC (Construction Industry Development Council of India) and Dr. A. K. Sarkar, Chairman, Indian Society for Trenchless Technology (IndSTT) yielded this formula.

get an approximate cost of vehicular wear. Depreciation value of vehicles can be estimated using the following formula:

Depreciation Cost = (Average depreciation cost/mile) x (Additional miles traveled) [5]

The above costs are incurred on a personal level, meaning for the individual person, rather than the cost incurred by a public agency or government. However, individual or public, these costs have to be assessed in estimating social costs for traffic disruption.

2.4.6. Loss of Revenue

Loss of revenue is incurred by business in the shops affected due to the utility construction. Utility construction in urban areas, such as business plazas and near shopping malls, can create unrest among the customers visiting those places. Initial studies have shown that people tend to avoid roads with lane closures due to utility construction. Loss of customers transforms to a loss in income for the shops. For example, if a retail store situated on a primary road in a city makes $1000 a day, and in the event of a utility construction on that particular road loses $200 a day for the duration of the project, the number of days multiplied by the number of dollars in loss per day, gives the total revenue loss for that store. This cost should be added to the original construction cost to determine the life-cycle-cost of the project. The loss of business can be estimated using the following formula:

Cost of Business Loss = (Average dollar loss /day) x (Duration of project in days) [6]

The loss of revenue on the business in a particular location need not be detrimental in estimating the loss of revenue. Often, the business profit or loss revolves within the community in the area of construction. Loss of business in one area due to construction would only transfer the potential clients or consumers to another shop or business within the area. In case of a specific shop or kind of business that is very specific to the locality with the lack of competition in the vicinity would mean a business loss for that particular kind of business. For example, if a particular store sells a particular type of clothes, which is a favorite among the surrounding counties, a road closure in the area due to construction forcing the shop to close down for a particular duration would mean a loss of revenue for the community. In calculating the loss of businesses, care must be taken in locating a few other shops having the same kind of business within the vicinity. A coffee shop on a lane undergoing construction work might lose its business, but another shop on the parallel line would gain. This is a transfer of consumers rather than a complete loss as explained earlier.

There is also a risk of complete closures of shops and businesses in areas with successive utility construction work. Such construction would mean a complete loss of revenue for the shops as well as for the local governments.

Revenue loss also includes two other costs. Boyce and Bried suggest the following as a loss of revenue to the community:

2.4.6.1. Parking Meter Revenue

Parking meters along the road with the utility construction have to be closed for the duration of the project. This would effectively mean loss of revenue for the society in terms of the money generated for the public body. The loss of revenue on parking meters can be estimated using the following formula (Boyce & Bried, 1994):

Loss of Parking Meter Revenue = (Meter rate) x (Number of meters) x (Operational hours per day) x (% Occupancy) x (Project duration in days) ***[7]***

2.4.6.2. Parking Ticket Revenue

Revenue generated on the tickets issued for parking violations or expired meters also accounts for a loss to society. The loss of revenue on expired meters can be estimated using the following formula (Boyce & Bried, 1994):

Loss of Parking Ticket Revenue= (Ticket fine) x (Frequency of ticketing/day) x (Project duration in days) [8]

Duration of the project determines the amount of revenue loss. For a shorter duration the loss might be minimal, but for longer durations of construction the loss of revenue would be greater.

2.4.7. Sales Tax

Almost all the states in US carry a certain amount of sales tax on commodities sold. Infact everyone ends up paying a certain amount of money to the government in terms of sales tax. This money in theory is used entirely for the benefit of the citizens, or at least that is one theory, and is important in terms of the dollar value to the government. But nobody wants to pay more than what is required as sales tax. In case of lane closures and traffic diversions due to utility construction, additional funds spent on gas for vehicles and wasted during waiting in traffic, transforms to additional tax paid in purchasing the fuel. This is a personal loss to the individual, which might be beneficial for the government.

This whole situation changes while considering loss of revenue to shopping areas, affected due to utility construction. The loss of business in these areas means loss of money to the government in terms of sales tax. The better the sales the more sales tax generated by any shop or business entity. As explained earlier, in the event of utility construction on the access road to the business area, the amount in terms of loss is very significant.

In estimating social costs, care has to be exercised in calculating the sales tax. While considering an individual, sales tax would mean a loss to the individual. But while calculating the same for any local governing body, the amount of sales tax lost due to the loss of business would be detrimental in terms of the revenue loss. The loss of sales tax can be estimated using the following equation (Boyce & Bried, 1994):

Loss of Sales Tax to Local Government = (Total sale receipts) x (Sales tax percentage) x (Project duration) x (Percentage of lost sales) ***[9]***

The loss of revenue in terms of sales tax for business, would be a loss to the local government, assuming that the customer has to go outside the community to shop or purchase goods and household items.

2.4.8. Loss of Productivity due to Noise

Loss of productivity can be associated with the noise pollution generated during the construction activity. Most of the time, the effect of noise pollution on people is impossible to quantify. Offices with soundproof enclosures tend to reduce the noise pollution and hence the productivity is not affected. People behave differently to noise pollution, some can continue working, while others call it a day and go home, unable to sustain the noise. If data were available the following formula can be used to estimate the loss of productivity (Boyce & Bried, 1994):

Cost of productivity = (Time lost/day) x (Number of persons) x (Value of time) x (Project duration in days) ***[10]***

Value of the time is normally the hourly pay of the person and the time lost would be estimated in hours lost per day due to the noise pollution.

2.4.9. Dust and Dirt Control

Dust and dirt control are affected by the number of openings in the building or enclosure and the number of people moving around the office during the construction. One way of estimating the cost of dirt and dust control is to calculate the additional time spent by a janitor of a facility in cleaning. The cost would be derived from the additional pay to the janitor. The following formula can be used to estimate the cost of dust and dirt control (Boyce & Bried, 1994):

Cost of Dirt and Dust Control = (Increased cleaning time/day) x (Hourly pay rate) x (Number of units impacted) x (Project duration in days) ***[11]***

2.5. Conclusions

This chapter briefly discussed various available techniques in trenchless technology and the costs associated in calculating the social costs for utility construction. Also, this chapter focused on the various categories within the social costs for calculating the cost of traffic disruption due to utility construction. Each of the above mentioned parameters contribute significantly to the social costs associated with traffic disruption. Costs associated with traffic disruption have to be identified within these costs. These costs have to be calculated for each a given site to estimate the cost of traffic disruption due to utility construction. Once each of the parameters is estimated the cost of traffic disruption for the project could be achieved by adding these costs to the original estimated cost of construction. Such an estimate would be helpful in determining the unforeseen costs that often result in project over runs in terms of money and time.

3. METHODOLOGY

The last chapter discussed the various techniques of trenchless technology and the costs associated with each of the factors considered in calculating the social cost of a utility construction project. This chapter presents the methodology used to achieve the specified objectives.

The main aim of this research is to present an analysis of the various costs involved in utility construction using open-cut method and trenchless method of pipe installation. This is achieved in the following steps:

1. Collect information on the existing methods and practices.
2. Understand and document the traffic flow rate and pattern through case studies.
3. Understand and estimate the various costs involved in utility construction for the case studies.
4. Develop a flow chart and prediction model to estimate the various costs involved for traffic disruption in utility construction.

This research is built around these four steps and is limited to the constraints identified in the scope of work.

3.1. Methods and Tools for Objectives

In the following sections, the methods used to achieve the aim of the research in establishing a direct method or comparing and estimating the various costs for traffic disruption for utility construction are discussed. The author also documented two case studies to understand the traffic flow rate and pattern for utility construction. Information collected during the case studies will also be discussed.

3.2. Methodology for Objective 1

The first objective of this research is to present an overview of the various trenchless construction methods (and costs) being used for utility construction. This is done in two steps:

1. Study of the various existing practices and costs involved in both trenchless and open-cut methods of utility construction. Studying the existing research papers or articles on trenchless construction methods as well as various magazines involving trenchless technology helped in understanding the methods and applications along with the associated costs for trenchless technology. A few of the references include Engineering News Record (ENR), *Trenchless Technology Magazine*, *Underground Construction Magazine*, No-Dig Conference *Proceedings*, and ASCE Pipeline Conference *Proceedings*.

2. Various personnel involved in underground utility construction were contacted to collect data on the methods, practices, costs and applications of trenchless technology. Members of the Center for Underground Construction Research and Education (CUIRE) at Michigan State University were contacted to get information about the existing or new practices of installing pipes or a utility line.

3.3. Methodology for Objective 2

The second objective of this research is to study and document the traffic flow rate and pattern during utility construction and analyze the impact of utility construction on the traffic flow. This is done through selection of two case studies within the limitations set during the scope of work. Traffic flow pattern and traffic flow rate were analyzed for two sites used as case studies. Data collected during the case studies was used in developing the prediction model.

3.3.1. Traffic Documentation

Due to the time and resource constraints during this research, only two case studies were chosen to analyze the data for developing a prediction model. However, these case studies yielded significant information in terms of the traffic flow rates and traffic flow patterns. The following are the sites chosen for case study:

- Site 1: Installation of telephone cables across North Shaw Lane, Michigan State University, Michigan.
- Site 2: Installation of 100-foot long storm water drain at University of Florida, Gainesville, Florida.

Traffic flow pattern for the case studies chosen for study was documented using existing information from previous study and on-site documentation. Traffic is documented for two scenarios:

1. Total Road Closure or Detour
2. Partial Road Closure or Lane Blockage

During total road closure, the traffic is routed through a detour road, since the road is completely closed to traffic. During partial road closure, the traffic movement is restricted to one lane or two depending on the size of the road. As a general rule, for utility work across the street, the road is completely closed to traffic. For utility construction running parallel to the road, the traffic is restricted to a single lane. The following section discusses the documentation for both the scenarios.

3.3.1.1. Total Road Closure

Total road closure generally occurs for utility work across the streets for open-cut method of pipe installation. Traffic is routed through a detour road, and the road will be opened after the completion of the utility work. To better understand the effect of road closure on traffic, the traffic flow pattern has to be documented. During case studies, traffic was documented for two categories:

- Traffic Flow Pattern
- Traffic Volume

3.3.1.1.1. Traffic Flow Pattern

Traffic flow pattern requires the understanding of movement and direction of traffic on the particular road of study. The study helps in establishing the direction and pattern of traffic flow and possible congestion areas on the road. The study is done in the following stages:

a) Method of Study

Traffic flow pattern was observed for the site chosen for the study. The regular pattern of traffic flow was studied. Traffic was observed while standing at the intersection and taking notes. In addition to the observation on the site, previous traffic studies and pattern analysis studies were studied. The civil engineering department and since the case studies were conducted at university campuses, campus traffic study departments for the respective areas of study were consulted to get data. Study was done in two phases:

Phase 1: Before Construction

Traffic flow on the road under consideration for utility work was documented prior to the commencement of construction work. This gave an estimate of the traffic pattern before construction and is important in understanding the areas of congestion. The flow pattern was documented in the form of a layout to better understand the flow.

Phase 2: During Construction

Traffic flow during construction was observed by studying the detour provided for the regular traffic. This helped in understanding the disturbance in traffic pattern due to the construction. The study was carried out in the following steps:

a) Documentation

The traffic flow pattern was documented in the form of maps and traffic flow pattern for the site chosen for study. The maps provided flow pattern for traffic before construction and during construction.

b) Analysis

Traffic flow patterns before the construction and during the construction were studied and the additional miles each vehicle has to travel due to the detour were determined.

The additional miles were calculated using the following formula:

Additional Distance = Original distance – New distance due to construction

The distances were calculated from plans obtained from the respective university physical plant and related departments dealing with such information.

3.3.1.1.2. Traffic Volume

The traffic flow rate was documented for the two case studies chosen under this research. The number of vehicles flowing through the road before and during construction are studied and documented. Amount of traffic flow for each site was documented in three stages:

a) *Method of Study*

- Amount of traffic flowing through the road was obtained from existing studies.
- In addition to the existing data, number of vehicles flowing through the road was counted by standing at the site.
- When no existing data was available data collected on site was used in calculating the traffic volume.
- In case the data collected during study did not match with the data collected from previous studies, data obtained from previous study was used in estimating the number of vehicles flowing through the road.
- Existing data on the traffic volume was obtained from previously done studies or from departments specializing in such study.

b) Documentation

- Number of vehicles obtained during the study was noted and the volumes were documented in the form of charts or tables.

c) Analysis

- The total number of vehicles was determined by multiplying the number of vehicles per day with the duration of the project. The following formula was used:

Total Number of Vehicles = Number of vehicles per day x Duration of project

- The above equation gave the total number of vehicles flowing through the road before construction, which were also the number of vehicles disrupted due to construction.

