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A Carbon Dioxide Comparison of Open Cut and Pipe Bursting

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A Carbon Dioxide comparison of open-cut and pipe bursting

Project

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ABSTRACT

This study focuses on the environmental aspect of the underground utility construction methods namely open-cut and pipe-bursting. The research is aimed at determining the CO_2 emission due to the use of construction machinery as well as the excess CO_2 emission due to the obstruction to traffic during the construction process.

A Gravity sewer project in Bowling Green, OH was used as a case study. Open-cut method was implemented on this project and for the purpose of this research the pipe-bursting method was simulated. A 5100 feet long, 8 inches diameter pipeline was considered at a depth of 10 feet and all the calculations were based on these measurements for both these methods. All the real life data was collected from the construction project and the site & management factors as well as the load factors were applied in order to come up with practical CO_2 emission calculations for construction machinery. Various traffic control plans were taken into consideration and pre-established formulas were applied to the traffic data in order to derive the excess CO_2 emission for the traffic.

The outcome of this study indicated that pipe-bursting results in 68% less CO_2 emission due to traffic disruption and 73.4% less CO_2 emission due to use of construction machinery as compared to the open-cut method. The total reduced CO_2 by implementation of pipe-bursting method was found to be 72.6%. Thus, it was concluded that this drastic reduction in the CO_2 emission due to pipe-bursting method was mainly because of lesser excavation, shorter job duration and lesser traffic disruption.

ACKNOWLEDGEMENT

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My special thanks to all the field personals and ODOT officials to help me obtain the field readings and giving me an opportunity to learn about their ongoing project.

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Regards,

Akshay Vivek Joshi

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CHAPTER 1

INTRODUCTION

Context of the Problem

There are a large number of underground Infrastructure projects undertaken in America since the service life of these utilities is rapidly approaching its end. The underground Infrastructure which exists in the America was installed by digging trenches during the post-world-war era and thus most of these utilities are nearing their design life and some have even exceeded it. There is an urgent need to replace, rehabilitate and renew this underground infrastructure. The traditional open-cut method includes direct installation of utility systems into trenches. Advancements in technology and improvements in obtaining geotechnical data and development of new equipment led to improvements in utility pipe installation work (Gangavarapu, Najafi, & Salem, 2004). Although open cut may appear economical in terms of direct cost it can have high social and environmental costs when the construction work is executed in densely populated urban areas (Rashid & Knight, 2007). Since trenchless construction methods typically require only minimal excavation (entrance and/or exit pits) or no excavation to install a pipeline they are considered have lower direct costs and significantly lower social and environmental costs than open cut (Rashid & Knight, 2007). The costs associated with open cut sewer construction, especially in the densely populated urban areas are, direct cost, indirect cost (social and environmental impacts), operation and maintenance cost.

Direct costs are those which can be quantified and can be accounted for in the Tenders. These costs are mainly the operation cost, material cost and labor costs.

Allouche & Gilchrist (2004) describes Social cost as “The monetary equivalent of the resources consumed by the parties not engaged in the contractual agreement solely due to a construction process”. Social costs can take many forms including loss of revenue (customers avoiding area due to poor accessibility), productivity losses (reduction of ability of people to perform their work), loss of time (due to traffic delays), consumption of resources (gasoline) and accelerated deterioration (secondary roads) (Allouche & Gilchrist, 2004). McKim (1997) defined social as “costs of construction to society which are not included in the construction bid.” Apeldoorn (2008) describes the social cost as “the costs associated with the construction works that are paid for by the community at large, and not realized as a cost that is included in the tendered contract price.”

Indirect costs associated with traditional methods are:

- Traffic delays caused by restricted roads and detours.
- Reduction of life of the repaired road, resulting in Transportation of additional quantities of asphalt and concrete and trench restoration material, during repair and maintenance of road.
- Environmental impact (The excess CO_2 emission through the machinery and the delay caused to the traffic).
- Risk to public due to the obstruction to the movement of traffic.
- Lost revenue to business along the utility line.

All the above factors contributed to the excess emission of greenhouse gas. The more time the vehicles will spend due to the traffic obstruction the more CO_2 they will emit; also the vehicles will travel at lower speeds which will cause the efficiency of the vehicles to drop causing more consumption of fuel and in turn more CO_2 emission.

“UNFCCC” (United Nations Formwork Convention for Climate Change) has proposed the “International Environment Treaty” which binds all the nations against excess pollution.

While we wait for industry and governments to sign on to binding international agreements that will fix limits on air pollution, one possible solution is good to go right now: '*carbon trading*'.

'Carbon Trading' allows person or a company to benefit from the reduced GHG emission or pay charges for the excess GHG (Green House Gas) emission. One Carbon Credit equals to one ton of Carbon. Based on the number of carbon credits earned or lost by the company the company will be benefited or it will be charged per carbon credit respectively.

Trenchless technology is defined by North American Society for Trenchless Technology (NASTT) as "techniques for utility line installation, replacement, rehabilitation, renovation, repair, inspection, location and leak detection with minimum excavation from the ground surface."

Trenchless technology requires minimal or no trench excavation they are considered as lower direct cost and significantly lower social and environmental impacts. The difficulty of excavating around existing utilities and the societal impacts (traffic congestion, loss of business, noise, etc.) of open-cut work in busy streets are fueling the interest in trenchless alternatives (Allouche & Gilchrist, 2005). Thus, the advantages of trenchless technology are:

- Shorter job duration, which results in lower energy and power consumption.
- Using less construction equipment's resulting in less CO_2 emission.
- limited or no disruption to traffic flow, which will result in more efficient performance of vehicles and eventually less fuel consumption resulting in less CO_2 emission.

This paper is particularly focusing on the climate change and the resulting environmental impacts, which are mainly because of the fuel used by the construction equipment's as well as the excess fuel used by the vehicles due to traffic delay.

This study is focusing on pipe-bursting method, which like other trenchless construction methods requires least excavation and can be carried out with minimal or no disruption to the ongoing traffic. We compare the CO_2 emission from pipe-bursting method to the traditional open-cut pipe utility construction. We take into account the excess CO_2 emitted from the traffic delays resulting in reduced speeds. Also, the emission from the use of construction machinery and the hauling of excavated material is taken into account.

PROBLEM STATEMENT

This study aims towards estimating a total CO_2 emission for open-cut and pipe-bursting methods for underground utility sewer construction. It will give the statistical data for the amount of CO_2 emitted and will enable us to determine the magnitude of environmental impact of both these methods. Thus this study will assist the construction industry to implement a more environmental friendly method.

OBJECTIVES OF STUDY

The main objective of the study is to make a quantitative analysis of the CO_2 emissions from the pipe-bursting and open cut methods. This study will help us determine the social and environmental benefits of the using pipe-bursting method over open-cut. The study signifies further research on what was the first step taken by NASTT-BC towards an environment friendly underground utility construction method. O'Sullivan (2007) after the successful implementation of the carbon calculator said that "Public works projects using trenchless construction will now enhance the efforts of many cities striving for increased sustainability for their operations." The amount of money paid for installation or renewal of water and wastewater pipelines by local authorities does not represent the total cost to society; broader consideration of all costs, project and social cost, should be given when selecting the best method for construction or renewing piped infrastructure (Apeldoorn, 2008). As More Work has being undertaken and more industry players have become involved, unit cost have generally decreased and proven track records have been established with a wider embrace of trenchless technologies (Apeldoorn, 2008). This study will help us quantitatively determine the advantages of pipe-bursting method and thus increasing the awareness towards trenchless technology. The objectives of this study are as follows.

1. In order to determine the increased CO_2 emission because of the time delay caused to the traffic.
2. In order to determine the CO_2 emission of construction equipment.
3. In order to compare the open-cut with the pipe-bursting method on basis of excess CO_2 emission.

SIGNIFICANCE OF STUDY

This study will help us to determine the significance and importance of the use pipe bursting technology in installation and rehabilitation of underground infrastructure. Further it will help us to get an estimate of net CO_2 emission reduction caused by the implementation of this trenchless technology as compared to the traditional open-cut method. This study will help us know the social and environmental advantages of using trenchless technology and why is it such a widely implemented concept now. This will be achieved by applying some analytical tools to the findings and the data collected from the site.

Climate has changed on all time scales throughout Earth’s history. Some aspects of the current climate change are not unusual, but others are such as the rapid increase of CO_2 level in the atmosphere (IPCC, 2007). The concentration of CO_2 in the atmosphere has reached a record high relative to more than the past half-million years, and has done so at an exceptionally fast rate (IPCC, 2007).

While many factors continue to influence climate, scientists have determined that human activities have become a dominant force, and are responsible for most of the warming observed over the past 50 years. Human-caused climate change has resulted primarily from changes in the amounts of greenhouse gases in the atmosphere (IPCC, 2007).

Energy reaching the Earth from the Sun has been measured precisely by satellites. These measurements indicate that the Sun's output has not increased since 1978, so the warming during the past 30 years cannot be attributed to an increase in solar energy reaching the Earth (The National Academics, 2008). Additional evidence for a human influence on climate can be seen in the geographical pattern of observed warming, with greater temperature increases over land and in Polar Regions than over the oceans (The National Academics, 2008).

An increase (0.35°C) occurred in the global average temperature from the 1910s to the 1940s, followed by a slight cooling (0.1°C), and then a rapid warming (0.55°C) up to the end of 2006. The warmest years of the series are 1998 and 2005 (which are statistically indistinguishable), and 11 of the 12 warmest years have occurred in the last 12 years (1995 to 2006) (IPCC, 2007). Within the past 30 years, the rate of warming across the globe has been approximately three times greater than the rate over the last 100 years (EPA, 2005).

The Earth's greenhouse effect is a natural occurrence that helps regulate the temperature of our planet. When the Sun heats the Earth, some of this heat escapes back to space. The rest of the heat, also known as infrared radiation, is trapped in the atmosphere by clouds and greenhouse gases, such as water vapor and carbon dioxide. If all of these greenhouse gases were to suddenly disappear, our planet would be 60°F colder and would not support life as we know it (EPA, 2005). However, human activities, primarily the burning of fossil fuels and clearing of forests, have greatly intensified the natural greenhouse effect, causing global warming (IPCC, 2007).

Water Vapor is the most important greenhouse gas, and CO_2 is the second most important one (IPCC, 2007).

If humans continue to emit greenhouse gases at or above the current pace, we will probably see an average global temperature increase of 3 to 7°F by 2100, and greater warming after that. Even if we were to drastically reduce greenhouse gas emissions, returning them to year 2000 levels and holding them constant, the Earth would still warm about 1°F over the next 100 years (EPA, 2005).

Carbon dioxide has increased from fossil fuel use in transportation, building heating and cooling and the manufacture of cement and other goods. Deforestation releases CO_2 and reduces its uptake by plants (IPCC, 2007). Plants reduce the carbon content in the atmosphere by using CO_2 for photosynthesis which helps maintain the ecological balance of the earth system. Since deforestation had occurred at such a rapid rate along with the intensive combustion fossil fuel through various human activities the ecological balance of the earth is disturbed resulting in global warming. Because of slow removal processes, atmospheric CO_2 will continue to increase in the long term even if its emission is substantially reduced from present levels (IPCC, 2007).

More rapid climate change makes adapting to change more difficult and costly. This is especially true for vulnerable groups (such as the poor, the very young and older adults) and fragile ecosystems which may struggle to adapt to even small changes. IPCC (2007) suggests that temperature increases above the range of 3.5 to 5.5°F over the next 100 years would dramatically increase the negative impacts of climate change. This climate change will affect our health, agriculture, forests, water resources, energy, coasts, wildlife and recreational opportunities (EPA, 2005).

Since 1950, the number of heat waves has increased and widespread increases have occurred in the numbers of warm nights. Tropical storm and hurricane frequencies vary considerably from year to year, but evidence suggests substantial increases in intensity and duration since the 1970s (IPCC, 2007).

Important coastal regions of the ice sheets on Greenland and West Antarctica, and the glaciers of the Antarctic Peninsula, are thinning and contributing to sea level rise. The total contribution of glacier, ice cap and ice sheet melt to sea level rise is estimated as 1.2 ± 0.4 mm yr–1 for the period 1993 to 2003 (IPCC, 2007).

The *United Nations Framework Convention on Climate Change (UNFCCC)*, in its Article 1, defines climate change as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (Baede, Alfons, Linden, & Verbruggen, 2008). The UNFCCC Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (Baede *et al*., 2008).

The first addition to the treaty, the Kyoto Protocol, was adopted in 1997 and entered into force in February 2005. As of February 2007, 168 states and the European Economic Community have ratified the Protocol. The first addition to the treaty, the Kyoto Protocol, was adopted in 1997 and entered into force in February 2005. As of February 2007, 168 states and the European Economic Community have ratified the Protocol (IPCC, 2007).

Fully trenchless or partially trenchless (where some excavation is required) technologies offer many benefits as a methodology for rehabilitating or renewing pipelines that mitigate some of the social and environmental impacts and often some of the cost of open cut excavations. Competition for space in service corridors, the intensification of urban and residential developments, the risk to the public and contractors, and the impact on property owners and the community environment in a growing number of cases limit the options for open excavation (Apeldoorn, 2009).

Traffic delay costs are due to increased time spent traveling and they are based the value of time to users (driver and passengers) and can account for more than 50% of the social cost (Matthews, 2010). Traffic congestion accounts for 6.8 billion gallons of fuel consumption and 4.5 billion hours of travel time, costing the nation $78 billion dollars (Gangavarapu *et al*., 2004).

Therefore a key advantage of trenchless construction methods is the ability to install new and rehabilitate existing underground assets with limited disruption to traffic and business activities, reduced damage to existing paved surfaces, fewer adverse environmental impacts and less disruption to normal life patterns of the people living, working and shopping around the construction zone (Apeldoorn, 2009). Approximately 70% of the cost of open excavation construction is simply excavating and replacing the ground dug up during the process (Mohammed, Najafi, Hashemi, 2008).

Trenchless technology projects have a far smaller impact on the project zone, not only reducing the disruption that may be caused but also the stress and effect on the lifestyle of the inhabiting community particularly during large and long duration projects (Apeldoorn, 2009). Currently, approximately one-third of the North American businesses operate on a just-in-time delivery basis. If deliveries are disrupted due to travel delays, those businesses and thus the economy could be significantly affected (Allouche & Gilchrist, 2004).

ASSUMPTIONS

1. All the trenchless methods were assumed to have the same site conditions and the recordings were based on the observations from the site.
2. The calculation of CO_2 emission from various machineries and traffic flow were based on the fuel consumed by the machines during the process.
3. The calculations for amount of excess fuel used and the CO_2 emitted were based on previously proven techniques and methods.
4. Other aspect involved in a construction project such as the site conditions, weather, personnel, construction material, construction management were consider to have insignificant effect on the CO_2 emission from the process. Moreover whatever effect they do have was considered to be same irrespective of any construction method used.

LIMITATIONS

1. The utilities were considered to be installed at the depth of 10 feet from the ground surface and the size of the pipeline considered for this study is 8 inches for equal comparison between these methods.
2. Traffic control plan-4 was considered for finding the excess CO_2 emission from traffic.
3. No instruments were used for measuring the actual CO_2 emission from the construction machinery and the vehicles and this study is just an estimate of the CO_2 emission.
4. The Fuel to CO_2 conversion rate as given by the U.S Environmental Protection Agency (EPA) may cause slight difference to the actual CO_2 emission.

CHAPTER 2

REVIEW OF LITERATURE

Studies were conducted previously on the cost resulting from the two methods considering the traffic delay, direct cost, indirect cost as well as social and environmental impacts (which only included the noise pollution aspect of it).

Before NASTT-BC in 2007 started conducting their research on the CO_2 emission caused by the open cut and trenchless methods, there was no significant research on the greenhouse gas emission resulting from these two construction methods. O'sullivan (2008) said in his paper that "By linking the energy reduction with carbon output, we were able to come up with the carbon reduction by using trenchless technology." A student at University of British Columbia then developed a carbon calculator, which estimates the reduction of CO_2 emission when trenchless technologies are used as compared to the traditional open-cut method.

Apeldoorn in 2009 in his paper tried to answer the question "What is the cost of trenchless construction or renewal projects related to conventional open-cut methods?" The cost of both open-cut and trenchless methodologies are affected by many factors, such as the location of the pipeline, its depth, size and also the local availability of the various trenchless technology methodologies (Apeldoorn, 2009).

A recently published case study by Hashemi (2008) comparing the potential cost of open excavation versus pipe bursting to replace the sewer network in the City of Troy, Michigan in the United States concluded that the trenchless method of renewal if implemented would be 25% less expensive than open excavation (Apeldoorn, 2009).

The Social Cost Calculator (SCC) was developed by Matthers, J. C. and Allouche E.N in a study they conducted in 2010. The SCC guides the user through an interactive interface to yield a more complete cost forecast taking into account the project specific parameters, calculating user travel delay costs, increased vehicle operating costs, pavement repair costs, decreased property values due to noise pollution, and loss of parking space (Matthews &Allouche, 2010).

Boyce and Bried (1994), developed detail equation for estimating trenchless construction social cost saving, which included, traffic and pedestrian disruption cost, loss of productivity in terms of public awareness and lost revenue from parking meters and tickets.

McKim (1997) built on this Boyce and Bried study and put forward an estimating method based on the average social cost from 14 construction projects. Using this generalized estimate method McKim demonstrated the need for including social costs in selection process of municipal bids.

Tighe (1999), analyzed cost associated with traffic disruption using various construction durations and typical traffic control plans. In their analysis, equations were developed that relate costs to annual average daily traffic (AADT) under various traffic control plans. Costs are determined based on user delays arising from speed, queuing and detour delays. Open cut excavation for pipe installations were also shown to result in premature pavement deterioration.

Gangavarapu *et al.*, (2004) compared open cut and auger boring (one of the trenchless technologies) in terms of total costs arising from the project which also included traffic disruption. The paper presented a summary of the costs of traffic disruption due to the method of pipe installation chosen for the utility construction. It was found that the cost of fuel and the cost of time delay are the major contributors in estimating the cost of traffic disruption. In this paper there are two case studies show which based on different scenarios and the project location differ in cost out comes when the two technologies are compared. In first case study the auger boring technology cost much less when the cost of traffic disruption is considered. But, in the second case study the auger boring costs significantly more as compared to the traditional open-cut method.

Jung and Sinha (2004), studied the economic productivity, safety and structure issue associated with underground pipeline construction and introduces trenchless as an alternative.

Jung and Sinha (2007), Considered direct costs, social costs (Which included traffic delay cost, loss of revenue and business and environmental impact (which included only noise cost). Furthermore, they discussed but did not quantify productivity, workers' safety, and structural costs.

Davis and Diegel (2007) came up with the graph which shows the effect of speed on the efficiency of a vehicle. Thus the variation in consumption of fuel due to the variation in its speed can be computed from this graph.

Knight (2007), in his report Do Trenchless Pipeline Construction Methods Reduce Greenhouse Gas Emission applied these concept and analytical data from the above mention studies and developed a fairly accurate estimate of the CO_2 emission and compared the open cut and the trenchless methods. He did this study for Center for the Advancement of Trenchless Technology (CATT). This was a preliminary estimate that does not include greenhouse gas emissions resulting from: the production and transportation of additional quantities of asphalt concrete and trench restoration materials; loss of pavement life; and/or pavement maintenance and rehabilitation. Thus, it was a conservative preliminary estimate.

Since 2007, NASTT-BC (North American Society for Trenchless Technology- British Columbia) has offered project designers a simple online Carbon Calculator to highlight the CO_2 reduction potential of trenchless technology. A study was done in order to evaluate the CO2 emission reduction potential of the trenchless technology. This study has plenty of scope for improvement.

In 2011 a graduate student from Bowling Green State University compared the CO_2 emission resulting from implementation of horizontal directional drill and open cut methods for an underground utility project located in Bowling Green, Ohio. This project focused on the CO_2 emission resulting from the traffic disruption as well as the construction machineries involved in the project. This study was based on the actual data gathered from the workplace. This data was applied to the previously developed analytical equations for the amount of fuel additional fuel consumed by the vehicles due to traffic disruption as well as fuel consumed by the construction machinery. This amount of fuel consumed was then converted to the resulting CO_2 emission by applying the conversions given by Environment Protection Agency (EPA). The current project is an extension of the this project and it is different in a way that it in this paper we are comparing open-cut, pipe bursting, and CIPP methods whereas the earlier study compared open-cut with HDD. The results revealed that HDD construction produced 53.1% less CO2 than the open-cut method.

RESEARCH BOUNDARY

The data for the research was collected from the actual field by observations and by talking to the site personnel. For comparing open-cut and pipe bursting methods, an pipe length of 5100 feet and diameter of 8 inches was be consider to be laid at 10 feet from the ground surface.

The construction site which was used for the data collection for the study is located in Bowling Green, OH at the Intersection of N. Main and E. Poe Road. Careful readings were taken in order to have real data which can be used for this study. Traffic movement along the construction area was observed and the Annual Average Daily Traffic (AADT) was found. The obstruction caused to the traffic due to the construction activities was also recorded. The make and model of machinery used on the field was noted and the time for which each machine operates was recorded through observation. All this data was then applied to the various equations and methods described in chapter 3.

CHAPTER 3

METHODOLOGY

Problem Restatement

This study aims towards estimating a total CO_2 emission for open-cut and pipe-bursting methods for underground utility sewer construction. It will give the statistical data for the amount of CO_2 emitted and will enable us to determine the magnitude of environmental impact of both these methods. Thus this study will assist the construction industry to implement a more environmental friendly method.

Objectives

1. In order to determine the excess CO_2 emission due to the time delay caused to the traffic; this will be done by applying the analytical methodology derived earlier by (Tighe, 1999)
2. In order to determine the CO2 emission by construction equipment's; this will be done by applying the methodology discussed in the (NASTT-BC, 2007).
3. Further the net CO2 emissions will be calculated by summing up the CO2 emission quantities obtained in first two steps.

Figure 1 show typical traffic controls plans. Plans 1, 2, and 3 were implemented in the research by Tighe (1999). Traffic control Plan 1 refers to a situation in which construction work warrants closure of one lane of the road for a certain length. Traffic from the two directions is controlled by a flag person who alternately opens and closes the other lane to the two directional streams of traffic. In traffic control Plan 2, one lane is closed to the traffic but enough shoulder width is available so that the traffic of closed lane could be diverted onto the shoulder for the length of the construction zone. Traffic Plan 3 depicts a situation in which requires complete closure of all the lanes to traffic. For instance, when a pipeline has to be constructed across the road width, Plan 3 would be implemented. Traffic on the closed road would be diverted onto alternate routes where after it will re-merge onto the closed road (Knight, 2007). In Plan 4 one or two lanes are closed on a multi-lane road and thus the traffic can flow both the ways with needing to stop or take a detour. Plan 4 was used in this study since the N. Main road is multilane and there is no need to stop or divert the traffic.

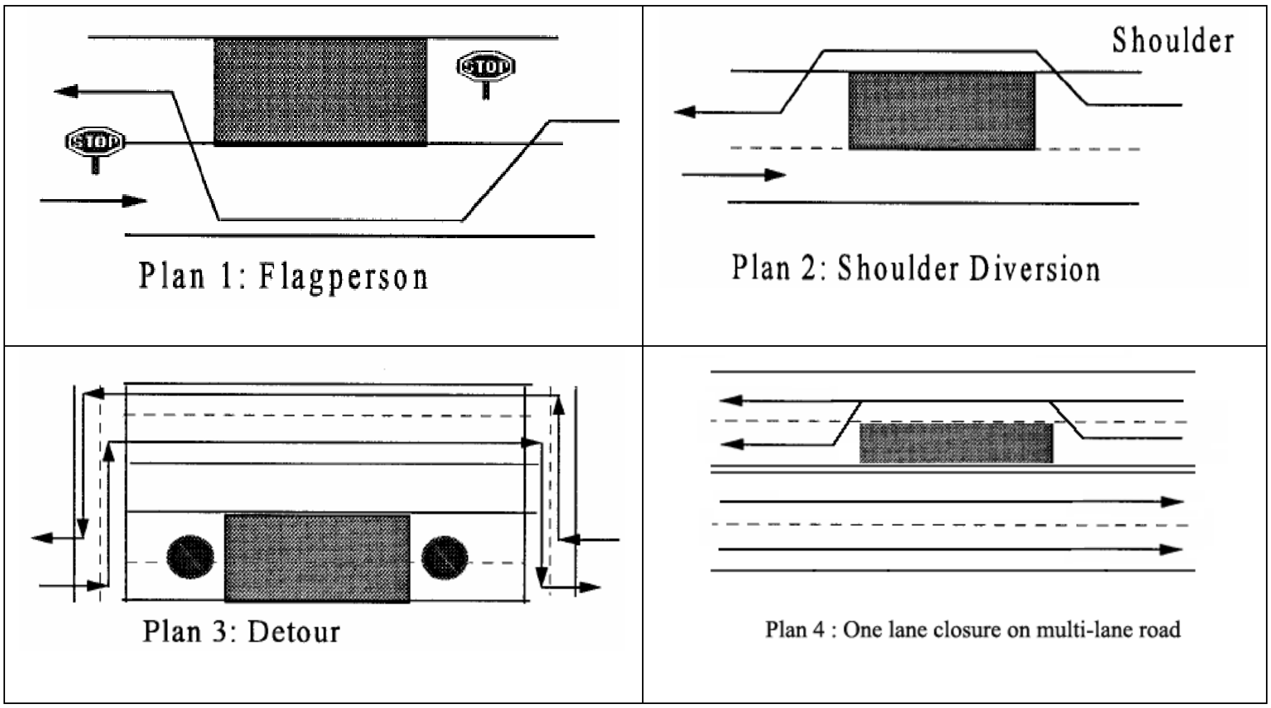

Figure 1. Various traffic control plans

Depending upon the layout of the construction zone on a road, various traffic control plans can be implemented. These traffic control plans will alter the geometric conditions of road and hence influence the traffic operating speeds (Knight, 2007).