3.3.1.2. Partial Road Closure or Lane Blockage

Partial road closures occur during the construction of utility work that does not require total or complete closure of road. A detour is not required to allow the traffic flow, but rather one or more lanes of the road are closed for construction and traffic is regulated through the remaining open lanes. Most often during partial road closures, areas of congestion can be observed at the start and end of the construction area. The traffic flow pattern is studied in the following stages:

1) Method of Study

Traffic flow pattern was observed for the site chosen for the study. The regular pattern of traffic flow was studied. Traffic was observed and documented at the intersection. Study was done in two phases:

Phase 1: Before Construction

Traffic flow on the road under consideration for utility work was documented prior to the commencement of construction work. The flow pattern was documented in the form of a layout to better understand the flow.

Phase 2: During Construction

The traffic flow during construction was observed by studying the lane closure and traffic regulation procedure.

2) Documentation

The traffic flow pattern was documented in the form of maps and traffic flow pattern for the site chosen for study. The maps provided traffic flow pattern before construction and during construction. The traffic flow for each category, before and during construction, was documented in three stages:

Method of Study

- Amount of traffic flowing through the road was obtained from existing studies.
- In addition to the existing data, number of vehicles flowing through the road was counted by observing the traffic flow.
- When no existing data was available data collected on site was used in calculating the traffic volume.
- When data collected during study did not match the data collected from previous studies, data obtained from previous study was used in estimating the number of vehicles flowing through the road.

- Existing data on the traffic volume was selected from previous studies or from local authorities.

Documentation

- Number of vehicles counted during the study was noted and were documented in the form of charts or tables.
- The waiting time for a particular vehicle, due to lane closure, was observed and recorded.

Analysis

- The total number of vehicles was determined by multiplying the number of vehicles per day with the duration of the project. The following formula was used:

  Total Number of Vehicles = Number of vehicles per day x Duration of project in days

- The above equation gave the total number of vehicles flowing through the road before construction, which are also the number of vehicles disrupted due to construction.
- The waiting time of vehicles was calculated using the following formula:

  Total Waiting Time = Waiting time of cars / hr x Number of hours

3.4. Methodology for Objective 3

The third objective for this research was to estimate the cost of traffic delay using the information attained from the traffic flow and other related studies. The cost for traffic disruption for utility construction was achieved using the formulae derived from literature. The following costs were calculated based on the information from the site studies:

- **(A)** Cost of Fuel, Equation [1] on page 21
    - Was estimated from the additional miles calculated during the traffic flow analysis.
- **(B)** Cost of Delay, Equation [2] on page 24
    - Was estimated in two methods:
        - For detour: was estimated based in the additional time required in traveling the detour.
        - For lane closure: was estimated based on the time spent in waiting due to lane blockage.
- **(C)** Depreciation Cost, Equation [5] on page 29
    - Was based on the national average depreciation cost and the additional miles traveled due to the detour.
- **(D)** Cost of Business Loss, Equation [6] on page 29
    - Business establishments along the road under observation were contacted.
    - Information on the daily loss due to construction was obtained in person based on a questionnaire. Please refer to Appendix A for the questionnaire. Appendix G contains the confidentiality form used for the survey.
    - The total loss of business per day was a summation of the loss per shop.
- **(E)** Loss of Sales Tax to the Local Government, Equation [9] on page 33
    - Business establishments along the road under observation were contacted.

- Information on the daily loss of sales due to construction was obtained in person based on a questionnaire (Please refer to Appendix A).
- The total loss of sales per day is summation of the loss per shop.
- The loss of sales for a local government multiplied with the sales tax percentage gave the loss in terms of sales tax.
- The loss in terms of sales tax for the individual is also the wasted fuel per car, which is a loss to the person using the road. This factor would be a gain to the local government.

- The final cost for traffic delay was derived by summing up all the above items or categories:
    - **Final Cost = A + B + C + D + E**
- The final cost was estimated for both open-cut method of pipe installation and trenchless method of pipe installation.
    - The above-mentioned procedure for estimating the cost of traffic disruption was performed for both methods of installation.
    - Wherever necessary, estimators or project managers of respective firms were contacted by phone or in person to obtain information on the number of days or duration of the project.
    - For sites utilizing open-cut the duration of the project was evident and clear from the number of days of road closure.
    - For the same site, for alternate trenchless method, one of the advisory board members of the Center for Underground Infrastructure Research and

Education (CUIRE) was contacted to get an estimate of the duration of the project.

- The trenchless method of pipe installation was assumed as a generic method with no detail to a specific method in particular. All the trenchless options involve little or no footprints, which would make it fair to categorize them as trenchless methods for use in comparison against the open-cut method of pipe installation.

3.5. Methodology for Objective 4

The fourth objective or this research was to prepare a flow chart or model for estimating the costs due to traffic disruption. This was done in the following steps:

- A flow chart with the above formulae was drafted to reduce the burden to input all the data.
- The flow chart provided a method to calculate the social cost for traffic disruption, which would be handy for contractors and engineers.
- Charts and models such as graphs were developed that would give a rough estimate on the cost of traffic disruption as applicable for similar projects.
- Individual cost per each sector was presented in percentages and shares.
    - The individual sectors included personal costs, costs to the government, and costs to various agencies.
    - Costs are categorized for each of the above-mentioned sectors.
    - The most affected category was identified and suggestions were made to improve the construction method for each site.

3.6. Summary

This chapter presented the tool and methods used to achieve the aim of the research set it chapter 1. This chapter also presented the methods used in collecting the data required in developing the flow chart and prediction model. The two case studies required for understanding the traffic flow rate and traffic flow pattern were also identified. The next chapter presents in detail the data collected during the case studies.

4. DATA COLLECTION AND ANALYSIS

In chapter 3, the methods and tools to achieve the goal and objectives of this research were presented. This chapter uses those tools and methods in presenting the data and compiling the information. Also, the various costs discussed in chapter 3 were calculated using the information from the data collection. Finally, a flow chart is presented using the information collected to predict the cost associated with traffic disruption.

4.1. Case Studies and Data Collection

The case studies were selected based on the scope of the project and the time constraint of the project. Keeping in view the scope of the project the case studies were limited to small roads. Working on a time constraint, the case studies presented were chosen to best reflect the scope and limitations of the project. Under each case study, the actual method of installation was documented and the traffic flow patterns were established. The alternate method was chosen amongst the trenchless methods that best suit the purpose. Each of the trenchless construction methods explained in chapter 2 was analyzed for each construction site. Utility contractors and members of Center for Underground Infrastructure and Research and Education (CUIRE) were contacted to assist in analyzing the available methods.

4.1.1. Site 1: Installation of Telephone Cables across North Shaw Lane, Michigan State University (MSU), East Lansing, MI. (April 30 – May 2, 2003)

North Shaw lane is a primary road leading to various buildings for the vehicles entering Michigan State University (MSU) from Hagadorn road. Traffic was limited to one-way towards west on this road, which leads to Farm Lane. Most of the commuters are MSU employees and students. University traffic included cars among other vehicles and also buses belonging to the Capital Area Transportation Authority (CATA) that operate in and around the university. This road is the main and only exit to the buses originating from a newly constructed terminal on the road. Figure 3 provides site layout of the site under study.

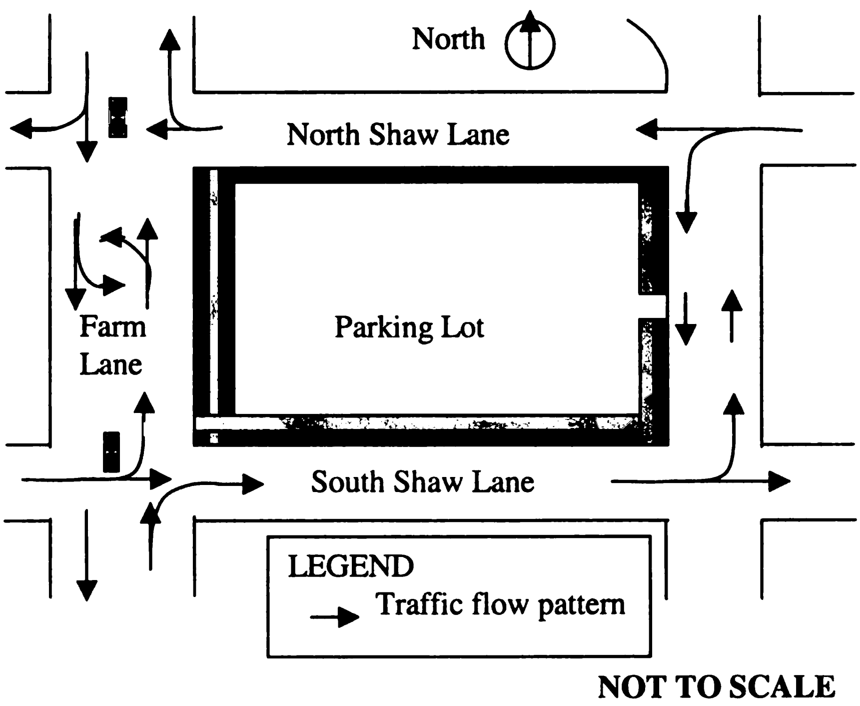

Figure 3: Traffic Flow Pattern before Construction, MSU

The utility work involved the installation of telephone cables and optical cables for Michigan State University. The depth of installation based on the survey was placed at 5 ft below the surface. The cables have to be installed about 250 ft of length from an access pit at the north side of the road all the way across to the north side of south Shaw lane. Figure 4 shows the location of the access pits for the installation.

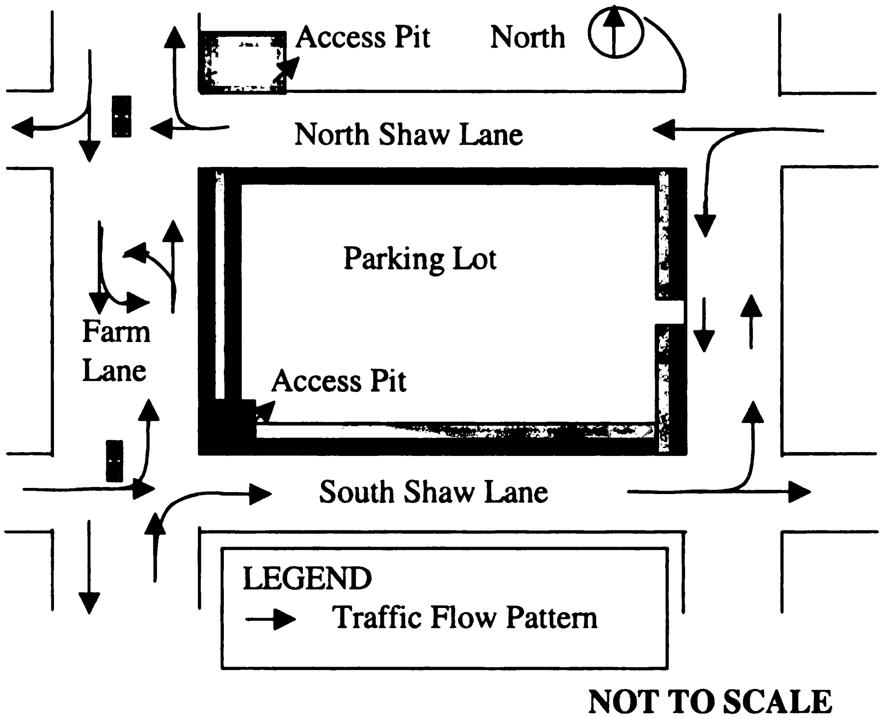

Figure 4: Traffic Flow Pattern during Construction, MSU

4.1.1.1. Original Method

The original method used for installing the cables was horizontal directional drilling. As mentioned earlier, this method consisted of boring a small pilot hole along the path of the proposed utility line and pulling the utility line back along the same line. This was a trenchless method of utility construction and does not require surface excavation. An entry pit was excavated at the beginning of the utility line and an exit pit was excavated at the far end of the line. The access pits, as they are termed, were located outside the road width and cause no disruption to the traffic. Figure 5 illustrates the location and the drilling path of the original method of construction.

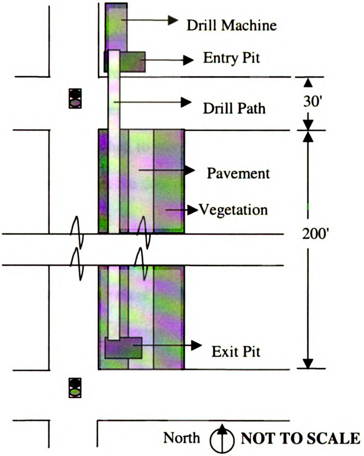

Figure 5: Utility Construction Activity, MSU

There was no closure or detour required for carrying out the construction. During the duration of the project the road was open to traffic. As required for any construction activity, caution signs were placed along the road. The project duration was 3 days, starting on April 30, 2003 and was completed on May 2, 2003. Traffic was not disturbed and there was minimal surface disruption. No heavy equipment was required to install the pipe, except the use of a backhoe for a brief period to excavate the access pits.