Figure 2 shows the relationship between speed and fuel consumption for vehicles. Data for average fuel economy for a mix of various vehicle types under varying operating speeds has been reported in Davis and Diegel, 2007 (Knight, 2007). The fuel economy, provided as miles per gallon, was converted gallons per kilometer and speed was converted from miles per hour into kilometers per hour (Knight, 2007).

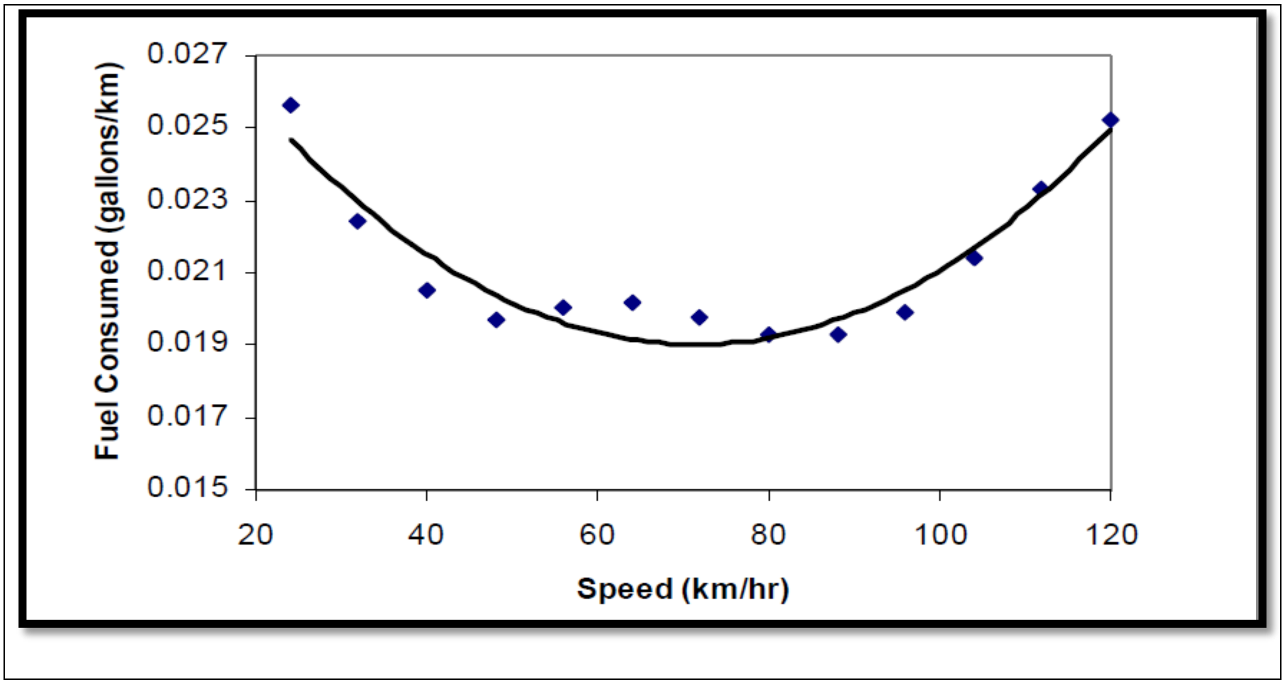

Figure 2. The relation between fuel consumption and speed. (Knight, 2007)

To determine fuel consumption due to traffic disruption

The Code of Federal Regulations (40 CFR 600.113) provides values for carbon content per gallon of gasoline and diesel fuel which EPA uses in calculating the fuel economy of vehicles:

- Gasoline carbon content per gallon: 2,421 grams (EPA, 2005)
- Diesel carbon content per gallon: 2,778 grams (EPA, 2005)

Finally, to calculate the CO_2 emissions from a gallon of fuel, the carbon emissions are multiplied by the ratio of the molecular weight of CO_2 (m.w.44) to the molecular weight of carbon (m.w.12) 44/12.

CO_2 emissions from a gallon of gasoline = 2,421 grams x 0.99 x (44/12) = 8,788 grams = 8.8 kg/gallon = 19.4 pounds/gallon (EPA, 2005)…… ….Equ. 1

CO_2 emissions from a gallon of diesel = 2,778 grams x 0.99 x (44/12) =10,084 grams = 10.1 kg/gallon = 22.2 pounds/gallon (EPA, 2005….. …Equ. 2

To determine the CO2 emission caused by construction machinery

To determine the heavy construction equipment CO2 emissions, the time duration for which any piece of equipment is operated has to be determined and the associated fuel consumption. Data reported in RS Means (2006) was used to estimate the time for various construction activities to be completed (Knight, 2007). Similarly different CO2 emissions by heavy construction machinery can be calculate by using RS means 2011.

The equation for calculating the fuel consumed by the construction machinery is:

$\sum^{n} (F_1 \text{ x } T_1 + F_2 \text{ x } T_2 + \ldots\ldots +F_n \text{ x } T_n)\ldots\ldots$ ....Equ 3

The total fuel consumption can be calculated by adding the Equations 1, 2 and 3.

CHAPTER 4

RESULTS/FINDINGS

This chapter gives a detailed analysis of all the results derived from the data collected for determining the CO_2 emission from open-cut as well as pipe-bursting methods for installation of a gravity sewer line. All the results were based on the field observations made during the course of the project.

This gravity sewer line runs 5100 feet in N-S direction along N. Main Street. The project starts 350 feet south of the intersection of Poe road and N. Main Street and proceeds north to end near Woodland mall on N. Main Street. This gravity sewer line is considered to be installed at a depth of 10 feet from the ground surface and is 8 inches in diameter for both methods. The manholes are assumed to be located at a distance of 300 feet and three lateral connections are assumed to be present between each two manholes on average. For open-cut, a new pipeline was considered to be installed instead of replacing an old line and for pipe-bursting an old pipeline was replaced by new pipeline. High density polyethylene (HDPE) pipe was used in the pipe-bursting method and Polyvinyl chloride (PVC) pipe was used in the open-cut method. For

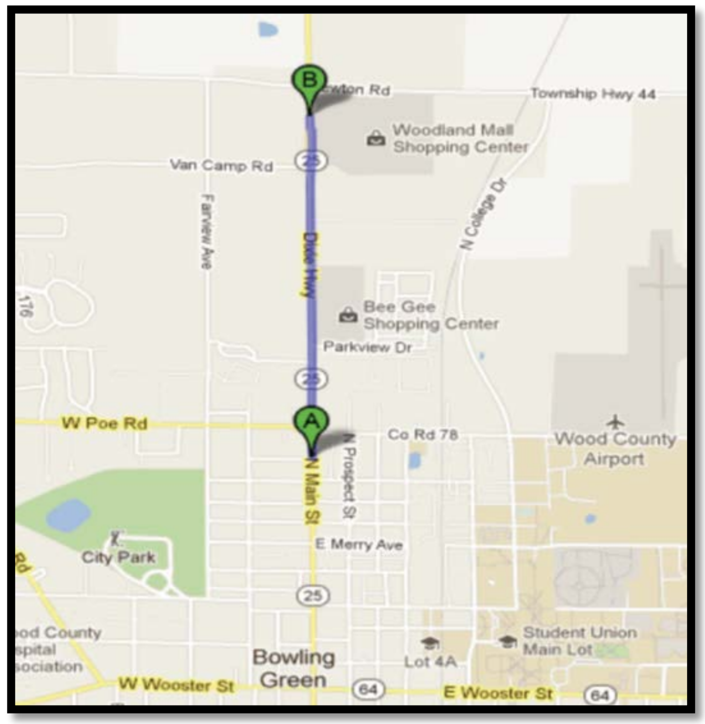

Figure 3. Span of the pipeline project - start and the end points

this study, it was assumed that the different pipe materials did not have any direct bearing on the CO_2 emission for the project.

For open-cut it was considered that a new pipeline was installed parallel to the old pipeline. Thus, the project consisted of installation of pipeline, installation of new manholes and 10 feet extension of lateral lines joining the new line. For pipe-bursting, the old pipe line was replaced by a new line and thus this project consisted of set-up, pipe bursting, and finishing. It was also considered that all the excavated material is suitable for backfilling.

Determining the impact of traffic disruption on fuel consumption

The data collected from the field was used to determine the volume of traffic, type of traffic control plans, the length and duration of traffic control plans and amount of speed reduced. All these calculations are shown in detail in the spreadsheets attached in the appendices B, C, D, E & F.

The traffic volumes (number of vehicles between 8:00 am and 6:00 pm) on N. Main Street were divided into four parts according to the locations. It was observed that the volumes differ for different locations along the main street. The first part considered, was south of the intersection between Poe and N. Main; second part spanned 1750 feet towards north starting at the intersection; third part spanned 1500 feet and continued north and the fourth part was 1500 feet as well that ended at the Woodland mall area. The traffic volumes for the period between 8:00 am and 6:00 pm for all these areas are 16810, 18870, 13680 and 8580 respectively. The traffic volume for Poe road was also calculated and was found out to be 10575. These traffic volumes are the number of vehicles moving in both the directions along the N. Main Street. These volumes were considered when two lanes were closed for traffic. It was assumed that there are equal numbers of cars moving in both directions. Thus, when one lane was closed during pipe-bursting the traffic in only one direction was affected and this volume was exactly half of the volume of traffic in both directions.

The speed reductions caused due to the presence of cold batches, steel plates and signs after the construction hours were also considered. A 24 hour traffic volume of 18,100 vehicles/day was found from the (ODOT, 2009). The average of all the traffic volumes on N. Main Street from 8:00 am to 6:00 pm given above was 13,710 Vehicles and was subtracted from the 24 hour traffic volume to get the traffic volume from 8:00 am to 6:00 pm as 4,390 vehicles. Speed reduction of 10 MHP and 5 MPH was considered for open-cut and pipe-bursting methods respectively. In this case no lane is closed and the speed reduction is purely due to uneven surface and minor obstructions caused by the signs. Knowing the traffic volume, duration and the reduced speed the additional fuel consumption was calculated.

The traffic control plan 4 was used in each of the calculations; since N. Main Street is a 4 lane street either 2 lanes or 1 lane was closed every time during both the methods. For pipe-bursting, two lanes were needed to be closed during the excavation, set-up and backfilling phases. While during the bursting phase only one lane was considered to be closed, since there is no moving machinery and material during actually bursting phase. For open-cut two lanes were considered to be closed the whole time.

A timeline was formulated for both methods taking into consideration all the detailed construction activities and the time required for each one of them. This enabled the researcher to have a clear idea about the length of the traffic control zones and their durations, both of which are critical components in determining the increased fuel consumption due to traffic disruption. Figures 4, 5, 6 & 7 show the timeline worksheets for open-cut, pipe-bursting and the asphalt restoration process for both methods. The timeline depicts the real work conditions and accounts for time delays due to site and management factors. Asphalt restoration process is considered to be separate since it begins after the pipeline construction is over and is completed all at once.

Days	Monday		Tuesday				Wednesday			
Time										
8:00-8:30	Placing cones and	Placing cones	Placing cones	Placing cones	Placing cones and	Placing cones	Placing Cones	Placing Cones	Placing Cones	Placing Cones
8:30-9:00	Making cut into asphats (1)		Backfilling and	Putting aggregat			Backfilling and	Putting aggregat		
9:00 -9:30			Cold batch (1)	Backfilling and Compacting (3)			Cold batch	Compacting and Backfilling (3)	Exploring for the utilities and Excavating (3)	
9:30 - 10:00	Exploring for the utilities and Excavating (3)				Exploring for utlities and Excavating (2)					
10:00 - 10:30										
10:30 - 11:00										
11:00 - 11:30				Cold batch (1)				Cold batch (1)	Laying the	
11:30 - 12:00	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Lunch Break
12:00 - 12:30	Laying the bedding material	Exploring for the utilities and Excavating (2)			Laying the bedding material	Exploring for the utilities and Excavating (3)			Placing the pipe and fitting	Exploring for the utilities and excavating
12:30 - 1:00	Placing the pipe and fitting (2)				Placing the pipe and fitting (2)					
1:00 - 1:30									Putting aggregat	
1:30 - 2:00	putting aggregate				Putting aggregate				Backfilling and Compacting	
2:00 - 2:30	Backfilling and Compacting (3)	Laying bedding			Backfilling and Compacting (3)	Laying the				Laying the
2:30 - 3:00		Placing the pipe and fitting (2)				Placing the pipe and fitting				Placing the pipe and fitting
3:00 - 3:30										
3:30 - 4:00	Site clearing	Site clearing	Site clearing	Site clearing	Site clearing	Site clearing	Site clearing	Site clearing	Site clearing	Site clearing