Although a bit of congestion was noticed during the construction period, it could not be directly attributed to the construction activity, as there was also a traffic signal located next to the site. Altogether around 332 vehicles moved without any delay. The MSU Civil Engineering Department provided the data on number of vehicles. This figure is reasonable considering it is an average per day for the annual traffic rate. Since there was no detour required, the vehicles had to travel no extra distance to reach their respective destinations. Table 8 summarizes the data obtained for traffic flow and volume in using the original method of utility work.

Table 8: Analysis of the Data Collected From Site

Description	Quantity
Original Distance (in miles)	0.3213
New Distance (in miles)	0.3213
Additional Distance (in miles)	*0*
Number of Vehicles/day	332
Duration of the Project (in days)	3
Total Number of Vehicles	*996*

The data collected during this case study was utilized in estimating the cost of traffic disruption for this type of utility construction method.

4.1.1.2. Alternate Method

For comparison between trenchless and open-cut methods of pipe installation, the open-cut method was chosen as the alternate method. The open-cut method requires direct installation of the proposed utility line in an excavated trench. For the sake of this study, it was assumed that all other site restrictions applicable for the original method of utility work are applicable to the alternate method. Figure 6 provides information on the installation of the proposed utility line using open-cut method.

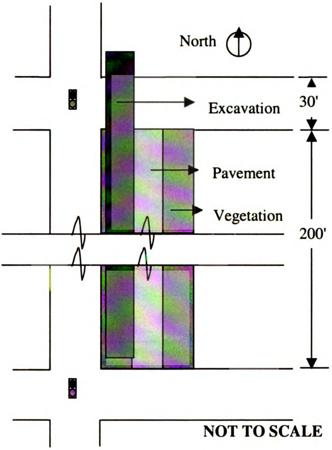

Figure 6: Utility Construction Activity, MSU

For installing the utility line, a trench had to be excavated from north side of North Shaw Lane, across the parking lot. This included excavation of the pavement and sidewalk. North Shaw Lane had to be closed for the duration of the project and a detour had to be provided. Based on previously available information, the least detour distance would have been going around Bouge Street onto Wilson and merging into Farm lane to get to the destination. Figure 7 illustrates the detour route and traffic pattern for utility work using the open-cut method of pipe installation.

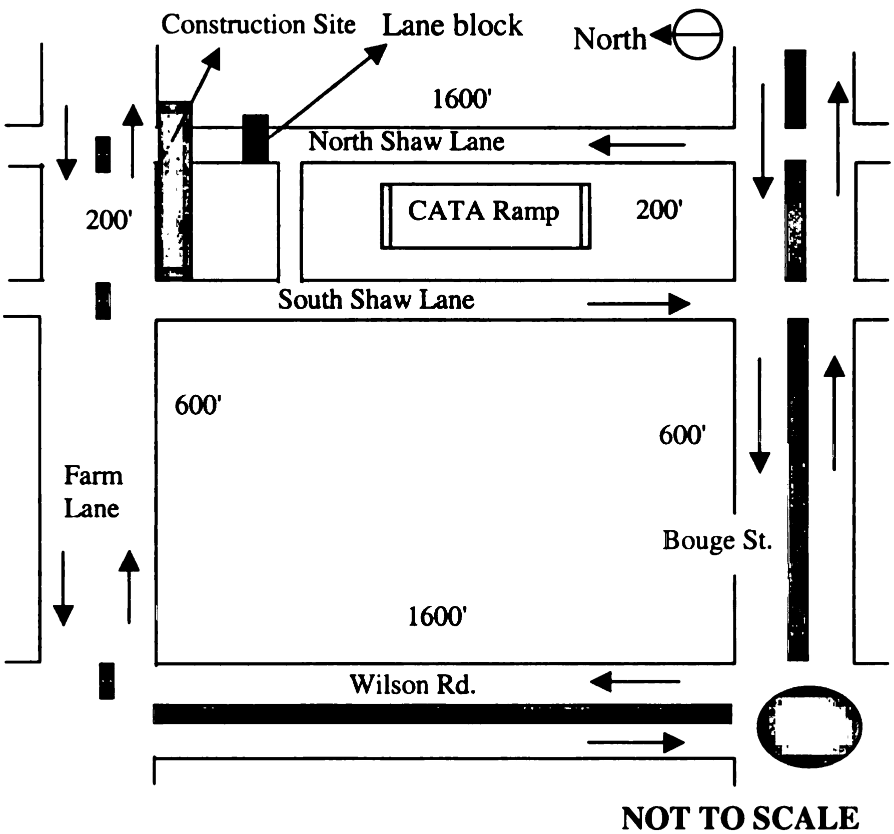

Figure 7: Detour Pattern and Dimensions in Using Open-Cut Methods, MSU

In case of a detour, almost all the vehicles flowing through North Shaw Lane had to use Bouge and Wilson to get to Farm Lane. The volume of traffic that would have required detour was the same amount of traffic using North Shaw Lane in case of no detour. The duration of the project while using the open-cut method was calculated using Means Building Construction Cost Data (2002). The labor-hours required for the crew were estimated for each of the activities and the total duration of the project was calculated. Appendix B presents calculations on duration for open-cut method of pipe installation. Table 9 presents the data collected while assessing the alternate method.

Table 9: Analysis of Data Collected from the Site for Open-Cut Method

Description	Quantity
Original Distance (in miles)	0.3213
New Distance (in miles)	0.662879
Additional Distance (in miles)	*0.341579*
Number of Vehicles/day	332
Duration of the Project (in days)	6
Total Number of Vehicles	*1992*

4.1.2. Site 2: Utility Construction over Union Road, University of Florida (UFL), Florida (December 16 -- December 20, 2003)

The project was the installation of a 12-inch diameter, 100-foot long storm water pipe at 5-foot depth, on Union Road on the University of Florida campus. The construction was carried out parallel to the road during the month of December 2002 for 5 days. Figure 8 shows the Union Road location of the construction site.

Union road is one of the primary roads leading to the university campus from the South West 13th main road. Most of the commuters using this road were coming form the various residential units located around the vicinity of the campus. Union Road leads to the various departments in the university. Although no buses were using this road, a lot of vehicular movement was observed over this road.

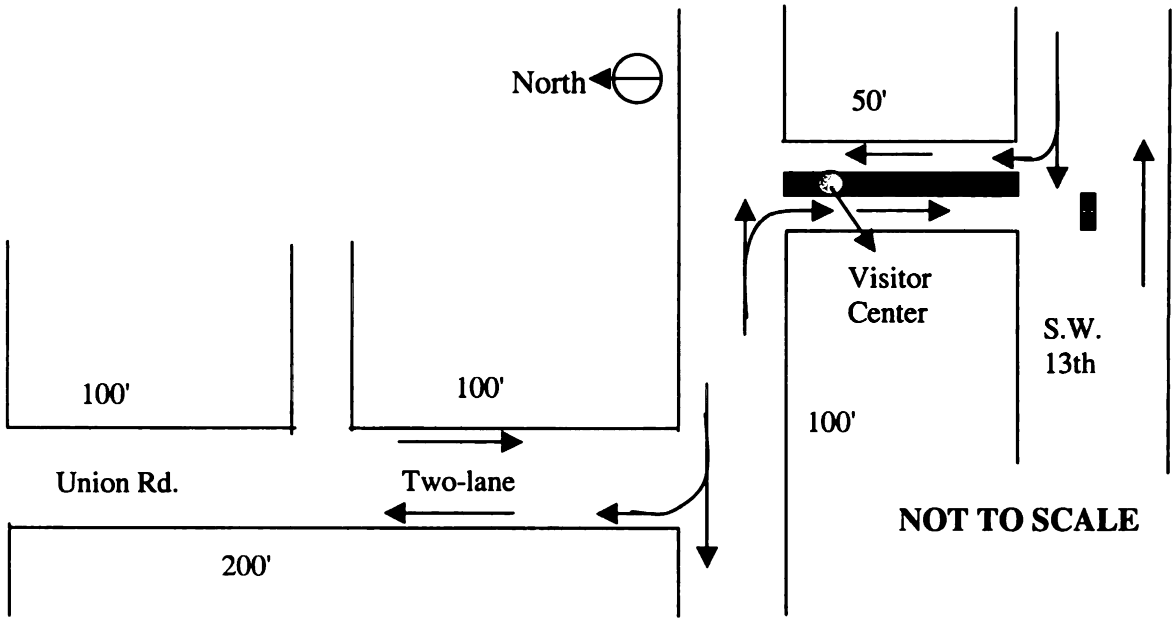

Figure 8: Traffic Flow Pattern before Construction on the Union Road, UFL

4.1.2.1. Original Method

The original method used for installing the storm water pipe was the open-cut method. The pavement was excavated for the entire 100 ft length to install the pipe in place. Union road is a two-way traffic road with two lanes leading each way. During construction, the road was partially closed to traffic. Only one lane was open to Northbound and Southbound traffic during the duration of the construction, limiting the movement of traffic on this road. Vehicles had to wait at both the ends of the construction area, and flagmen were controlling the movement of traffic. Figure 9 illustrates the construction activity and waiting areas for cars during the construction period.

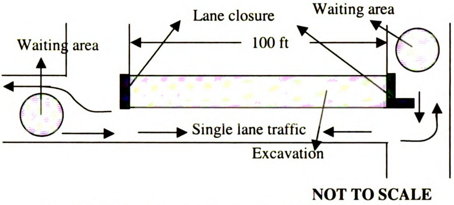

Figure 9: Construction Site for Open-Cut Method, UFL

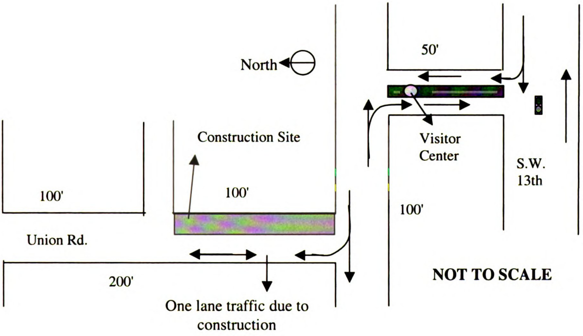

Figure 10: Traffic Movement during the Construction Activity, UFL

During the construction, one lane of traffic was open to both traffic flows, alternating one direction for time period. Waiting spaces were created on either side of the road to facilitate the movement of the vehicles. Each vehicle had to wait for a period of time before it was allowed to pass through the road. Figure 10 illustrates the movement of traffic for the duration of the construction activity.

The duration of the project was 5 days, carried out during December 16, 2002 until December 20, 2002. A total of 128 vehicles per day (8 hours) were affected due to the construction activity. Each car had to wait for an average time of 2 minutes before they were allowed to pass. Table 10 represents the data collected from the site.

Table 10: Analysis of the Data Collected During Case Study

Description	Quantity
Average Waiting Time (in min)	2
Number of Cars/Day	128
Speed Limit (mph)	20
Fuel Consumption (mpg)	22
Duration (in days)	5

During the case study, no information was available for the traffic volume on the Union Road. The author observed data on the traffic flow rate and pattern during the construction period by counting number of vehicles flowing through the road. Then the total number of vehicles passing through the road was counted and the respective waiting times were noted. The low volume of traffic flowing through the road was attributed to the fact that the school was closed for Christmas and New Year holidays during the construction period. The vehicle count was from the general traffic entering the university for the regular work and a few prospective students. The traffic movement was also hampered during the excavation process with truck movement hauling the dirt. This meant more waiting time during construction, and was reflected in the average waiting time per car.

4.1.2.2. Alternate Method

Auger boring was chosen as the alternate method of construction for this site. Because of the versatile nature of horizontal auger boring to be carried out in a variety of soil conditions and the ease of mobilization and setup, this method was chosen as the alternate method. Select members of Center for Underground Infrastructure Research and Education (CUIRE), were consulted for collecting information on the best alternate method suitable for this project. The industry personnel were also asked for the duration of the project, if the alternate method is used, considering all other site restrictions. The duration of the project starting form the setup to decommissioning was suggested at 4 days. Figure 11 illustrates the setup of the alternate horizontal auger boring method for the proposed site.

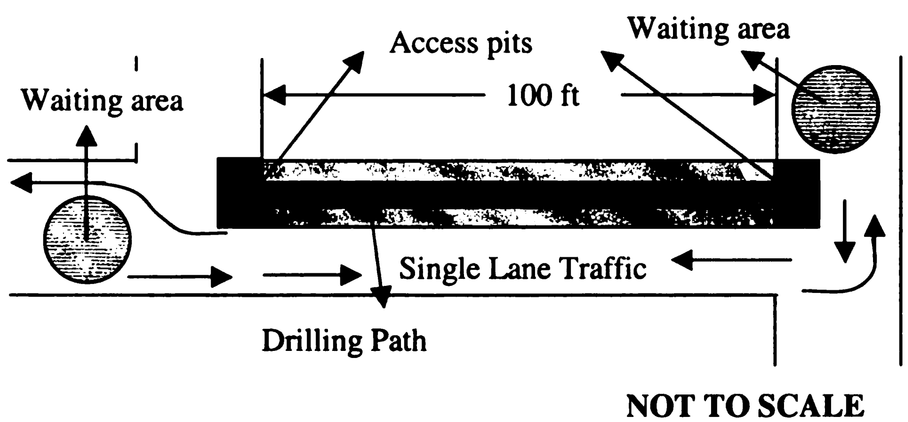

Figure 11: Site Layout for the Alternate Method of Installation, UFL

Horizontal auger boring method requires, as with any other trenchless method, an entry pit and an exit pit. As explained in chapter 2, the process requires setting up auger boring machine in the entry pit. Therefore, the entry pit must be excavated at the start of the proposed utility line. An exit pit is also required at the end of the proposed utility line to facilitate the connection of the new line to the old line. The entry pit and the exit pit would be located at the two ends of the proposed line with 100 ft apart between them.