Figure 4. Timeline spreadsheet for open-cut

Time	Monday		Tuesday		Wednesday		Thrusday	
8:00 - 8:30	Placing cones and preparing	Placing cones	Placing cones and preparing	Placing cones and preparing	Placing cones and preparing	Placing cones and preparing	Placing cones and preparing	Placing cones and preparing
8:30 - 9:00	Marking out the areas to be cut	Making the fusion joints for 300' long pipe (2 persons)	Excavating for laterals and shoring (3)	Bring pipe on the site (1)	Placing the pluggs and inflating (2)	Lowering bursting head (2)	Backfilling and compacting (3)	Excavating for laterals and shoring (3)
9:00 -9:30								
9:30 - 10:00	Asphalt cutting for entry pit (1		Getting the air hose through the pipe (2)	Enlargement of pipe dia inside manhole and removing the benching (2)				Bring pipe on the site (1)
10:00 - 10:30	Exploring the utilities, Excavating the entry pit (3 persons)				Run pump and disconnect laterals (2)	Exploring for utilities and Excavating for the entry pit (3)		
10:30 - 11:00			Joining the bursting head to the hose and pipe (3)				Cold Batch (2)	Getting the air hose through the pipe (2)
11:00 - 11:30					Lunch Break			
11:30 - 12:00	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Pipe bursting (3)	Lunch Break	Lunch Break	Lunch Break
12:00 - 12:30	exploring the utilities and excavating and shoring(3)	Making the fusion joints for next 300' long pipe (2 persons)	Joining the bursting head to the hose and pipe (3)	Bypass Excav. (1)		Exploring for utilities and Excavating for the entry pit and shoring (3)	Joining the bursting head to the hose and pipe (3)	Enlargement of pipe dia inside manhole and removing the benching (2)
12:30 - 1:00					Letting the pipe shrink & Doing the benching for manhole			
1:00 - 1:30			Layin out the bypass line (2)	Threading the cable through the old pipeline (2)				
1:30 - 2:00								
2:00 - 2:30								Threading the cable through the old pipeline (2)
2:30 - 3:00	Exacavating the laterals (3persons)		Setting up the winch in place (3)		Connect laterals and remove the plugs (2)	Excavating for laterals (3)	Setting up the winch in place (3)	
3:00 - 3:30								
3:30 - 4:00	Clearing the site	Clearing the site	Clearing the site	Clearing the site		Clearing the site	Site clearing	Site clearing

Figure 5. Timeline spreadsheet for pipe-bursting

Day 1	1st 300'	2nd 300'	3rd 300'	4th 300'	5th 300'	6th 300'
8:00 - 8:15	Placing cones and Preparing					
8:15 - 8:30						
8:30 - 8:45	Cutting asphalt for Entry pit and laterals (1)					
8:45 - 9:00						
9:00 -9:15						
9:15 - 9:30	Excavating (2)	Cutting asphalt for Entry pit and laterals (1)				
9:30 - 9:45						
9:45 - 10:00	Base course (2)					
10:00 - 10:15	Compacting (2)	Excavating (2)				
10:15 - 10:30						
10:30 - 10:45	Tack Coat (1)	Base Course (2)				
10:45 - 11:00	Laying asphalt (2)	Compacting(2)				
11:00 - 11:15			Cutting asphalt			
11:15 - 11:30	Rolling (1)	Tack coat (1)				
11:30 - 12:00	Lunch Break	Lunch Break	Lunch Break	Lunch Break		
12:00 - 12:15	Rolling (1)	Laying asphalt (2)	Cutting asphalt			
12:15 - 12:30			Excavating (2)	Cutting asphalt for Entry pit and laterals (1)		
12:30 - 12:45		Rolling (1)				
12:45 - 1:00			Base course (2)			
1:15 - 1:30			Compacting (2)	Excavating (2)	Cutting asphalt for Entry pit and laterals (1)	
1:30 - 1:45			Tack coat (1)	Base course (2)		
1:45 - 2:00			Laying asphalt (2)	Compacting (2)		
2:00 - 2:15					Excavating (2)	
2:15 - 2:30			Rolling (1)	Tack coat (1)		Cutting asphalt for Entry pit and laterals (1)
2:30 - 2:45				Laying asphalt (2)	Base course (2)	
2:45 - 3:00					Compacting (2)	
3:00 - 3:15				Rolling (1)		Excavating (2)
3:15 - 3:30					Tack coat (1)	
3:30 - 3:45					Clearing the site	Clearing the site
3:45 - 4:00						

Figure 6. Timeline spreadsheet of asphalt restoration for pipe-bursting. The number is parenthesis shows the number of persons required to do the job.

8:00-8:30	Placing cones and Preparing					
8:30-9:00	Cutting asphalt for Entry pit and laterals (1)					
9:00 -9:30	Excavating (2)	Cutting asphalt for Entry pit and laterals (1)				
9:30 - 10:00	Base course (2)					
10:00 - 10:30	Compacting (2)	Excavating (2)				
10:30 - 11:00	Tack Coat (1)	Base Course (2)				
11:00 - 11:30	Rolling (1)	Tack coat (1)	Cutting asphalt			
11:30 - 12:00	Lunch Break	Lunch Break	Lunch Break	Lunch Break		
12:00 - 12:30	Rolling (1)	Laying asphalt (2)	Cutting asphalt Excavating (2)	Cutting asphalt for Entry pit and laterals (1)		
12:30 - 1:00		Rolling (1)	Base course (2)			
1:00 - 1:30			Compacting (2)	Excavating (2)	Cutting asphalt for Entry pit and laterals (1)	
1:30 - 2:00			Tack coat (1)	Base course (2)		
2:00 - 2:30			Laying asphalt (2)	Compacting (2) Tack coat (1)	Excavating (2)	Cutting asphalt for Entry pit and laterals (1)
2:30 - 3:00			Rolling (1)	Laying asphalt (2)	Base course (2) Compacting (2)	
3:00 - 3:30				Rolling (1)	Tack coat (1)	Excavating (2)
					Site Clearing	Site Clearing

Figure 7. Timeline spreadsheet of asphalt restoration for open-cut

Determining construction machinery fuel consumption

As explained in the methodology chapter, all the machinery fuel consumption was calculated by multiplying the duration for which the machinery was working and its fuel consumption rate at full load. The fuel consumption rates were derived from the company literature and by talking to the machine manufacturers. Load factors were applied to these estimates to adjust for fact that the machine does not work at full capacity all the time. The fuel consumed by the transportation vehicle in transporting the material from the factory to site was also considered. It was calculated simply by multiplying the distance travelled by the mileage of these vehicles. The production rates of the machines were estimated from RS Means Heavy Construction Cost Data (1996) while taking into consideration the site and Management factors which will affect the production rates.

Calculating the increased fuel consumption due to traffic disruption

The increased fuel consumption due to traffic disruption was calculated to be 1089 gallons and 348 gallons for open-cut and pipe-bursting respectively as shown in Figure 8. This gives us the CO_2 emission of 21,447.86 pounds for open-cut and 6,849.11 pounds for pipe-bursting. Thus there is a reduction of 68.0 percent in traffic disruption increased fuel consumption during pipe-bursting as compared to open-cut method. This reduction is mainly due to shorter job duration as well as lesser obstruction to traffic during pipe-bursting process. It should be noted that all this increased fuel consumption is due to speed reduction caused due to disruption to traffic. It was assumed that 10 percent of the vehicles on the road worked on diesel powered engine and remaining 90 percent worked on gasoline powered engine. Using these factors the CO_2 emitted by 1 gallons of fuel was determined.

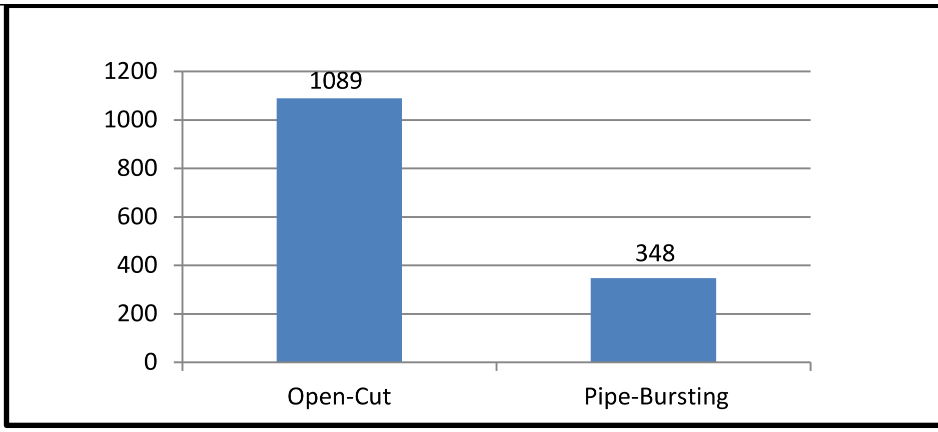

Figure 8. The fuel consumption comparison for open cut and pipe-bursting due to traffic disruption (in gallons)

Results obtained from calculating the machinery fuel consumption

The fuel consumption due to construction machinery was calculated to be 5716 Gallons and 1518 gallons for open-cut and pipe-bursting respectively as shown in Figure 9. This gives the CO_2 emission is 126829.2 for open cut and 33715.1 for pipe-bursting. Thus there is a reduction of 73.4 percent in the CO_2 during pipe-bursting as compared to open-cut method. This reduction is mainly due to lesser excavation, lesser asphalt restoration and shorter job duration.

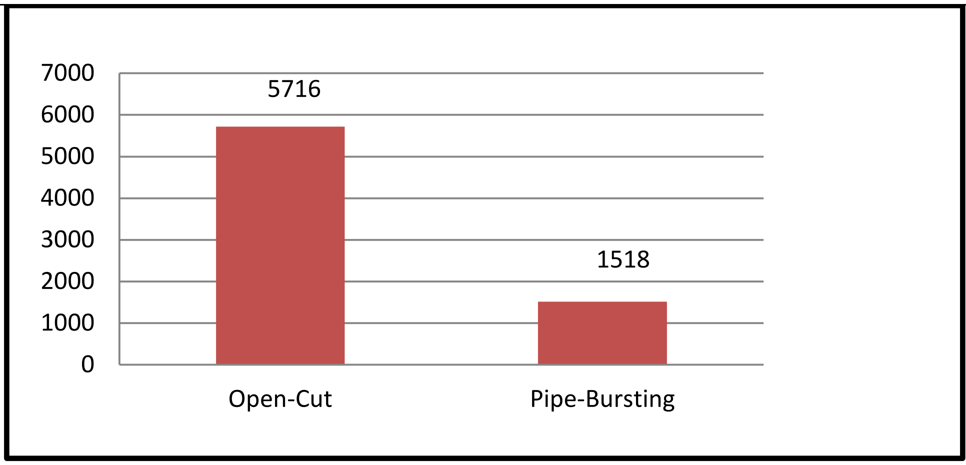

Figure 9. Construction Machinery fuel consumption comparison between open-cut and pipe-bursting

Total CO_2 emission comparison for open-cut and pipe-bursting

The CO_2 emitted during the open-cut process from machinery and traffic is much more in comparison to pipe-bursting. The total CO_2 was calculated to be 148,227.05 pounds for open-cut and 40,564.22 pounds for pipe-bursting as shown in Figure 10, which is 72.6 percent less as compared to open-cut. This is a drastic reduction achieved mainly due to lesser excavation, shorter job duration and lesser traffic disruption.

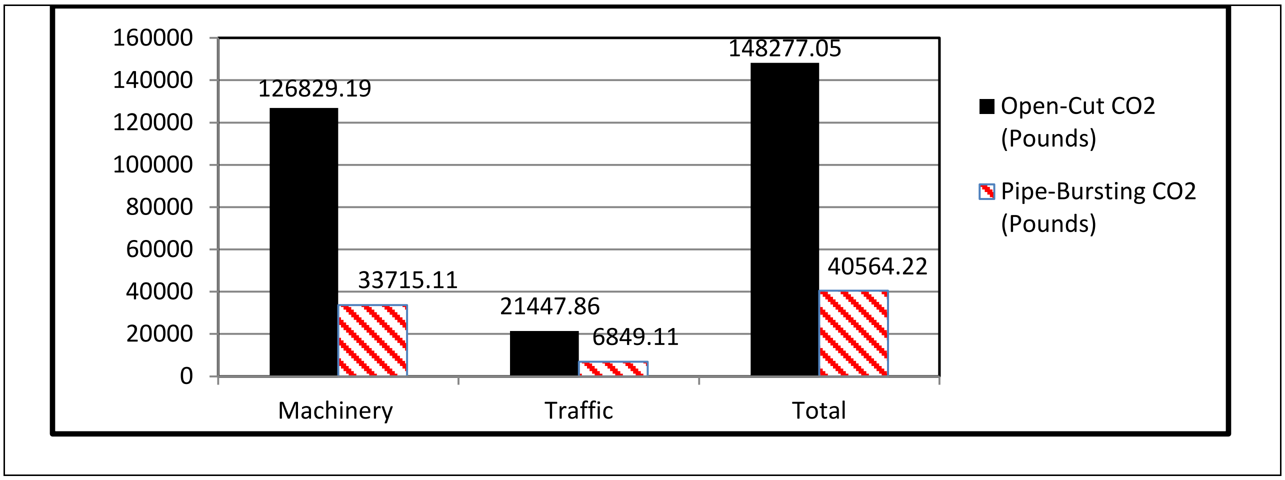

Figure 10. Total CO_2 emission comparison for open-cut and pipe-bursting

The Total CO_2emission from construction machinery and due to traffic disruption for open-cut was calculated to be 126,829.19 pounds and 21,447.86 pounds respectively. For open-cut as shown in Figure 11, the CO2 emission from construction machinery constitutes of 83.0 percent of total CO_2 emission. Similarly, for pipe-bursting the CO_2 emission from machinery constitutes of 79.6 percent of the total CO_2 emission.

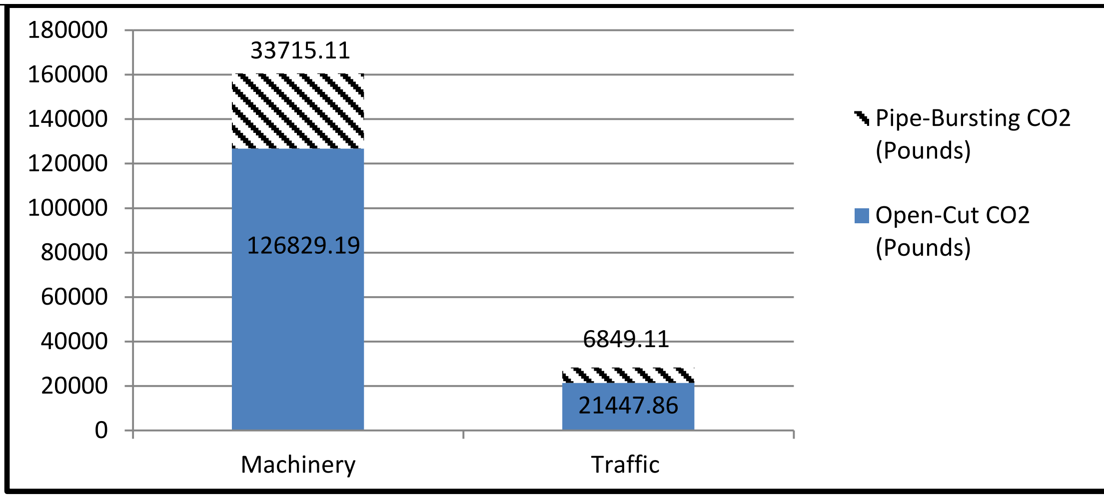

Figure 11. The CO2 emission comparison for machinery and traffic

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

This study aimed towards finding the CO_2 emission caused due to open-cut and pipe-bursting methods. The CO_2 emission calculation was divided into two parts.

1. CO_2 emitted by the construction machinery.
2. Excess CO_2 emitted due to disruption to traffic.

The study was based on actual site observations recorded from an underground utility project located along N. Main Street in Bowling Green, OH. For the purpose of study, a sewer pipeline 5100 feet long, 10 feet deep and 8 inches in diameter was considered.

For calculating the machinery fuel consumption, the fuel consumption rates for each machine was found from manufacturer's literature and interviews. The duration was calculated by determining the volume of work and the production rate of the machines. The fuel consumed was then converted to CO_2 emission by using the conversion formulas discussed in Chapter 3.

For traffic fuel consumption various traffic control plans were established and the volume of traffic disturbed was calculated. The excess fuel consumed was calculated by using the formulas for speed reduction fuel consumption discussed in Chapter 3.

Conclusion

There were various objectives for which the above study was performed. After the results were derived the following objectives were achieved:

1. To determine the excess CO_2 emission due to traffic delay:

The traffic data was collected from the field observations as well as referring to the ODOT manuals. The traffic control plans were determined for both methods and the durations were determined from the timeline worksheet discussed in Chapter 4

- The increased fuel consumption due to traffic disruption was calculated to be 1089 gallons and 348 gallons for open-cut and pipe-bursting respectively. This gives us the CO_2 emission of 21,447.86 pounds for open-cut and 6,849.11 pounds for pipe-bursting.
- Thus there is a reduction of 68.0 percent in traffic disruption increased fuel consumption during pipe-bursting as compared to open-cut method.
- This reduction is mainly due to shorter job duration as well as lesser obstruction to traffic during pipe-bursting process.

2. To determine the CO2 emission by construction Machinery:

The above objective was met by collecting the data such as duration of work, production rate and fuel consumption. This fuel consumption was converted to CO_2 in pounds by using the conversion given in EPA (2005) and following results were obtained

- The fuel consumed was calculated to be 5716 Gallons and 1518 gallons for open-cut and pipe-bursting respectively. This gives the CO_2 emission is 126829.2 for open cut and 33715.1 for pipe-bursting.
- Thus there is a reduction of 73.4 percent in the CO_2 during pipe-bursting as compared to open-cut method.
- This reduction is mainly due to lesser excavation, lesser asphalt restoration and shorter job duration.

3. Net CO2 emission for both the methods and calculating the percentage CO_2 reduced by pipe-bursting:

This was found by simply adding up the result from the first two objectives to get the total CO_2 emission for both methods and deriving the percentage CO_2 reduced by pipe-bursting method

- The total CO_2 was calculated to be 148,227.05 pounds for open-cut and 40,564.22 pounds for pipe-bursting.
- This means 72.6 percent of CO_2 emission is reduced using pipe-bursting as compared to open-cut.
- The construction machinery constitutes of 83.0 percent of total CO_2 emission from open-cut method. Similarly, for pipe-bursting the machinery CO_2 emission constitutes of 79.6 percent of the total CO_2 emission. Thus machinery CO_2 is the major contributor towards the total CO_2.

Recommendations for Future Studies

1. This study was limited to gravity sever line of 5100 feet long, 10 feet deep and 8 inches in diameter. Thus, future study is recommended on pipeline of various lengths, depths and sizes.
2. There is need to study the CO_2 during the production of various pipe materials. This will have an impact since different methods use different pipe materials.
3. Fuel consumption rate for machinery needs to be measure in field since this correlation of fuel consumption rate and the type of machinery along with the site conditions is very complex.

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APPENDIX A

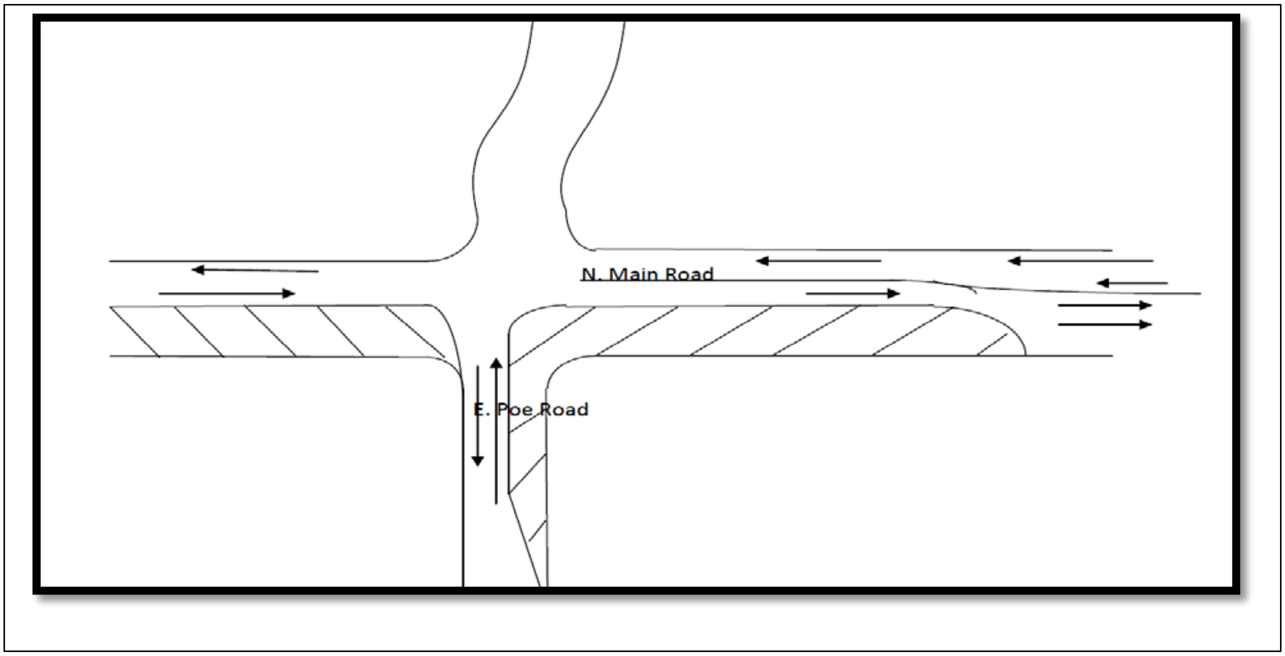

Figure 12. Shows a typical traffic control plan 4 for open cut where 2 lanes are closed for traffic

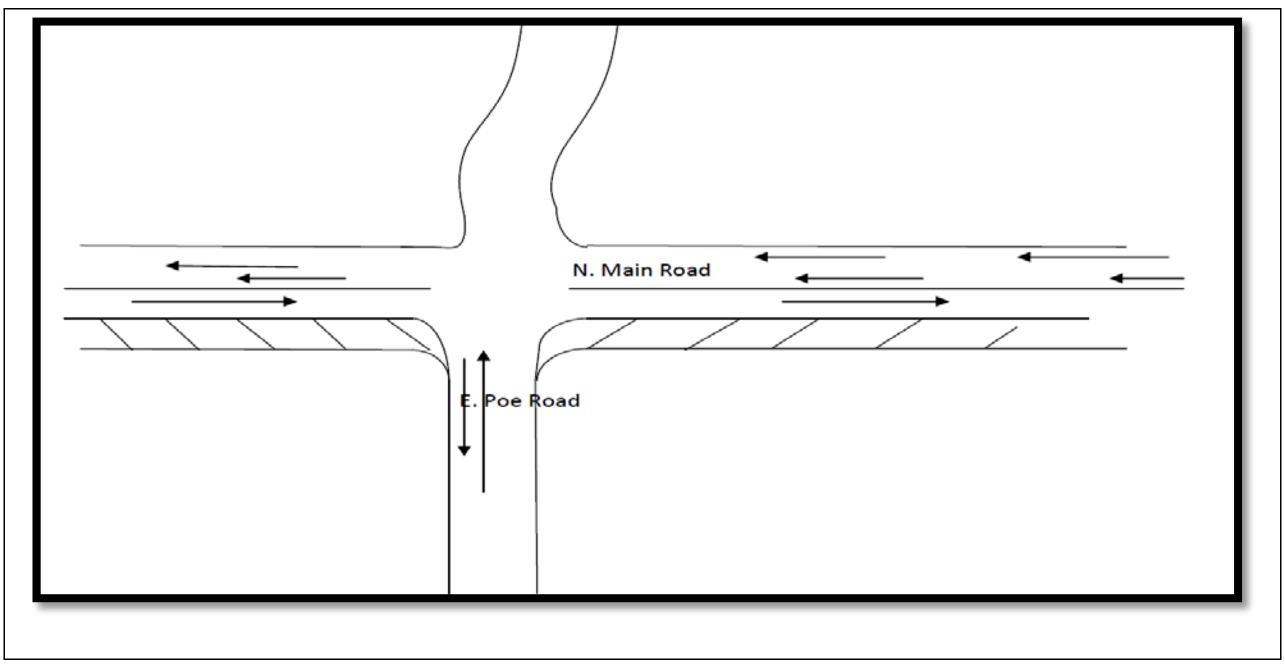

Figure 13. Typical traffic control plan 4 for pipe-bursting with one lane closed for traffic

APPENDIX B

	No. of bursti	**MH Spacing**	**Size of dewaterin**	**Length of pipeline (ft)**	**Bucket volume of**	**length of pipe (ft)**	**Length of the entry pit (Ft.)**		**Width at intersection Ft.**		
							Sloping part	10' deep	Poe	parkview	Mall
	17	300	900	5100	2.5	40	25	12	50	25	30
	Speed of loa	**Dist 1 trip**	**Depth**	**Cap. truck**	**Dia pipe**	**no. of MH**	**No. of Laterals**	Total	industrial	Kroger	
	5	1	10	20	0.66	18	44	37	25	30	
	Process	**Quantities**	**Unit**	**Prod Rate/hr.**	**Unit**	**Time (hours)**	**Machine**	**cons.**	**factor**	**Cons.**	**Remarks**
1	**Set up**										
1.1	Placing the Pluggs	34	Plugs	4	Hr.	8.5	PC 228 LC Komats	4.2	0.75	26.775	Time = Quantity /Production rate
1.2	Inflating the Pluggs	34	Plugs	6	Plugs/Hr.	5.666666667	Small Compresso	0.5	0.9	2.55	
1.3	Lowering the pump	17	Lowerings	4	Lowerings /Hr	4.25	WA 320 Komatsu	3.8	0.58	9.367	
1.5	Cutting the asphalt at intersection	160	Feet	100	Feet/Hr.	1.6	Vermeer CC135 A	2.5	0.9	3.6	
1.6	Excavating trenches for	5.92592593	CY	5	CY/Hr.	1.185185185	Trencher	1.5	0.78	1.386667	Total Consumption = Time*Fuel Cons.*Load Factor
1.7	Cold patch	1.18518519	Trips	5	Trips/Hr.	0.237037037	WA 320 Komatsu	3.8	0.7	0.630519	
1.8	Running the dewatering	9	Hrs.			153	2" Dewatering Pump	0.46	0.9	63.342	
1.9	Getting the HDPE pipes	17	Trips	3	Trips/Hr.	5.666666667	WA 320 Komatsu	3.8	0.7	15.07333	
1.10	Fusing the HDPE pipes	7	Joints	4	Joints/Hr.	29.75	Butt fusion machine	1.38	0.7	28.7385	
	Total									**151.463**	