Considering the pit excavation the traffic movement would be mostly the same for the alternate method as in the original method. With the location of the two access pits on either side of the line, the logistics would remain the same for regulating the traffic. Each car would have to wait for a specific time before it was allowed to move ahead. Waiting spaces have to be created to facilitate such a movement of the vehicles during construction. Since, the traffic movement would remain the same; the traffic flow pattern would be the same as for the original method. Figure 10 is used to illustrate the traffic movement during construction. Data collected in using the alternate method is summarized in Table 11.

Table 11: Data for the Alternate Method of Pipe Installation

Description	Quantity
Average Waiting Time (in min)	2
Number of Cars/Day	128
Speed Limit (mph)	20
Fuel Consumption (mpg)	22
Duration (in days)	4

In establishing the traffic volumes and wait time for the vehicles, it was assumed that the same logistics for open-cut method would prevail for trenchless method. Since the alternate method of utility construction is not implemented on the site, the waiting time and volume of traffic were assumed to remain the same as that in open-cut method. Calculations in the following sections were drawn from these assumptions.

4.2. Cost of Traffic Disruption

The formulae suggested in chapter 3 were used to estimate the cost of traffic disruption for both the case studies. The data collected during the case studies was also incorporated into the formulae to estimate the cost for each of the category suggested.

4.2.1. Cost of Fuel

Equation [1] on page 21 was used to calculate the cost of fuel as follows:

Cost of Fuel per car = (gallon/mile) x (additional miles) x (cost of fuel/gallon)

Total cost of Fuel = (cost of fuel/car) x (number of cars/day) x (duration of the project)

To calculate the cost of fuel for lane blockage, the formula was modified as:

Cost of fuel per car = (waiting time, min) x (miles/minute) x (gallons/mile) x (cost/gallon)

Total cost of fuel = (cost of fuel/car) x (number of cars/day) x (duration of the project)

It is assumed that the fuel consumption for waiting time is approximately equivalent to moving at a speed of 20 miles/hour (0.33 mils/min). Table 12 summarizes the cost of fuel for traffic disruption due to utility construction. Appendix C presents cost calculations.

Table 12: Cost of Fuel for Traffic Disruption Due To Utility Construction

Category	MSU	UFL
Original Construction method	0	27.38
Alternate Construction Method	43.43	21.90

4.2.2. Cost of Delay

The cost of delay per person was established as 50 percent of his or her value of time in dollars, if the individual is the driver, and 35 per cent of the value, if the person is a passenger (VTPI, 2003). In estimating the delay costs, it is assumed that one person is traveling in a car. The passenger is not accounted for in calculating these costs. Equation [2] on page 24 is used to calculate the cost of delay as follows:

Detour:

Cost of delay/car= (time/mile) x (additional miles to travel) x (value of time in dollars)

Total cost of delay = (delay cost/car) x (number of cars/day) x (duration of the project)

Lane blockage:

Cost of delay = (average waiting time/car) x (value of time in dollars)

Total cost of delay = (delay cost/car) x (number of cars/day) x (duration of the project)

Table 13 summarizes the cost of delay due to utility construction. Please refer to Appendix D for cost calculations.

Table 13: Cost of Delay Due To Utility Construction

Category	MSU	UFL
Original Construction method	0	128
Alternate Construction Method	169.3	102.4

4.2.3. Depreciation Cost

The depreciation cost is calculated based on the number of miles a car has traveled. Equation [5] on page 29 is used in estimating the depreciation cost. The formula is as follows:

Depreciation cost = (Average depreciation cost/mile) x (additional miles traveled)

Table 14 summarizes the depreciation cost due to utility construction. Please refer to Appendix E for cost calculations.

Table 14: Depreciation Cost Due To Utility Construction

Category	MSU	UFL
Original Construction method	0	N/A
Alternate Construction Method	81.67	N/A

Since the vehicles did not actually travel any greater distance for site 2, there is no difference in depreciation cost. The same is reflected in Table 14.

4.2.4. Business loss

Although there was some presence of business within the vicinity of the construction site, there was no loss reported to the business community due to the method of construction. Both sites have reported no loss to their business and hence no cost could be attributed to the method of construction.

4.2.5. Sales Tax

Sales tax, as suggested in chapter 2, was calculated based on the revenue generated from sale of goods. With the business establishment reporting no loss on their daily income, the only sale was that of the fuel. Formula [9] on page 33 was used to calculate the sales tax.

Additional sales tax = (total cost of fuel) x (sales tax)

Table 15 summarizes the loss of sales tax due to utility construction. Please refer to Appendix F for cost calculations.

Table 15: Loss of Sales Tax Due To Utility Construction

Category	MSU	UFL
Original Construction method	0	1.64
Alternate Construction Method	2.61	1.31

4.2.6. Total Cost For Traffic Disruption Due To Utility Construction

The cost of traffic disruption would be the sum of all the above estimation. The cost of traffic disruption would be:

(Cost of fuel) + (cost of delay) + (depreciation cost) + (additional sales tax)

MSU

Trenchless method

TOTAL = 0 Dollars + 0 Dollars + 0 Dollars + 0 Dollars = **0 Dollars**

Open-cut method

TOTAL = 43.43 Dollars + 169.32 Dollars + 81.67 Dollars + 2.61 Dollars = **$297.08**

UFL

Open-cut method

TOTAL = 27.38 Dollars + 128.00 Dollars + N/A + 1.64 Dollars = **$157.02**

Trenchless method

TOTAL = 21.90 Dollars + 102.4 Dollars + N/A + 1.314 Dollars = **$125.614**

The above cost estimates provide information on the cost of traffic disruption for each method of utility construction used. The costs for each of the individual sites are different from each other, due to the number of vehicles flowing through the road and the duration of the project.

Based on the information form the two sites and the estimate of the cost of traffic disruption a flow chart were prepared. The flow chart is a useful tool as a quick reference in estimating the cost of traffic disruption due to utility construction.

4.3. Flow Chart

Information gathered during case studies and literature review was used to prepare a flow chart, which is useful in calculating the cost of traffic disruption. The flow chart is developed to eliminate repeated entry of quantities under each item. Information collected during case studies and literature review was formulated in developing the flow chart. The flow chart is presented in Figure 12.

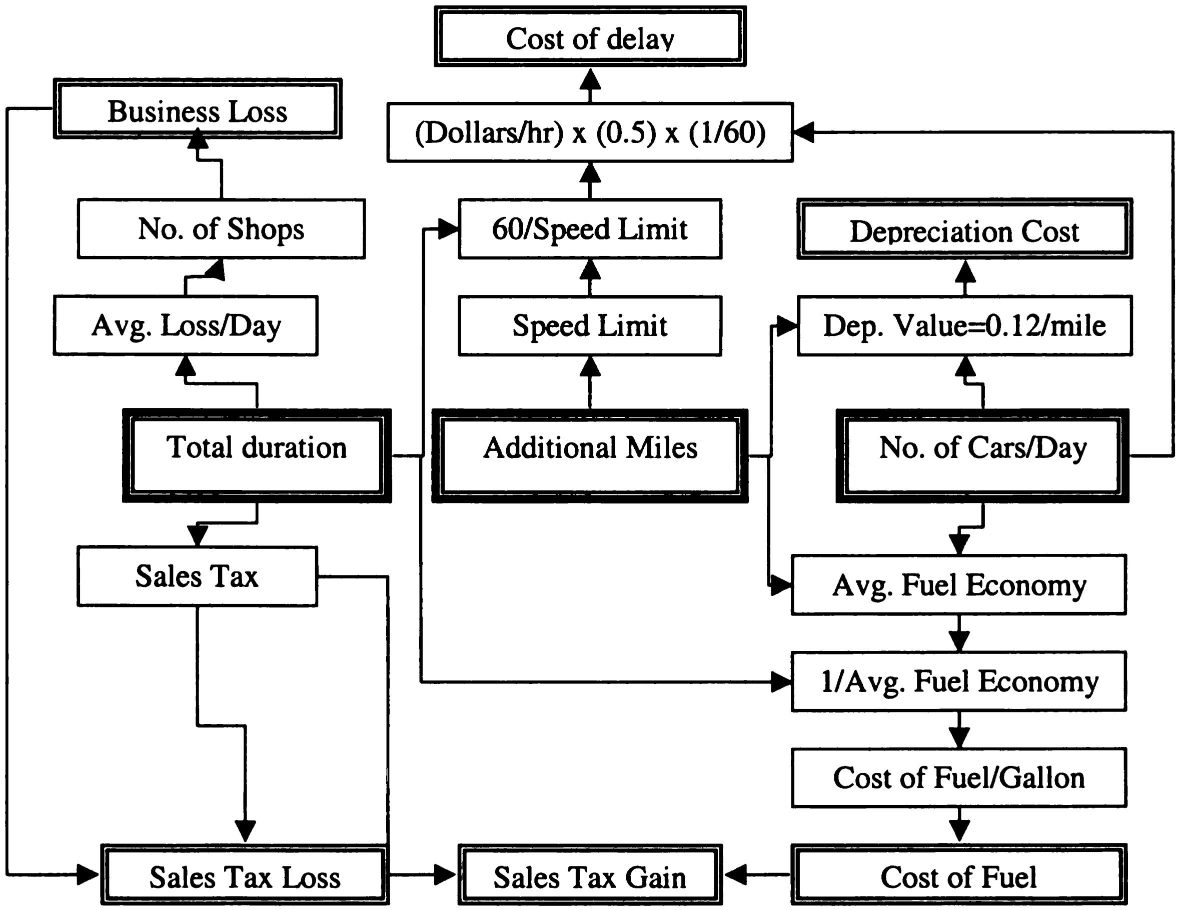

Figure 12: Flow Chart for Calculating the Cost for Traffic Disruption

Each of the outputs can be backtracked to the input data to obtain the formula for calculating the costs. It can be observed that the number of cars, total duration of the project and the additional miles traveled by the vehicle due to utility construction are the primary data sources in controlling the output, i.e., the cost of traffic disruption. The flow chart is also a helpful tool in understanding the various factors influencing the cost for each item.

The flow chart is devised on input and output formats. Items that control the outcome or in this case the cost items are located towards the center of the flow chart. The cost items are located at the end of every section of the flow chart. The required cost item can be backtracked using the flow chart to arrive at the formula for calculating the item. Each of the categories in the box is multiplied with the category encountered in the previous step to get the required cost item.

For example, if the cost of fuel is required, start at the cost of fuel box and follow the arrows backwards. The logic is to multiply each item with every successive item that is linked by the arrows. Following this logic, the first thing we notice is the cost of fuel per gallon. The next box is linked to the one above it requiring the average fuel economy of the vehicle. The major categories that are linked to this box are the number of cars, additional miles traveled by the car and the total duration of the project. Once all these parameters are entered, multiply each of these together to get the cost of fuel for traffic disruption. Thus the formula for calculating the cost of fuel for traffic disruption due to utility construction is:

Cost of fuel = Cost of fuel/gallon x gallons/mile x No. of cars/duration x Additional miles x Total duration

Similar steps can be repeated for all the other cost items explained in the flow chart. The flow chart is a quick reference to calculate the cost of traffic disruption due to utility construction. The flow chart is also a base for developing the prediction model, which is explained in the next chapter.

4.4. Conclusions

This chapter presented the case studies used during this research. Each of the costs for traffic disruption is calculated using the available data obtained during the case studies. The formulae obtained in chapter 2 are modified or developed to best reflect the scope and limitations of the research. The subcategories under the cost of traffic disruption due to utility construction are quantified for each of the sites under the original and alternate methods. The information obtained during case studies and the literature review is used in developing the flow chart that forms a basis for developing the prediction model.

5. RESULTS AND CONCLUSIONS

The previous chapter focused on data collection and analysis to determine the various costs that add up to the cost of traffic disruptions. Some of the variables that are needed to understand the costs associated with utility work were addressed. In this chapter, results of the analysis, cost comparison between open-cut and trenchless methods of utility work, will be addressed.