Figure 14. Spreadsheet calculations for the machinery fuel consumption during the pipe-bursting process

	Process	Quantities	Unit	Prod Rate/hr.	Unit	Time (hours)	Machine	Fuel cons.	Load factor	Total Cons.	Remarks
2	**Entry Pit**		**Width of Entry Pit**		**Length of the entry pit (Feet)**						The length of the entry pit consist of a sloping portion and a 10 feet deep portion
			For slope	for 10' deep							
			1	3	37						
2.1	Making Cut into the asphalt	1446.7	Feet	100	Feet/Hr.	14.467	Vermeer CC 135 A	2.5	0.84	30.3807	Time = Quantity/Production rate
2.2	Excavating	305.3703704	CY	20	CY/Hr.	15.26851852	PC 228 LC Komatsu	4.2	0.81	51.9435	
2.3	Hauling the material from the site	311.2903704 124.5161481	CY Trips	5	Trips/Hr.	24.90322963	WA 320 Komatsu	3.8	0.7	66.24259	
2.4	Place and remove the	17	Placings	3	Place/Hr	5.666666667	PC 228 LC Komatsu	4.2	0.84	19.992	Total Consumption = Time*Fuel Cons.*Load Factor
2.5	Joining the bursting head to the pipe and compressor	17	Joints	1	Joint/Hr.	17	PC 228 LC Komatsu	4.2	0.75	53.55	
2.6	Placing the bursting head in the pit	17	Placings	2	Times/Hr.	8.5	PC 228 LC Komatsu	4.2	0.75	26.775	
2.7	Placing and removin the steel plates	34	Placings	6	Times/Hr	5.666666667	PC 200 LC Komatsu	4.2	0.75	17.85	
	Total									**266.7338**	

Figure 15. Fuel consumption during the entry pit preparation for pipe-bursting

	Process	Quantities	Unit	Prod Rate/hr.	Unit	Time (hours)	Machine	Fuel cons.	Load factor	Total Cons.	Remarks
3	**Bursting Process**										
3.1	Bursting	17	Bursting	1.5	Hrs./Burst	25.5	Compressor 400 CF	5.8	0.9	133.11	The three step in bursting are shown and the same equation are used for calculations
							Groundowich RW 1	2.12	0.9	48.654	
3.2	Taking the expander out	17	Times	12	Times/Hr	1.416666667	PC 200 LC Komatsu	4.2	0.78	4.641	
3.3	Reversing the Bursting	17	Reverse Pulls	4	Pulls/Hr.	4.25	PC 228 LC Komatsu	4.2	0.66	11.781	
	Total									**198.186**	
4	**Finishing**										
4.1	Removing the Blocks	34	Plugs	4	Plugs/Hr.	8.5	PC 228 LC Komatsu	4.2	0.78	27.846	
4.2	Backfilling for entry Pit	305.37	CY	5	Trips/Hr.	24.4296	WA 320 Komatsu	3.8	0.7	64.98274	
		122.148	Trips								
4.3	lowering the Compactpor	34	Lowering	6	Lowering/Hr.	5.666666667	PC 228 LC Komatsu	4.2	0.78	18.564	
4.4	Compacting	305.37	CY	7	CY/Hr.	43.62428571	LP8500 DYNAPAC	0.85	0.84	31.14774	
4.5	Cold Patch	1	Trip	5	Trips/Hr.	3.4	WA 320 Komatsu	3.8	0.7	9.044	
		17	Number	2	Hrs.	8.5	PC 228 LC Komatsu	4.2	0.75	26.775	
	Total									**178.3595**	

Figure 16. The fuel consumption during the bursting and finishing process for pipe-bursting

	Process	Quantities	Unit	Prod Rate/hr.	Unit	Time (hours)	Machine	Fuel cons.	Load factor	Total Cons.	Remarks
5	**Lateral trenches**	**Length**	**Width**	**Depth**							
		4	3	10							
5.1	Cutting the asphalt	8	Feet	100	Feet/Hr.	3.52	Vermeer CC 135A	2.5	0.84	7.392	The dimensions of lateral trenches are decided and then used in the steps in the process of lateral connections
5.2	Excavating lateral	195.5555556	CY	20	CY/Hr.	9.777777778	PC 228 LC Komatsu	4.2	0.81	33.264	
5.3	Hauling the material from	195.5555556	CY	5	Trips/Hr.	15.64444444	WA 320 Komatsu	3.8	0.7	41.61422	
		78.22222222	Trips								
5.4	Backfilling					15.64444444	624E John Deere	3.8	0.7	41.61422	
5.5	Compaction	195.5555556	CY			48.88888889	Multiquip Mvc82Vhw	0.31	0.84	12.73067	
		4	CY/Hr.								
5.6	Cold Patch	1	Trip	5	Trips/Hr.	3.4	WA 320 Komatsu	3.8	0.7	9.044	
		17	Number	2	Hrs.	8.5	PC 228 LC Komatsu	4.2	0.75	26.775	
5.7	Placing - removing the steel plates	44	Placings	6	Placing/Hr	7.333333333	PC 200 LC Komatsu	4.2	0.75	23.1	
	Total									**195.5341**	

Figure 17. Fuel consumption during the construction of lateral trenches for pipe-bursting

6	**material and equipments from store to**	**No. of pipes**	**loads for base**	**loads for asphalt**	Loads for pipe			No. of loading required for pipe, base and asphalt were determined	
		128	6	2	2				
		Milage	**Unit**		**Hours**	**Vehicles**	**Distance**	**Total Cons**	**Remarks**
6.1	cold patch	5	MPG			Sterline	40	8	Total Consumption = Distance/Milage
6.2	pipes (40 feet long)	4.77	MPG			Flat bed truck	70	14.6750524	
6.3	base material	5	MPG			Sterling	300	60	
6.4	Asphalt	5	MPG			Sterling	120	24	
6.5	plates and Boxes (2)	4.77	MPG			Flat bed truck -	40	8.38574423	
6.6	PC 200 LC	4.77	MPG			Flat bed truck -	70	14.6750524	
6.7	PC 228 LC	4.77	MPG			Flat bed truck -	70	14.6750524	
6.8	Groundwinch	16	MPG			GMC Sierra 2500	50	3.125	
6.9	Comp. & Burst Head	16	MPG			GMC Sierra 2500	50	3.125	
6.10	Compactor	16	MPG			GMC Sierra 2500	60	3.75	
6.11	Dewatering pump	16	MPG			GMC Sierra 2500	60	3.75	
6.12	Fusion Machine	16	MPG			GMC Sierra 2500	50	3.125	
6.13	Concrete machine	16	MPH			GMC Sierra 2501	40	2.5	
6.14	road signs & cones	5	MPG			Utility Truck	40	8	
6.15	Loading/unloading Pipes		12	Pipes/Hr.	10.66666667	WA 320 Komatsu	3.8 **GPH**	40.5333333	
	Total							**212.319235**	

Figure 18. Fuel consumption for moving the material and equipment for pipe-bursting

7	**Taking machinery to site and back**	**Distance/ Day**	**Number of days**	**Total distance**					
		1	52	52					
		Milage	**Unit**	**Time (Hrs.)**	**Vehicles**	**Fuel cons.**	**Load Factor**	**Total Cons**	**Remarks**
7.1	Compressor	16	MPH		GMC Sierra 2500 HD			3.25	52/16 = 3.25
7.2	Groundowinch	16	MPH		GMC Sierra 2500 HD			3.25	
7.3	Bursting Head			10.4	WA 320 Komatsu	3.8	0.85	33.592	
7.4	Compactor			10.4	WA 320 Komatsu	3.8	0.85	33.592	
7.5	Cones and Signs	10	MPH		Utility truck			5.2	
7.6	Trench Boxes			10.4	PC 228 LC Komatsu	4.2	0.75	32.76	
7.7	Placing the metal sheet and			10.4	PC 228 LC Komatsu	4.2	0.81	35.3808	
	Total							**111.644**	

Figure 19. Fuel consumption for moving the machinery and material on the site

8	Asphalt Restoration	Entry Pit (For asphalt cutting)			Depth of asphalt	Depth of Base Ft.	Laterals (Asphalt cutting)			Area of concrete (Sft)	Area of restoration Sqft.
		Length(Ft)	Width (Ft)	Depth (Ft.)			Length (Feet)	Width	Depth (Ft.)		
		25	3	1.33	0.33	1	4	5	1.33	12.75625	3175
		12	5	1.33							
	Process	**Quantities**	**Unit**	**Rate/hr.**	**Unit**	**Time (hours)**	**Machine**	**cons.**	**factor**	**Cons.**	**Remarks**
8.1	Making Cut into the Asphalt	1610	Feet	100	Feet/Hr.	16.1	Vermeer CC 135A	2.5	0.84	33.81	
8.2	Excavating the top 2 feet	156.3981481	CY	40	CY/Hr.	3.909953704	PC 228 PC Komatsu	3.8	0.81	14.85782	The top row shows the various dimensions used in the calculations
8.3	Hauling the excavated material	20	CY	0.75	Loads/Hr.	10.42654321	Sterling	7	0.75	54.73935	
		7.819907407	Trips								
8.4	Laying the Base course	117.5925926	CY	5	Trips/Hr.	9.407407407	WA 320 Komatsu	3.8	0.7	25.0237	
		47.03703704	Trips	30	CY/Hr.	3.919753086	416 E CAT Backhoe	4	0.75	11.75926	Following formulae are used
8.5	Compacting	117.5925926	CY	15	CY/Hr.	7.839506173	Compactor	1.25	0.84	8.231481	
8.6	Tack coat	3175	sqft.	1000	sqft./Hr.	4.675	Truck	4.5	0.75	15.77813	Time = Quantity/Production rate
		1.5	Hrs.								
8.7	Asphalt restoration	38.80555556	CY	15	CY/Hr.	2.587037037	416 E CAT Backhoe	4	0.75	7.761111	
8.8	Rolling the asphalt	3175	sqft.	500	sqft./Hr.	12.7	Dynapac CA25PD road roller	3	0.84	32.004	Total Consumption = Time*Fuel Cons.*Load Factor
		2	layers 2"								
8.9	Concreting around the	2.806375	CY	8.88	CY/Hr.	0.316033221	concrete mixer	2	0.78	0.493012	
	Total									**204.4579**	
	Gross Total (Gallons)									1518.69	
	CO2 emission (Pounds)									33715.11	

Figure 20. Fuel Consumption during asphalt restoration for pipe-bursting

APPENDIX C

	Length of line (Ft)	Length of 1 pipe (Ft)	Dist. For 1 trip (Mile)	Depth of trench	Width of trench	Speed WA 320 (Miles/H	Speed of Hauling truck (Miles/hr.)	Site factor	Volume (Cft)	Volume of excav. (CY)	loader bucket
	4940	20	1	10	3	5	35	0.9	148200	5488.889	**2.5**
Sr. No.	**Process**	**Quantitie**	**Unit**	**Prod Rate**	**Unit**	**Time (Hrs**	**Machine**	**Fuel Cons.**	**Load factor**	**Diesel Cons**	**Remarks**
1	**No intersection: The length of this line = 5100-160 = 4940**										calculations are for the portion of road without any intersections
1	**Making cut into asphalt**	10200	Feet	100	**Feet/Hr.**	102	Vermeer CC135 A	2.5	0.84	214.2	
2	**Moving pipes from Inventory**	123.5	Trips	5	**Trips/Hr.**	24.7	WA 320 Komatsu	5	0.75	92.625	
3	**Excavating the trench**	5488.889	**CY**	25	**CY/Hr.**	219.5556	PC 228 LC Komatsu	4.2	0.81	746.928	
4	**Placing the trench box and**	247	**Placings**	4	**Placing/Hr.**	61.75	PC 228 LC Komatsu	4.2	0.84	217.854	
5	**Hauling the material to the**	1278.911	**CY**	23.3	**Percentage**	85.26074	Sterling LT 9513	7	0.7	417.7776	
		63.94556	**Loads**	0.75	**Loads/Hr.**						
6	**Hauling exacavated**	1460.044	**CY**	26.6	**Percentage**	116.8036	WA 320 Komatsu	3.8	0.7	310.6975	
		584.0178	**Trips**	5	**Trips/Hr.**						
7	**Hauling of material to**	2744.444	**CY**	50	**Percentage**	91.48148	WA 320 Komatsu	3.8	0.7	243.3407	
		1097.778	**Trips**	12	**Trips/Hr.**						

Figure 21. Fuel consumption calculations for open-cut for the non-intersection area (Continued on next page)