5.1. Comparative Analysis

Data collected from literature review for both open-cut and trenchless methods of pipe installation is used to compare the results of the case studies. Each of the sites selected for case studies is analyzed for the method used and the alternate method. Data is analyzed for the same site for open-cut method and trenchless method of pipe installation. Cost analysis from the case studies for both forms of pipe installation is presented in tables and graphs for analysis. The result of the analysis is presented in this section.

5.1.1. Site 1: MSU

Cost of traffic disruption, from the case study is presented in this section. The data collected is presented in the form of graphs and tables for analysis. For MSU, which employed trenchless method as the original method of utility installation work, the costs of traffic disruption is lower when compared with the alternate method of open-cut installation. This can be due to the fact that the traffic was detoured for this case study. Figure 13 presents the costs for both the forms of work. It should be noted that should this study as conducted at a major street, the cost of traffic disruption would be significantly higher.

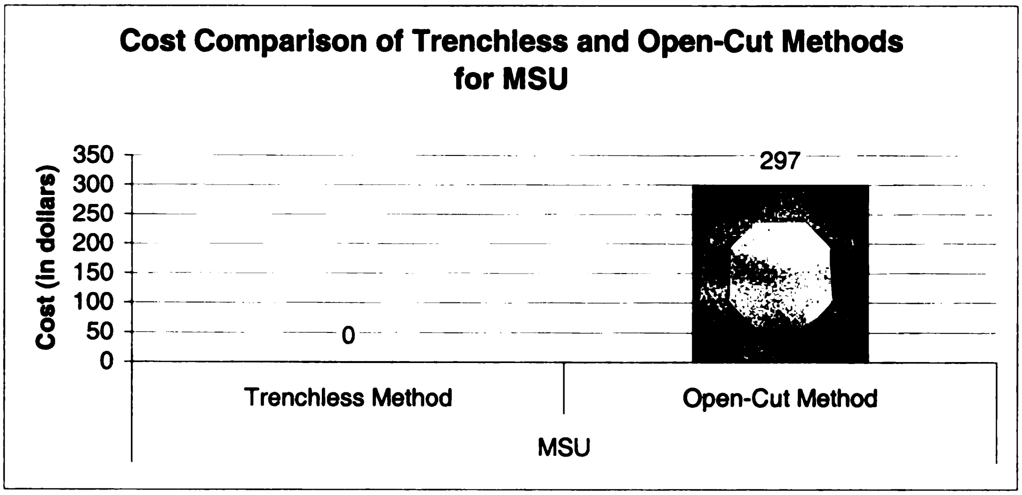

Figure 13: Traffic Disruption Cost-Comparison for Both Methods of Work, MSU

As is indicated in Figure 13, the cost of traffic disruption is literally non-existent for the trenchless method. This is mainly due to the fact that traffic is not disturbed during the construction period. The duration of the project also plays a critical role in determining the cost of traffic disruption for a particular site. The costs will increase with increase in duration. For site 1, since the trenchless method has resulted in no cost for traffic disruption, the duration of the project will not have any effect on the cost. Figure 14 plots the cost increase for traffic disruption with increase in time.

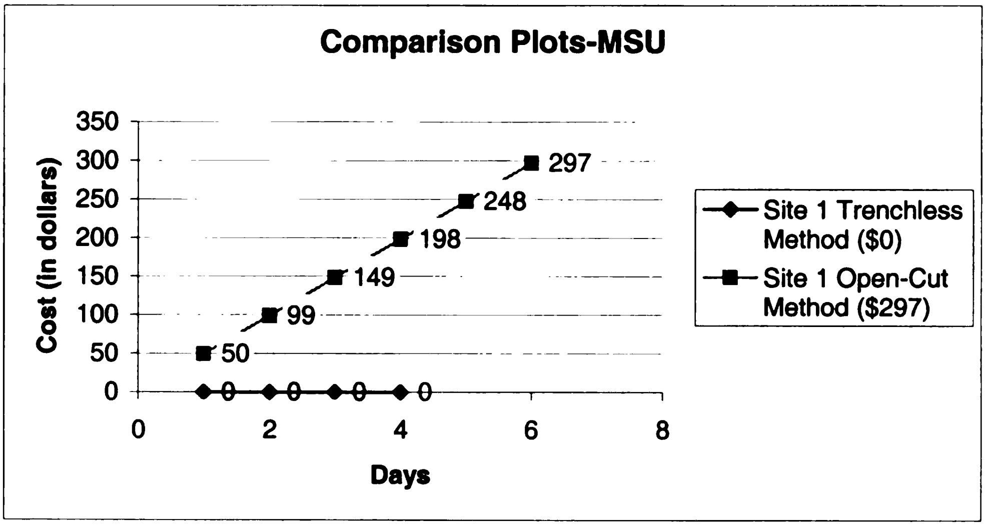

Figure 14: Comparison Cost of Traffic Disruption-MSU[3]

The cost of traffic disruption is not borne by the contractor. In fact these costs are a burden to the user or daily commuter on the road, as well as to the public entity or the owner. Cost of traffic disruption is a collection of all the costs incurred by the various parties involved, either directly or indirectly, in the utility work. The individual cost for each of the carious parties involved is illustrated in Figure 15. As shown in this figure, the user as well as the public entity shares the cost of traffic disruption while using open-cut method for road crossing in site 1 rather equally. The personal costs include the cost of fuel, the depreciation cost and the cost of sales tax over the fuel that is a burden to the user. Public costs include the cost of delay, which is not a personal cost in this case, as the user would not be losing his or her pay if he or she were late. If the user or the driver were to be a taxi driver, then the delay cost would have to be estimated as a personal cost, since the taxi driver would be losing his or her hourly pay if he were delayed. But, no such case was observed during the case study.

[3] Based on Average Daily Traffic for Duration of Case Study.

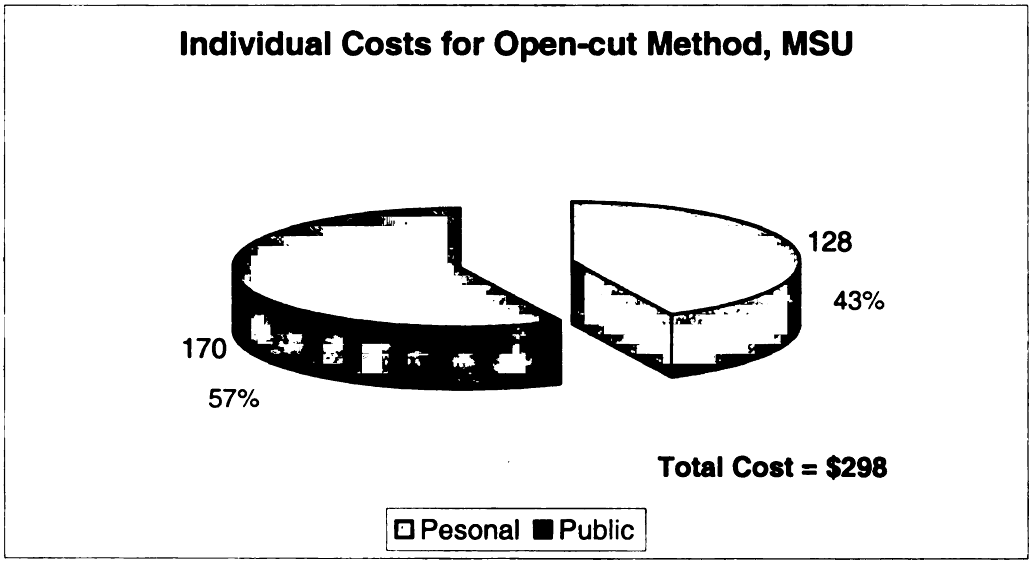

Figure 15: Distribution of Cost for Traffic Disruption among the Various Parties

5.1.2. Site 2: UFL

For UFL, the cost of traffic disruption was more or less the same for both methods of installation. This can be attributed to the fact that the site logistics remained the same for both methods. The road had to be limited to one lane, forcing the commuters to wait before given a chance to pass through the road. The duration of the project, as in the other case, was also one of the factors driving the cost of traffic disruption in this case study. The number of cars also had an impact on the overall cost of the traffic disruption. Figure 16 gives a comparison of the cost of traffic disruption for open-cut and trenchless method of installation.

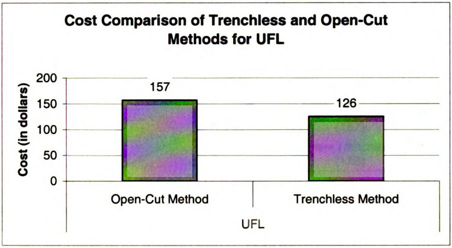

Figure 16: Traffic Disruption Cost-Comparison for Both Methods of Work, UFL

The costs in this case study also tend to increase with an increase in the duration of the project. There was a direct relation between the duration of the project and the cost for traffic disruption. The greater the duration the greater the number of vehicles disrupted due to traffic delays. The cumulative waiting time for these cars increases with the increase in duration. This adds up to the total cost of traffic disruption. Although the vehicles did not travel any greater distance to calculate the depreciation cost, the engine wear due to the wait for lane clearing is to be mentioned here. The engine wear can be a factor in calculating the depreciation cost. It was impossible to determine vehicular wear during this case study. Hence, it is not included while calculating the cost of traffic disruption. Figure 17 presents the cost increase with increase in duration for both forms of utility work.

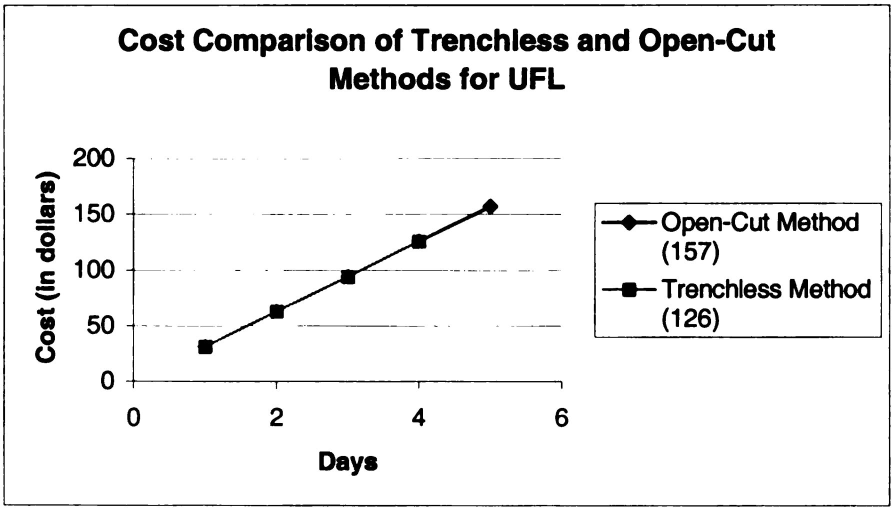

Figure 17: Plot Showing the Increase in Cost with Increase in Duration

Although the wear and tear due to waiting cannot be directly related to the construction activity, as the waiting period is no more than the normal waiting period at a signal light, this is an additional waiting period for the commuter. However, no data was available for this case study to be included in this cost. The various costs incurred by each of the parties, while using open-cut method are shown in Figure 18.

The various costs incurred people using the road in using trenchless method are shown in Figure 19. For this case study, the costs incurred remained the same in using either method, partially due to the fact that the site logistics remained more or less the same for both these methods. The costs would have been different if the length of the drive was more, or the duration was more or the number of cars was more.

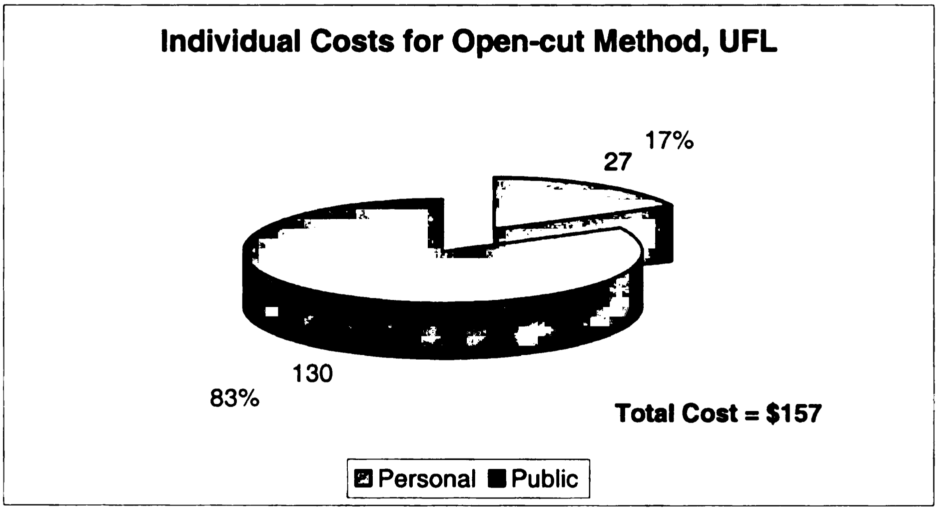

Figure 18: Individual Costs for the Various Parties using Open-Cut Method

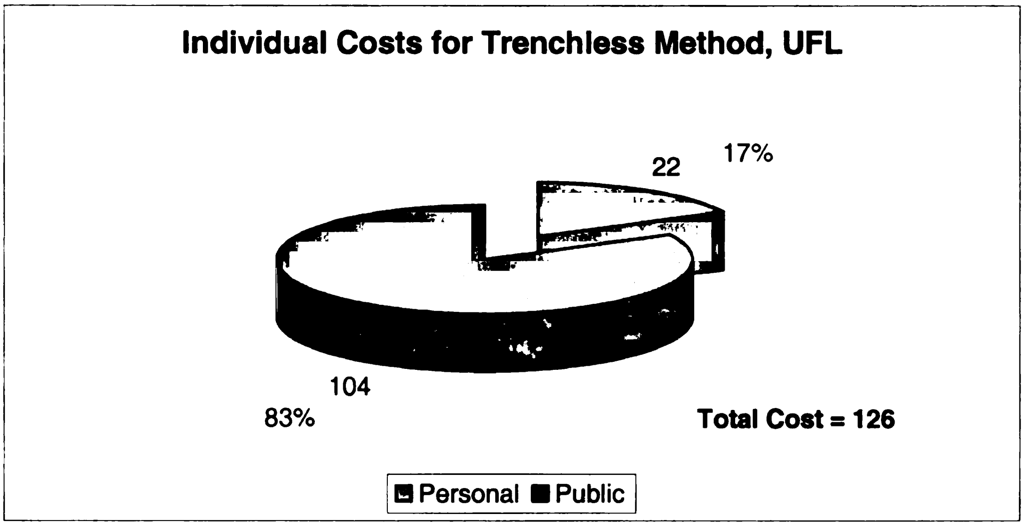

Figure 19: Individual Costs for the Various Parties using Trenchless Method

For both case studies, the trenchless method of installation produced lesser costs for traffic disruption than the open-cut method. During the case study, the ease of work in terms of the effort to lay the pipe or possible injuries to the workers is not considered, since they are not a direct comparison while estimating traffic disruption. However, the detour distance, the waiting time, the additional fuel consumed and the sales tax for the fuel consumed were all taken into account in estimating the cost. Figure 20 provides cost for individual categories added up to the cost of traffic disruption for both sites.

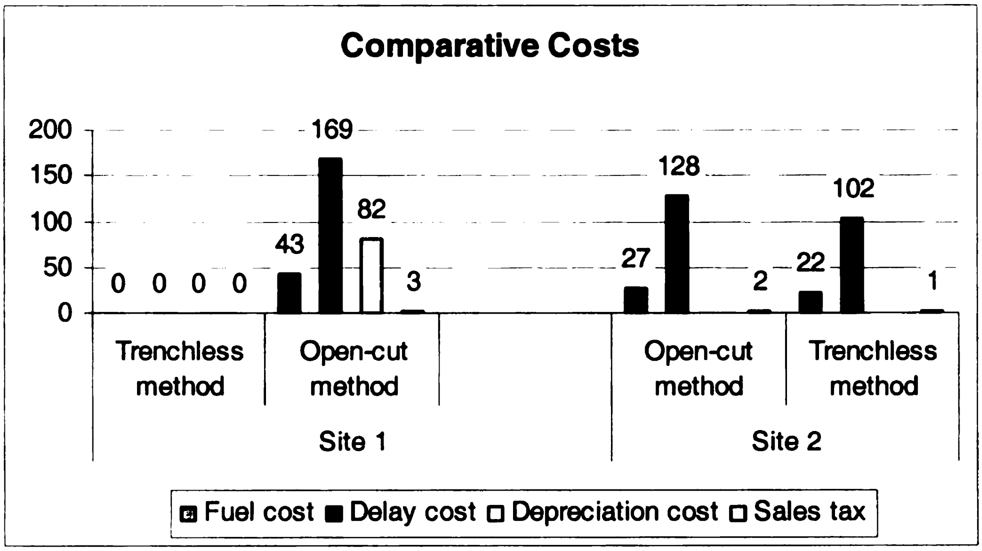

Figure 20: Comparative Costs for Both the Case Studies

Based on the discussion and analysis of the data collected for both case studies, the major factor influencing the cost of traffic disruption, other than the duration of the project, is the number of cars passing through the road. The disruption costs tend to be more in road crossing for open-cut method than for trenchless method. Road crossings require the total closure of the road for the duration of the project and each car has to take a detour to get to the destination. The numbers of cars flowing through the road dictate the cost of traffic disruption for the specific method of utility construction.

The effect of the length of the installation on the cost of traffic disruption cannot be positively determined from each of the case studies. It can be concluded from the data on the MSU case study that the length of the installation would only increase the costs for the open-cut method, while it has little or no effect on the costs for trenchless method. For utility work running parallel to the road, the costs of traffic disruption per foot of installation would decrease with an increase in drive lengths for trenchless methods, because the space between the two access pits would be more open than for what was in the case study. This would allow a significant reduction in the waiting spaces and waiting time for the vehicles using the road. This would not hold true for the open-cut method, because the total length of the line has to be excavated, which means that the whole length of the road has to act as a single lane. Duration of the project and the number of vehicles flowing through the road are major factors affecting the costs for traffic disruption. The detour length would also qualify to be an important parameter in considering the costs.

5.2. Prediction Model

In the previous chapter a flow chart was developed to reduce the burden of multiple entries of data. The flow chart can be developed or refined into a prediction model, with successive additions from further case studies. For example, the value of time due to delay has to added based on the site logistics. But with more case studies, this burden would also be reduced, given that an average value of time could be estimated that would reflect the national average value of time for users on the road. With the data from the case studies, this parameter was set at 6 dollars/hour.

The depreciation cost was placed at $0.12/mile (Business Strategies, 2002), reflecting the national average for depreciation of vehicles. The cost of fuel is tentative, which varies from state to state. But, at the time of the case studies, the national average had reached 1.497 (Lansing Gas Prices, 2003). Hence the cost of fuel per gallon was set at $1.50/gallon to reflect the rise in the fuel prices. The case studies were also limited to a university campus; hence the average speed limit was posted at 25 miles/hour, to reflect the same. This would also reflect the speed limit for most of the residential neighborhoods around the country. The sales tax was placed at 6 percent reflecting the prevailing sales tax collected from the consumer in many states. Individual state taxes may vary depending upon the location and time of the year. Average fuel consumption of the vehicles was set at 22miles/gallon (NTS, 2001), based on the national average for passenger cars. Figure 21 provides the basis for a prediction model using the above-mentioned information.

The prediction model would work with the information provided in the input box. The result would be available in the out put box, removing the factor of human error. This would be a powerful tool for contractors and other local government authorities to predict the cost of traffic disruption in using a particular method of construction. The data for the loss of business could not be entered as a part of the case studies, due to the lack of data. The case studies chosen did not yield any data for the parameter "Business Loss." This is reflected in the prediction model. As mentioned earlier, the prediction model could be more refined and perfected based on the data and feedback from successive case studies.

Presently, this can be used as a tool to predict the cost of fuel, cost of delay, depreciation cost and cost of sales tax due to additional fuel.

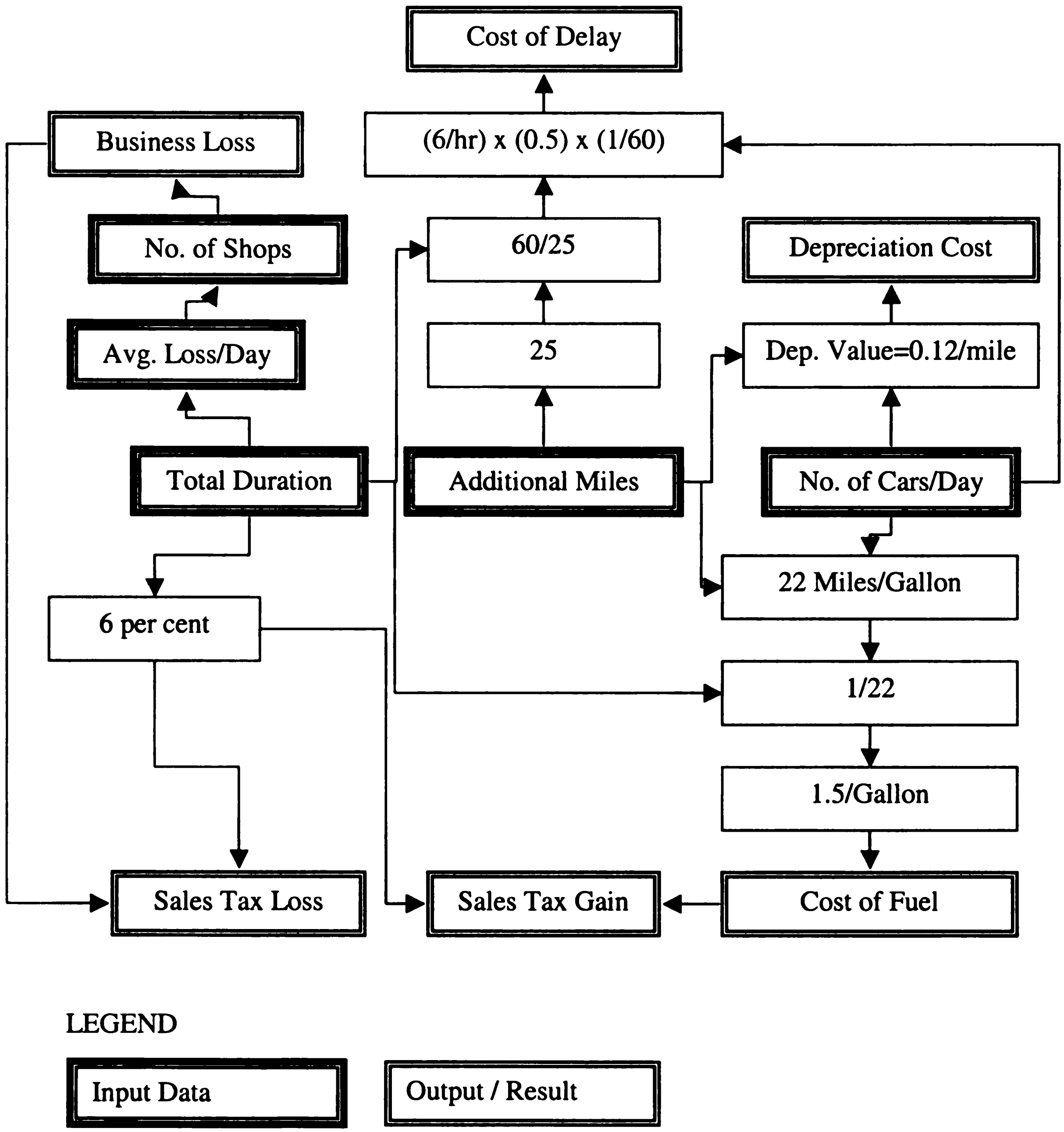

Figure 21: Prediction Model

5.2.1. How Prediction Model Works?

The prediction model can be executed using any software program. In this case, the author uses MS Excel software. The various categories are allocated to each cell in the table. Data obtained from the case studies and literature review is assigned to the respective cells. Figure 22 shows a snap shot of the set up using the program.