Sr. No.	Process	Quantitie	Unit	Prod Rate	Unit	Time (Hrs	Machine	Fuel Cons.	Load factor	Diesel Cons	Remarks
8	Laying out	1.111111	CY	5	Trips/Hr.	49.4	WA 320 Koma	3.8	0.7	131.404	
	the bedding	247	Trips	12	levels/Hr.	20.58333	PC 200 LC Kom	4.2	0.78	67.431	
9	Placing the	247	Placings	6	Placings/	41.16667	PC 200 LC	4.2	0.75	129.675	
	pipe and				Hr.		Komatsu				
10	Putting	2.592593	CY	5	Trips/Hr.	49.4	WA 320	3.8	0.7	131.404	
	aggregate	247	Trips				Komatsu				
11		1460.044	CY	5	Trips/Hr.	116.8036	WA 320	3.8	0.7	310.6975	
	Backfilling	584.0178	Trips				Komatsu				
12	Placing	247	Placings	12	Placings/	20.58333	PC 228 LC	4.2	0.78	67.431	
	compactor				Hr.		Komatsu				
13		4391.111	CY	10	CY/Hr.	439.1111	LP 8500	0.85	0.84	313.5253	
	Compacting						DYNAPAC				
14		0.733333	CY	5	Trips/Hr.	49.4	WA 320	3.8	0.7	131.404	
	Cold patch	247	Trips				Komatsu				
15	Placing and	40	Feet/day	6	Times/Hr.	20.5	PC 200 LC	4.2	0.75	64.575	
	removing	123	Days				Komatsu				
	Total									**1347.547**	

Figure 21. Fuel Consumption calculations for open-cut at non-intersection area

Sr. No.	Process	Quantities	Unit	Prod Rate	Unit	Time (Hrs)	Machine	Fuel Cons.	Load factor	Diesel Cons	Remarks
2	**At the intersections**	**Volume (CY)** 177.777778	**Length of pipe (Ft)** 10		**Length of this line** 160						volume of the excavation and the lenghts of pipe are mentions in the top row
1	**Excavating the trench**	177.777778	**CY**	25	**CY/Hr.**	7.111111	PC 228 LC Komatsu	4.2	0.81	24.192	
2	**Moving pipe from the**	8	**Trips**	5	**Trips/Hr.**	1.6	WA 320 Komatsu	5	0.75	6	
3	**Placing the trench box**	16	**Placings**	4	**Placings/Hr.**	4	PC 228 LC Komatsu	4.2	0.84	14.112	
4	**Hauling the material**	8.88888889	**Trips**	0.75	**Loads/Hr.**	6.666667	Sterling LT 9513	7	0.7	32.66667	
5	**Laying the bedding**	16	**Trips**	5	**Trips/Hr.**	3.2	WA 320 Koma	3.8	0.7	8.512	
				12	**Levels/Hr.**	1.333333	PC 228 LC Kor	4.2	0.75	4.2	
6	**Placing the pipe and**	16	**Placings**	6	**Placings/Hr.**	2.666667	PC 228 LC Komatsu	4.2	0.75	8.4	
7	**Putting aggregate**	16	**Trips**	5	**Trips/Hr.**	3.2	WA 320 Komatsu	3.8	0.7	8.512	
8	**Backfilling**	56.8888889	**Trips**	5	**Trips/Hr.**	11.37778	WA 320 Komatsu	3.8	0.7	30.26489	
9	**placing the compactor**	16	**Placings**	12	**Placing/Hr.**	1.333333	PC 228 LC Komatsu	4.2	0.78	4.368	
10	**Compacting**	142.222222	**CY**	7	**CY/Hr.**	20.31746	LP 8500 DYNAPAC	0.85	0.84	14.50667	
11	**Cold patch**	16	**Trips**	5	**Trips/Hr.**	3.2	WA 320 Koma	3.8	0.7	8.512	
				50	**Ft./Hr.**	3.2	PC 200 LC Kor	4.2	0.75	10.08	
12	**Placing and Removing**	20	**Feet**	6	**Times/Hr.**	1.333333	WA 320 Komatsu	4.2	0.75	4.2	
		8	**Days**								
	Total									**178.5262**	

Figure 22. Fuel Consumption for open-cut at the road intersection area

Sr. No.	Process	Quantities	Unit	Prod Rate	Unit	Time (Hrs)	Machine	Fuel Cons.	Load factor	Diesel Cons	gas Cons.	Remarks
3	**Placing the Manholes**	**Dimensions (Excavation) (ft.)**		**Width outside the trench**	**No. of manholes**	**Volume (CY)**						The dimension for excavation and volume are mentioned in the top row and are used in the calculations
		Length	**Width**									
		8	**8**	5	18	266.66667						
1	**Excavation**	266.66667	**CY**	25	**CY/Hr.**	10.666667	PC 228 LC Komatsu	4.2	0.81	36.288		
3	**Laying the bedding**	18	**Trips**	5	**Trips/Hr.**	3.6	WA 320 Komatsu	3.8	0.7	9.576		
				6	**MH. Hr.**	3	PC 200 LC Komat	4.2	0.75	9.45		
4	**Constructing the manhole**			1.5	**Hr./MH**	27	PC 228 LC Komat	4.2	0.81	91.854		
5	**Backfilling**	106.66667	**Trips**	5	**Trips/Hr.**	21.333333	WA 320 Komatsu	3.8	0.7	56.74667		
6	**Compacting**	4	**CY/Hr.**			66.666667	Multiquip Tamper plate	0.31	0.84		17.36	
	Total									**203.9147**	**17.36**	

Figure 23. Fuel consumption during placing the manholes for open-cut method

Sr. No.	Process	Quantities	Unit	Prod Rate	Unit	Time (Hrs)	Machine	Fuel Cons.	Load factor	Diesel Cons	Remarks
4	**Connecting laterals to the main**			**Length (Ft) Lateral**	**Number of laterals**						
				10	**25**						
1	Excavating for laterals	277.77778	**CY**	**25**	**CY/Hr.**	11.11111	PC 200 LC Komatsu	4.2	0.81	37.8	
2	Hauling the material to	111.11111	**Trips**	**5**	**Trips/Hr.**	22.22222	WA Komatsu 320	3.8	0.7	59.11111	Time = Quantity /Production rate
3	Laying the bedding	25	**Times**	**5**	**Times/Hr.**	5	WA Komatsu 32	3.8	0.7	13.3	
				12	**Levels/Hr.**	2.083333	PC 200 LC Koma	4.2	0.75	6.5625	
4	Placing the pipe and	25	**Placings**	**6**	**Placings/ Hr.**	4.166667	PC 200 LC Komatsu	4.2	0.75	13.125	Total Consumption = Time*Fuel Cons.*Load Factor
5	Putting aggregate	25	**Trips**	**5**	**Trips/Hr.**	5	WA Komatsu 320	3.8	0.7	13.3	
6	Backfilling	212.77778	**CY**	**5**	**Trips/Hr.**	17.022	WA Komatsu 320	3.8	0.7	45.27852	
		85.11	**Trips**								
7	Compacting	212.77778		**7**	**CY/Hr.**	30.39683	LP 8500 DYNAPAC	0.85	0.84	21.70333	
8	Cold patch	25	**Trips**	**5**	**Trips/Hr.**	5	WA Komatsu 32	3.8	0.7	13.3	
		250		**50**	**Ft./Hr.**	5	PC 200 LC Koma	4.2	0.75	15.75	
	Total									**239.2305**	

Figure 24. Fuel Consumption during connection of the laterals to the main line during the open-cut

5	**machinery from Factory to site**		**Number of pipes**								
			20 Feet	**10 Feet**	**Total**						
			247	16	263						
		fuel Milage (MPG)	**Unit**	**Prod Rate**	**Distance**	**Time**	**Machine**	**Fuel Cons.**	**Load Factor**	**Total Cons**	**Remarks**
1	**Pipe**	4.77	**MPG**		70		Flat bed truck - 5565 HRST 07			14.67505	
2	**Loading and unloading the**			12 **Pipes/Hr**		21.91667	WA 320 Komatsu	3.8 **GPH**	0.78	64.961	
3	**Steel Plates and Trench**	4.77	**MPG**		40		Flat bed truck - 5565 HRST 07			8.385744	Total Consumption = Distance/ fuel Milage
4	**Road Signs and Cones**	5	**MPG**		40		Utility truck			8	
5	**Compactor**				60	3	WA 320 Komatsu	3.8	0.84	9.576	
6	**PC 228 LC Komatsu**	4.77	**MPG**		70		Flat bed truck - 5565 HRST 07			14.67505	
7	**PC 200 LC Komatsu**	4.77	**MPG**		70		Flat bed truck - 5565 HRST 07			14.67505	
8	**Cold patch**	5	**MPG**		40		Sterling			8	
	Total									**142.9479**	

Figure 25. Fuel consumption from moving the machinery from factory to site

6	**Asphalt Restoration**	Depth of excavation	Area of trench sqft	Area of manholes Sqft.	Depth of asphalt	Width of excav.	Depth of Base course (Ft.)					
		1.33	26750	1260	0.33	5	1					
Sr. No.	**Process**	**Quantities**	**Unit**	**Prod Rate**	**Unit**	**Time (Hrs)**	**Machine**	**Fuel Cons.**	**Load factor**	**Diesel Cons**	**gas Cons.**	**Remarks**
1	Making cut	11026	Feet	100	Feet/Hr.	110.26	Vermeer CC	2.5	0.84	231.546		The top row shows all the dimensions and quantities used in the calculation for asphalt restoration
2	Excavating the	1379.751852	CY	40	CY/Hr.	34.4937963	PC 228 PC	4.2	0.78	113.0017		
3	Hauling the	20	CY/Load	0.75	Loads/Hr.	51.74069444	Sterling	7	0.7	253.5294		
		68.98759259	Loads									
4	Laying the base	1037.407407	CY	5	Trips/Hr.	82.992	WA 320 Komat	3.8	0.7	220.7587		
		414.96	Trips	15	CY/Hr.	69.16049383	416 E CAT Backhoe	4	0.75	207.4815		
5	Compacting	7	CY/Hr.			148.2010582	LP 8500 DYNAP	0.85	0.84	105.8156		
6	sphalt restoratio	342.3444444	CY	15	CY/Hr.	22.82296296	416 E CAT Backhoe	4	0.75	68.46889		
7	Rolling	28010	sqft	500	sqft/Hr.	56.02	Dynapac CA25PD road	3	0.84	141.1704		
8	Concreting around the Manhole	2.8	CY	8.88	CY/Hr.	0.315315315	Concrete mixer	2	0.78	0.491892		
Total										**1342.264**		
	Gross Total (Gallons)									**5697.85**	**17.36**	Total fuel consumed (Gallons)
	CO2 emission (Pound)									**126492.3**	**336.784**	Total CO2 emitted (Pounds)
	Total CO2 emission (Pounds)										**126829.1**	

Figure 26. Fuel consumption during the asphalt restoration and total CO_2 for open-cut

APPENDIX D

Times		8 am - 9 am		9 am - 10 am		10 am - 12 pm		12 pm - 1 pm		1 pm-2 pm		2 pm -4 pm		4 pm - 6 pm		
Type os vehicles		Cars/min	Heavy	cars/min	heavy	Cars/min	Heavy	Cars/min	Heavy	Cars/min	Heavy	Cars/min	Heavy	Cars/min	Heavy	
Days	Average Numbers															Remarks
8/10/2011						26	4			28	3					These are the actual site readings taken at different times of the day (Vehicle/Min.)
8/17/2011										25	3			29	2	
8/19/2011						30	3			38	2	33	2			
8/22/2011								37	2							
9/2/2011										27	1					
9/8/2011						23	2	37	1	26	1					
9/19/2011												25	1	28	2	
						26	3							29	1	
9/28/2011						19										
10/10/2011						23	2									
10/18/2011						27	3	33	3							
10/26/2011		41	2									27	2	30	2	
										12		16	1	23	3	
11/15/2011														15	3	
11/16/2011		17				17	0.5									
11/20/2011								26	1	29	4	23	2	16	2	
11/28/2011				18.5	2	13										
				28	1			32	1	23	1					
12/6/2011				15	1			17	2	15	2					
		39	2									13	2	18.5	1	
		22	1	13										25	1	
12/8/2011		27	1	23												
				21												
				37	1			39	2	38	1					
12/9/2011				18.00	0.50			19	1	13	0.5					

		8 am - 9 am		9 am - 10 am		10 am - 12 pm		12 pm - 1 pm		1 pm-2 pm		2 pm -4 pm		4 pm - 6 pm		
Average per Hour	N. Main	2460		1950		1660		2260		2100		1800		1590		The above readings are convered to (Vehicles/Hr.)
	N'. Main	2340		1680		1380		1950		1600		1500		1740		
	Poe	1320		1095		1020		1140		840		960		1110		
	Kroger	1620		1320		1140		1560		1380		1380		1380		
	Mall	1020		840		780		1020		720		780		930		

Locations	N. Main	N' Main	Poe	Kroger	Mall	
AADT	18870	16810	10575	13680	8580	Then an average for the day was calculated

Figure 27. The traffic density measured during the day time from 8am-6pm

APPENDIX E

Bursting Zone	No. of Traffic	Location	Plan type	L'th of Zone (L)	Number of vehicles (T)	Duration (Hrs.)	Original speed	Reduced speed	Days (D)	Fuel increase	Remarks
Excavating, Set-up & Backfilling											
1	1	N. Main street south of Poe	Lanes Closed	0.135	16810	22	56.35	40.25	2.75	11.0724	Durations are calculated using the timeline spreadsheet
2	1	Poe and N.Main Intersection - N.Main North of Poe	Plan 4 - Two Lanes Closed	0.09	18870	20	56.35	40.25	2.5	7.532895	
3,4,5,6,7	5	N. Main street North of Poe	Plan 4 - Two Lanes Closed	0.135	18870	100	56.35	40.25	12.5	56.49671	Then these durations are converted to number of 8hr. Days
8,9,10,11, 12	5	N.Main at Kroger	Plan 4 - Two Lanes Closed	0.135	13680	100	56.35	40.25	12.5	40.95787	
13,14,15, 16,17	5	N.Main at Mall	Lanes Closed	0.135	8580	100	56.35	40.25	12.5	25.68849	
Total										**141.7484**	