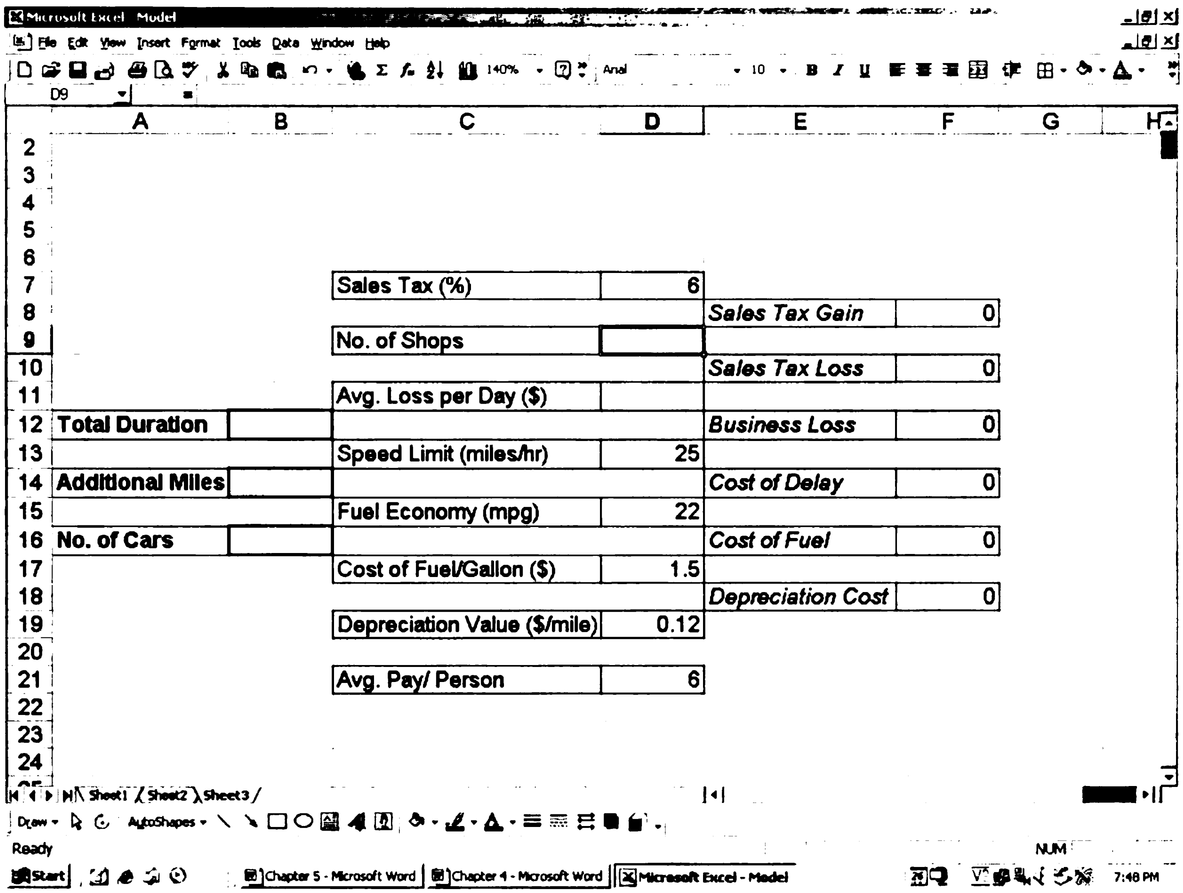

Figure 22: Snap Shot of Prediction Model

The required or entry fields are highlighted in bold for ease of communication. The output field is highlighted in italics. Data in column D was entered using information from case studies. Sales tax was set at 6% from literature review; speed limit was set at 25-miles/hour reflecting the average posted speed limit for the case studies. Fuel economy was set at 22 miles/gallon from literature review. Cost of fuel was set at an average of 1.5 dollars/gallon and depreciation cost was at 0.12 dollars/mile from literature study. The average pay per person at 6 dollars/hour was obtained from data collected during case studies. During the case study, the average pay rate per person in the respective universities was used as a basis for calculating the cost of delay. As mentioned in the previous chapter, no data was available for the loss of business to calculate the loss of revenue due to utility construction. If data were to be assumed to make the model work, say 10 dollars/shop/day is the loss of business and 10 shops were affected due to the construction, this data can be entered in column D. Figure 23 presents a snap shot of the model after all the data was entered.

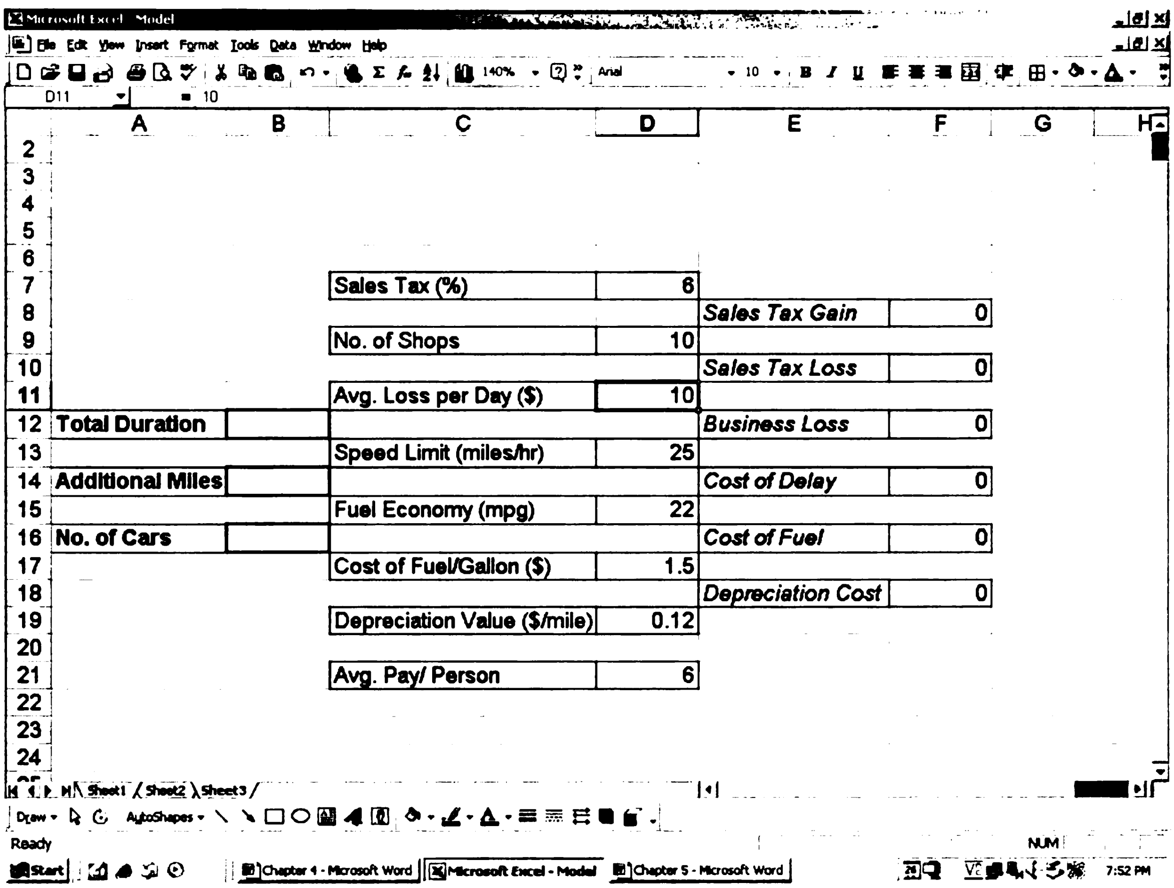

Figure 23: Snap Shot of Model with the Assumptions

The available information is fed into the model by selecting the cells B12, B 14 and B 16. This is the necessary information required for each site to get the cost of traffic disruption that is site specific. Figure 24 presents a snap shot of the model while entering the data in the input columns.

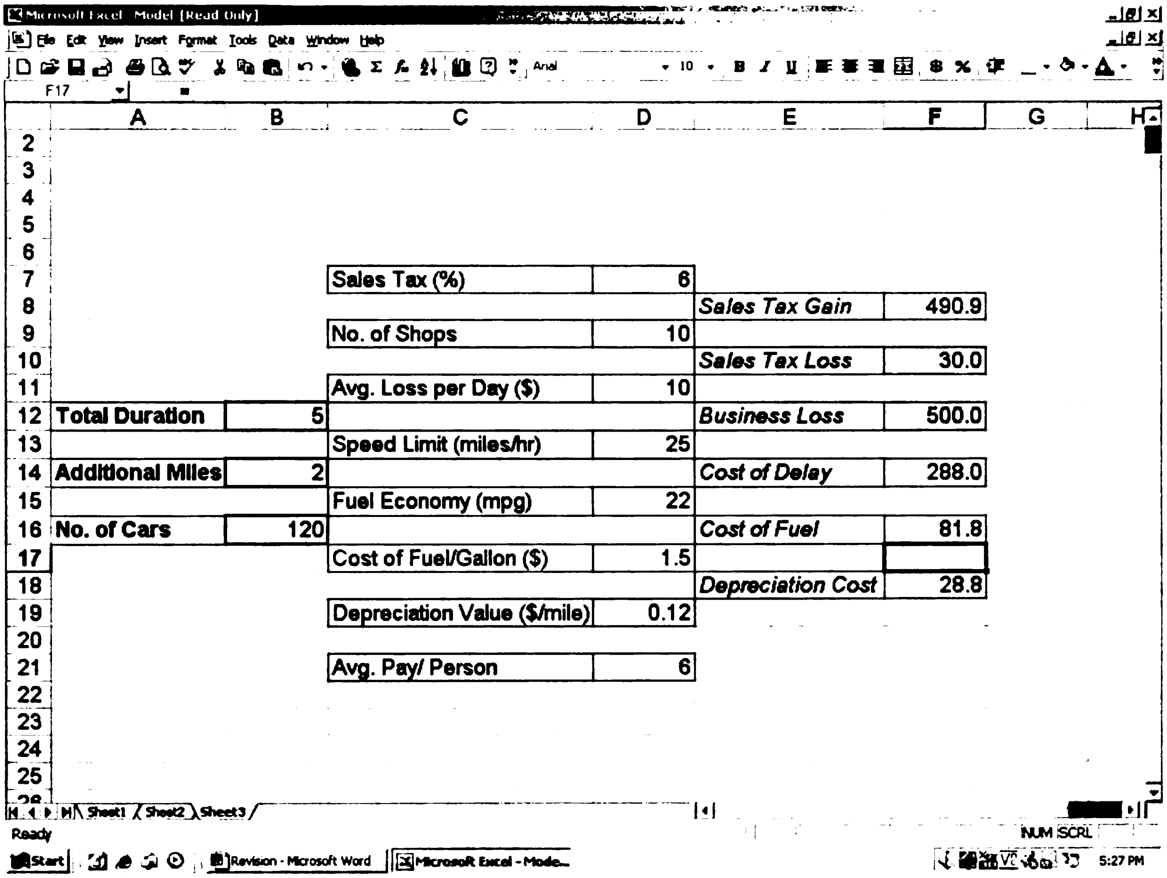

Figure 24: Snap Shot of the Model with the Predicted Costs

The data entered is used as an example and does not represent any data collected from the case study. The model works for any kind of site with in the set constraints that were specified under the scope and limitations of this research. With all the necessary information, the model predicts the cost for each of the categories, namely, gain and loss in sales tax, cost of fuel, cost of business loss, and cost of delay and depreciation cost. This model would yield an approximate cost of traffic disruption, which is very useful in determining the method of utility construction. The above program is used as a dry run for a given set of assumed input values. The data yielded from this model can also be used to develop graphs and pie charts to help better understand the social costs.

5.2.2. Prediction Model Software

In addition to the above model, a software program was developed to predict the cost of traffic disruption based on the prediction model. Since a major portion of the model involved number crunching, FORTRAN was used to write the code. On opening the program a brief introduction is displayed showing the credentials. Figure 25 presents a snap shot of the program during introduction.

Figure 25: Snap Shot of the Introduction for Prediction Model

The program guides the user through the prediction model through a series of questions. After a brief tutorial on using the program, the user is given a choice to continue or exit the software. The user is allowed to exit the program at any point of time. Once the user decides to use the program, the software presents a series of questions. These are the main inputs that are in the prediction model. The program considers only real numbers. Once this data is entered, the program presents a display of all the input data as "Inputs," and gives a choice for the user on the output data. The choice is based on a series of numbers from 1 to 9, each displaying the output pertaining to that number. Figure 26 shows a snap shot of the program at input stage.

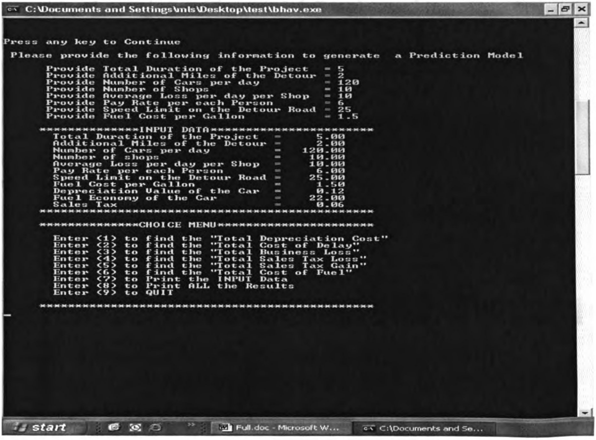

Figure 26: Snap Shot during Input Stage for Prediction Model

The output for each of these choices is displayed against the data and the user can decide on the required output. The user can quit the program at any point in time at this stage by pressing the appropriate number, which in this case is number 9. The output data can be obtained all at once by pressing the 8 key or can be sorted out individually by pressing the respective key number. Figure 27 presents a snap shot of the program presenting all the output data for an example problem as used in the previous section.

Figure 27: Snap Shot of the Output Data for Prediction Model

The user can quit at this point by pressing the key 9, or can press the respective keys to obtain individual cost items. Input data can be reviewed at any stage by pressing the key for 7, which would display all the input data. The program is based on the prediction model and given the input can predict the cost for a particular project. The prediction model as well as the software can be used to predict the cost of traffic disruption for open-cut methods of pipe installation. This is beneficial to the local bodies such as municipalities and the contractors in achieving an approximation on the traffic disruption cost for open-cut method. Future revisions of the software will display the individual costs as graphs or bar charts on a comparative scale. Due to the time constraint this could not be achieved during this research.

5.3. Conclusions

This research yielded significant data for making suggestions and recommendations for local municipal authorities and contractors. In both case studies, the trenchless method was the method producing the least cost for traffic disruption. Based on this research, different parties in utility construction are encouraged to consider the following suggestions:

5.3.1. Most Economical Method

The case studies yielded significant data to document the effectiveness of trenchless method over open-cut method of pipe installation. Each of the cost category or items identified as significant contributors towards the cost of traffic disruption due to utility construction was more for the open-cut method than trenchless method. The cost of fuel and the cost of delay are more for open-cut method. For road crossing, trenchless method of pipe installation has contributed little or nothing towards the cost for traffic disruption.

But for work running parallel to the road the cost of traffic disruption due to utility construction was almost the same for both the methods. Based on the literature research and the analysis of the data from the case studies, it can be suggested that the social costs associated with trenchless method of pipe installation are lower than open-cut method.

5.3.2. Suggestions for Designers

Designers and engineers should seek the alternative method to open-cut, before approving the utility work. A good understanding of all the social costs is as important as the cost of the project itself. Budget overruns and schedule delays can be attributed to the wrong choice of method for utility work. Some of the aspects of construction are site specific. A brief survey of the proposed site would be helpful in understanding the site characteristics before deciding on a specific method for utility construction. The prediction model would help in achieving a conclusion for the cost due to traffic disruption.

5.3.3. Personal Costs

The entity most affected by the method of utility work is the commuter or user of the road. In both the case studies the general public has to bear the burden of cost overruns and traffic disruptions. This can be frustrating to the user and ultimately would lead to complaints and protests. Effort should be made to understand the factors affecting these costs and every step should be taken to reduce them.

5.3.4. Suggestions for Local Authorities

Public officials and local municipalities could conduct a survey or perform a case study of the proposed site for utility work and use the prediction model to estimate the unseen costs for traffic disruption, before giving permission for a particular method of utility work. This is the best way to reduce the cost of traffic disruption and avoid citizen complaint.

5.3.5. Suggestions on Utility Contracts

Effort should be taken by the local municipal authorities to include terms and conditions in the contract to discourage the use of methods that are costly in terms of social costs. Ways of doing that would include:

1. Educate the engineers, contractors and decision makers about trenchless methods.
2. Perform case studies on the proposed site, prior to commencement of work, to document the effectiveness of alternate methods.
3. Include contract terms and guidelines for contractors and utility companies, to discourage contractors from digging up the roads.
4. Include a penalty for digging a road or for road closure, which are equal to the social costs.

5.4. Recommendations for Further Study

This research was based on literature search, the availability of sites for case studies and the data collected from the case studies. Due to time and resource limitations, freeways, expressways and major roadways were not considered as a part of the study. Due to the nature of the case studies, the duration and location of the project, yielded little data on some of the parameters identified during the literature review. The limitations were not significant in terms of yielding the expected deliverables. However, based on the study, the following are some of the suggested areas for future study:

1. Quantitative analysis of all other social costs involved in underground utility construction.
2. Comparative analysis of the trenchless method against the open-cut method in terms of the method of installation and project management.
3. Analysis of the bid documents to suggest ways of including the additional social costs during pre-construction.
4. Estimation of the cost of traffic disruption for categories or items not considered in this project such as highways and freeways.
5. Refine the prediction model as applicable to the various sites located in different geographic locations.

5.5. Overall Summary

This research has been presented in five chapters. In chapter 1, an overview of social costs and cost of traffic disruption was introduced. The problem statement and research goal and objectives were formulated. In chapter 2, a description of each of the different social costs was discussed. Also, the various aspects of the cost due to traffic disruption were detailed. In chapter 3, the methods and tools are discussed to achieve the objectives set forth in chapter 1. Detailed description of the steps necessary to achieve each of the objectives was discussed and the outcome of this research is forecasted. Chapter 4 presented the two case studies identified during chapter 3, to identify the cost of traffic disruption due to the method of utility work. Detailed graphs and analysis were provided in this chapter. In chapter 5, results from the case studies were analyzed and recommendations for further study were suggested. Also, for the two case studies, the best method of utility work was identified and recommendations were made to the various parties involved in the utility work on reducing the cost of traffic disruption.

Appendices

Appendix A

Questionnaire for Shop Owners

1. Name of the shop

2. Location of the shop

3. Name of the person

4. Position of the person, in case he is not the manager

5. Daily business for the shop in terms of amount in dollars

6. Does the construction activity affect your sales?
   Yes No

7. If yes, please provide the daily loss during the construction activity

8. Is this a steady loss over the duration of the construction?
   Yes No

9. If No, please provide an average daily loss for the duration of the construction activity.

10. Do you support the method of construction being practiced?
    Yes No

11. If No, please briefly describe any other construction method that you feel might have better suited the purpose or in other words your ideal construction method.

Appendix B

Duration of the Project for Open-Cut Method at MSU

Installation of 4, 4" cables at 5 ft depth for 250 ft length.

The work consists of the following tasks:

1) Excavate a trench for the entire length of the proposed utility line.
2) Put the cable in place.
3) Back fill and compact the excavated trench.
4) Complete resurfacing the pavement and sidewalk along with curb.

The objective is to calculate duration of the project using Building Construction Cost Data, 2002.

The following are calculations for each of the above-specified tasks:

1) Excavation:

   Using a chain trencher, 40 H.P., operator riding, 6" wide and 60" deep, includes backfill, the duration is:

$$200\ LF\ X\ 0.012\ {}^{LH}\!/_{LF} = 2.4\ {}^{LH}\!/_{1\ Labor} = {}^{2.4\,Hours}\!/_{8\,Hours\ /\ day} = 0.3\,Days$$

   Drilling Trenchless up to 1500 CY-for pavement and sidewalk, the duration is:

$$30'X4'X1.5'/27 = 6.67CY\ X\ 1.09\ {}^{LH}\!/_{CY} = {}^{7.27LH}\!/_{1\,Labor} = {}^{7.27Hours}\!/_{8Hours/day} = 0.909Days$$

$$5'X4'X1.5'\!/_{27} = 1.11CY\ X\ 1.091\ {}^{LH}\!/_{CY} = 1.2122\ {}^{LH}\!/_{1Labor} = {}^{1.2122Hours}\!/_{8Hours/day} = 0.15Days$$

2) Installation of 4@4" diameter cables for 250 ft length, the duration is:

$$250LF\ X\ 0.2\,{}^{LH}\!/_{LF} = {}^{50LH}\!/_{2Labors} = {}^{25Hours}\!/_{8Hours/day} = 3.125Days$$

3) Compaction of the excavated and backfilled soil, the duration is:

$$250\,LF\ X\ 0.044\,{}^{LH}\!/_{LF} = {}^{11\,LH}\!/_{1Labor} = {}^{11\,Hours}\!/_{8Hours/day}$$
$$= 1.375Days$$

4) Duration for replacing:

Sidewalk-6" thick

$$5'X4' = 20SF\ X\ 0.047\,{}^{LH}\!/_{SF} = 0.94\,{}^{LH}\!/_{3Labors} = {}^{0.3Hours}\!/_{8Hours/Day}$$
$$= 0.04Days$$

Curb-24" wide, straight, machine formed

$$2LF\ X\ 0.024\,{}^{LH}\!/_{LF} = {}^{0.048LH}\!/_{6Labors} = {}^{0.008Hours}\!/_{8Hours/day} = 0.001Days$$

Asphalted pavement over trench-6"thick

$$30'X4'\!/_{18} = 6.67SY\,X\,0.87LH\!/_{SY} = 5.82LH\!/_{6Labors} = 0.97Hours\!/_{8Hours/day}$$
$$= 0.12Days$$

Total Duration = 6.02 Days ~ 6 Days

Appendix C

Cost of Fuel for Traffic Disruption due to Utility Construction

MSU

Original method (Trenchless method)

Cost of fuel per car = 0.04545 gallons/mile X 0 miles X 1.50 Dollars/mile = 0 Dollars

Total cost of fuel = 0 Dollars X 332 cars/day X 3 days = **0 Dollars**

Alternate method (Open-cut method)

Cost of fuel/car =0.04545 gallons/mile X 0.341579 miles X 1.50 Dollars/gallon= $0.0218

Total cost of fuel = 0.0218 Dollars X 332 cars/day x 6 days = **43.43 Dollars**

UFL

Original method (open-cut method)

Cost of fuel per car = 2 min X 0.33 miles/min X 0.04545 gallons/mile X 1.426 $/gallon

Total cost of fuel = 0.0428 dollars/car X 128 cars/day X 5 days = **27.38 Dollars**

Alternate method (trenchless method)

Cost of fuel per car = 2 min X 0.33 miles/min X 0.04545 gallons/mile X 1.426 $/gallon

Total cost of fuel = 0.0428 dollars/car X 128 cars/day X 4 days = **21.90 Dollars**

Appendix D

Cost of Delay for Traffic Disruption due to Utility Construction

MSU

Original method (Trenchless method)

Cost of delay/car = 2.4 min/mile X 0 miles X 0.1042 Dollars/min = 0 Dollars

Total cost of fuel = 0 Dollars X 332 cars/day X 3 days = **0 Dollars**

Alternate method (Open-cut method)

Cost of delay/car = 2.4min/mile X 0.341579 miles X 0.1042 Dollars/mile = $0.085

Total cost of delay = 0.085 Dollars X 332 cars/day x 6 days = **169.32 Dollars**

UFL

Original method (Open-cut method)

Cost of fuel per car = 2 min X 0.1 dollars/min = 0.2 dollars

Total cost of fuel = 0.2 dollars/car X 128 cars/day X 5 days = **128 Dollars**

Alternate method (Trenchless method)

Cost of fuel per car = 2 min X 0.1 dollars/min = 0.2 dollars

Total cost of fuel = 0.2 dollars/car X 128 cars/day X 4 days = **102.4 Dollars**

Appendix E

Depreciation Cost for Traffic Disruption due to Utility Construction

MSU

Original method (Trenchless method)

Depreciation cost/car = 0.12 dollars/mile X 0 miles = 0 Dollars

Total depreciation cost = 0 Dollars X 332 cars/day X 3 days = **0 Dollars**

Alternate method (Open-cut method)

Cost of delay/car = 0.12 dollars/mile X 0.341579 miles = 0.041 dollars

Total cost of delay = 0.041 Dollars X 332 cars/day x 6 days = **81.67 Dollars**

UFL

Since the car actually did not travel any greater distance, the depreciation cost could not be calculated for this site.

Appendix F

Sales Tax Cost for Traffic Disruption due to Utility Construction

MSU

Original method (Trenchless method)

Additional sales tax = 0 Dollars x 6 percent = **0 Dollars**

Alternate method (Open-cut method)

Additional sales tax = 43.43 Dollars x 6 percent = **2.61 Dollars**

UFL

Original method (Open-cut method)

Additional sales tax = 27.38 Dollars x 6 percent = **1.64 Dollars**

Alternate method (Trenchless method)

Additional sales tax = 21.90 Dollars x 6 percent = **1.314 Dollars**

MSU

Original method (Trenchless method)

Additional sales tax = 0 Dollars x 6 percent = **0 Dollars**

Alternate method (Open-cut method)

Additional sales tax = 43.43 Dollars x 6 percent = **2.61 Dollars**

UFL

Original method (Open-cut method)

Additional sales tax = 27.38 Dollars x 6 percent = **1.64 Dollars**

Alternate method (Trenchless method)

Additional sales tax = 21.90 Dollars x 6 percent = **1.314 Dollars**

Appendix G

Subject Consent Form

Analysis and Comparison of Cost of Traffic Disruption

Principal Investigators: **Mohammad Najafi, PhD**
Research Assistant: **Bhavani Gangavarapu**

The Construction Management program at Michigan State University is conducting a research project to assess the cost of traffic disruption for utility construction. The research will help in improving the methods of installation for underground utility construction. You are being asked to participate in this project in your capacity as a small business owner.

As a participant in this research, you will be asked to complete an 11-question survey on the loss of business due to the method of utility construction.

Your assistance is voluntary and you may choose to stop assisting at any time during this project. Your privacy will be protected to the maximum extent allowable by law. Your company or you will not be identified by name. The estimated time for the survey is 10-15 minutes. As a participant, you may request a copy of this consent letter for your records.

If you have any questions about this project, you can do so by contacting Dr. Mohammad Najafi, Construction Management Program, Michigan State University at (517) 432-4937. Also if you have any question about your rights as a human subject to a research project, please contact Dr. Ashir Kumar, at University Committee on Research Involving Human Subjects (UCRIHS), Michigan State University at 517-355-2180 (email: ucrihs@msu.edu; email: ucrihs@msu.edu; 202 Olds Hall, East Lansing, MI 48824).

I voluntarily agree to participate in this study.

____

Subject Name	Occupation	Signature	Date

____

Witness Name	Occupation	Signature	Date

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