Figure 28. Excess fuel consumption by traffic during the set-up, excavation and backfilling processes for the pipe-bursting

Bursting Zone	No. of Traffic areas	Location	Plan type	L'th of Zone (L) (Km)	No. of vehicles (T)	Duration (Hrs.)	Original speed (Vn) (Km/Hr.)	Reduced speed (Vr) (Km/Hr.)	Days (D)	Fuel increase due to Speed	Remarks
Bursting											
	1	N.Main South of	Plan 4 - One lane Closed	0.225	8405	9	56.35	40.25	1.125	3.774681	Bursting is performed for every 300 feet length and is considered to be a zone
1	1	North of Poe	Plan 4 - One lane Closed	0.075	9435	9	56.35	40.25	1.125	1.412418	
	1	South of Poe	Plan 4 - One lane Closed	0.135	8405	9	56.35	40.25	1.125	2.264808	
2	1	North of Poe	Plan 4 - One lane Closed	0.135	9435	9	56.35	40.25	1.125	2.542352	
	1	South of Poe	Plan 4 - One lane Closed	0.045	8405	9	56.35	40.25	1.125	0.754936	
3	1	North of Poe	Plan 4 - One lane Closed	0.255	9435	9	56.35	40.25	1.125	4.80222	
4,5	2	North of Poe	Plan 4 - One lane Closed	0.315	9435	18	56.35	40.25	2.25	11.86431	

Figure 29. Excess fuel consumption by traffic during the bursting process for pipe-bursting (Continued on next page)

Bursting Zone	No. of Traffic areas	Location	Plan type	L'th of Zone (L) (Km)	Number of vehicles (T)	Duration (Hrs.)	Original speed (Vn)	Reduced speed (Vr)	Days (D)	Fuel increase due to Speed Reduction	Remark
	1	N. Main North of Poe	Plan 4 - One lane Closed	0.21	9435	9	56.35	40.25	1.125	3.954769647	**Speed Reduction Increased Fuel**=(((3*0.000001*Vr*Vr-0.0004*Vr+0.0319)-(3*0.000001*Vn*Vn-0.0004*Vn+0.0319))*L)*T*D
6	1	N. Main at Kroger	Plan 4 - One lane Closed	0.105	6840	9	56.35	40.25	1.125	1.433525405	
	1	N. Main North of Poe	Plan 4 - One lane Closed	0.12	9435	9	56.35	40.25	1.125	2.25986837	
7	1	N. Main at Kroger	Plan 4 - One lane Closed	0.195	6840	9	56.35	40.25	1.125	2.662261466	
8,9,10,11	4	N. Main at Kroger	Plan 4 - One lane Closed	0.315	6840	36	56.35	40.25	4.5	17.20230485	
	1	N. Main at Kroger	Plan 4 - One lane Closed	0.21	6840	9	56.35	40.25	1.125	2.867050809	
12	1	N. Main at Mall	Plan 4 - One lane Closed	0.09	4290	9	56.35	40.25	1.125	0.770654635	
	1	N.Main at Kroger	Plan 4 - One lane Closed	0.12	6840	9	56.35	40.25	1.125	1.638314748	
13	1	N. Main at Mall	Plan 4 - One lane Closed	0.18	4290	9	56.35	40.25	1.125	1.54130927	
4,15,16,17	4	N. Main at Mall	Plan 4 - One lane Closed	0.315	4290	36	56.35	40.25	4.5	10.78916489	
Total										**45.11922409**	

Figure 29. Excess fuel consumption by traffic during the bursting process for pipe-bursting

Asphalt Restoration		Length of Trench for bypass		Rate of Restoration for trench							
		50		100							
Bursting Zone	Traffic areas	Location	Plan type	Zone (L) (Km)	of vehicles	Duration (Hrs.)	speed (Vn)	speed (Vr)	Days (D)	increase due to	Remarks
1	1	N. Main South of Poe	Plan 4 - Two Lanes Closed	0.135	16810	3.75	56.35	40.25	0.46875	1.88734	The rate of restoration is used to determine the number of hours required
2,3,4	3	N. Main North of Poe	Plan 4 - Two Lanes Closed	0.135	18870	9.75	56.35	40.25	1.21875	5.508429	
5,6	2	N. Main North of Poe	Plan 4 - Two Lanes Closed	0.135	18870	8.5	56.35	40.25	1.0625	4.80222	
7	1	N. Main North of Poe	Plan 4 - Two Lanes Closed	0.135	18870	3.75	56.35	40.25	0.46875	2.118627	
8,9	2	N. Main at kroger	Plan 4 - Two Lanes Closed	0.135	13680	6.5	56.35	40.25	0.8125	2.662261	
10	1	N. Main at Kroger	Plan 4 - Two Lanes Closed	0.135	13680	3.75	56.35	40.25	0.46875	1.53592	
11	1	N. Main at Kroger	Plan 4 - Two Lanes Closed	0.135	13680	4.25	56.35	40.25	0.53125	1.740709	
12	1	N. Main at Kroger	Plan 4 - Two Lanes Closed	0.135	13680	3.75	56.35	40.25	0.46875	1.53592	
13,14,15	3	N. Main at Mall	Plan 4 - Two Lanes Closed	0.135	0	9.75	56.35	40.25	1.21875	0	

Figure 30. Excess fuel consumption by traffic during the asphalt restoration process for pipe-bursting

Bursting Zone	No. of Traffic areas	Location	Plan type	L'th of Zone (L) (Km)	Number of vehicles	Duration (Hrs.)	Original speed (Vn)	Reduced speed (Vr)	Days (D)	Fuel increase due to	Remarks
16	1	N. Main at Mall	Plan 4 - Two Lanes Closed	0.135	8580	4.25	56.35	40.25	0.53125	1.091761	
17	1	N. Main at Mall	Plan 4 - Two Lanes Closed	0.135	8580	4.75	56.35	40.25	0.59375	1.220203	
Bypass Trench at Poe	1	N. Main south of Poe	Plan 4 - One Lane Closed	0.045	8405	2	56.35	40.25	0.25	0.167764	
	1	N. Main North of Poe	Plan 4 - One Lane Closed	0.045	9435	2	56.35	40.25	0.25	0.188322	
	2	Poe Road	Plan 4 - Two Lanes Closed	0.045	10575	4	56.35	40.25	0.5	0.422153	Speed reduction due to batches, plates and signs is also considered
Total										**27.386**	
Cold Batches, steel plates and signs											
		N. Main Street	no plan	0.765	4390	416	56.53	48.3	45	**106.35**	
Gross Total (Gallons)							**Final fuel consumption**			**348.01**	Fuel Consumed (Gallons)
							Excess CO2 (Pounds)			**6848.83**	CO2 emitted (Pounds)

Figure 31. Total excess CO_2 emission by traffic during the pipe-bursting process

APPENDIX F

No Intersection Zone (Feet) =4940	Length of line laid in 1 day (Feet/day)	N. main North of Poe	N. Main at Kroger	N. Main at Mall	N. Main South of poe	Hrs./day				
	40	1700	1500	1500	350	8				
Zone	**Location**	**Plan Type**	**Length of zone (Miles)(L)**	**No. of vehicles (T)**	**Duration (Hrs.)**	**Original speed (Vn)**	**Reduced speed (Vr)**	**Days (D)**	**Fuel increase due to**	**Remarks**
	N.Main south of Poe	Plan 4 - Two lanes closed	0.06	16810	70	56.35	40.25	8.75	15.65794	Top row shows the length of the cons. zones separated according to the traffic density
	N. Main north of Poe	Plan 4 - Two lanes closed	0.06	18870	340	56.35	40.25	42.5	85.37281	
	N. Main at Kroger	Plan 4 - Two lanes closed	0.06	13680	300	56.35	40.25	37.5	54.61049	
	N. Main at Mall	Plan 4 - Two lanes closed	0.06	8580	300	56.35	40.25	37.5	34.25132	Prod. rate was determined using timeline
Total									**189.8925**	

Figure 32. Excess fuel consumption by traffic during the open-cut process at the non-intersection zone

Intersection Zone	Length of pipe laid in 1 day	width of Parkview	Industrial driveway	Mall entrance	Kroger entrance	Width of Poe Road	Hrs./day			
160	12.5	25	25	30	30	50	8			
Zone	**Location**	**Plan Type**	**Length of zone**	**No. of vehicles**	**Duration (Hrs.)**	**Original speed**	**Reduced speed**	**Days (D)**	**Fuel increase due to Speed**	Remarks
Main and Poe intersection = 50 feet wide	Poe Road	Plan 4 - Two Lanes Closed	0.03	10575	32	56.35	40.25	4	2.25148518	Width of the roads at the intersections is mentioned in the top row and is used for determining the length of pipeline at intersection
	N. Main South of Poe	Plan 4 - Two Lanes Closed	0.036	16810	16	56.35	40.25	2	2.14737395	
	N.Main North of Poe	Plan 4 - Two Lanes Closed	0.036	18870	16	56.35	40.25	2	2.410526261	
At Parkview Drive	N. Main south of Parkview Drive	Plan 4 - Two Lanes Closed	0.036	18870	8	56.35	40.25	1	1.20526313	
	N. Main North of Parkview Drive	Plan 4 - Two Lanes Closed	0.036	18870	8	56.35	40.25	1	1.20526313	
At Industrial Parkway	N. Main south of Industrial Parkway	Plan 4 - Two Lanes Closed	0.036	13680	8	56.35	40.25	1	0.873767866	
	N. Main North of Industrial Parkway	Plan 4 - Two Lanes Closed	0.036	13680	8	56.35	40.25	1	0.873767866	
At Mall Entrance	N. Main South of Mall entrance	Plan 4 - Two Lanes Closed	0.036	8580	9.6	56.35	40.25	1.2	0.657625288	
	N. Main North of Mall entrance	Plan 4 - Two Lanes Closed	0.036	8580	9.6	56.35	40.25	1.2	0.657625288	
At Kroger Entrance	N. Main south of Kroger	Plan 4 - Two Lanes Closed	0.036	13680	9.6	56.35	40.25	1.2	1.048521439	
	N. Main North of kroger	Plan 4 - Two Lanes Closed	0.036	13680	9.6	56.35	40.25	1.2	1.048521439	
Total									**14.37974084**	

Figure 33. Excess fuel consumption by traffic during the open-cut process for the intersection zone

Zone	Location	Plan Type	Length of zone (Miles)(L)	No. of vehicles (T)	Duration (Hrs.)	Original speed (Vn)	Reduced speed (Vr)	Days (D)	Fuel increase due to	Remarks
Asphalt Restoration - No intersection zone		Hrs./day	N. Main South of Poe	N. Main North of Poe	N. Main at Kroger	N. Main at Mall	Feet/Day			
		8	350	1700	1500	1500	200			
	N. Main South of Poe	Plan 4 - Two Lanes Closed	0.135	16810	14	56.35	40.25	1.75	7.046071	
	N. Main North of Poe	Plan 4 - Two Lanes Closed	0.09	18870	68	56.35	40.25	8.5	25.61184	
	N. Main at Kroger	Plan 4 - Two Lanes Closed	0.09	13680	60	56.35	40.25	7.5	16.38315	
	N. Main at Mall	Plan 4 - Two Lanes Closed	0.09	8580	60	56.35	40.25	7.5	10.2754	
Total									**59.31645**	

Figure 34. Excess fuel consumption by traffic during the asphalt restoration process for open-cut at no intersection zone

Zone	Location	Plan Type	Length of zone	No. of vehicles	Duration (Hrs.)	Original speed	Reduced speed	Days (D)	Fuel increase	Remarks
Asphalt restoration at the intersection		Hr./day	Length of poe Road	Length of Parkview	Industrial Parkway	Kroger Entrance	Mall Entrance	Feet/day		
		8	50	25	25	30	30	30		
At Poe Road	N. Main south of Poe	Plan 4 - two lanes closed	0.045	16810	6.666667	56.35	40.25	0.833333	1.118424	
	Poe road	Plan 4 - two lanes closed	0.045	10575	13.33333	56.35	40.25	1.666667	1.407178	
	North of Poe	Plan 4 - two lanes closed	0.03	18870	6.666667	56.35	40.25	0.833333	0.836988	
At Parkview Drive	N. Main North of Poe	Plan 4 - two lanes closed	0.075	18870	6.666667	56.35	40.25	0.833333	2.092471	
At Industrial Parkway	N. Main at kroger	Plan 4 - two lanes closed	0.075	13680	6.666667	56.35	40.25	0.833333	1.516958	
At Kroger entrance	N. Main at kroger	Plan 4 - two lanes closed	0.075	13680	8	56.35	40.25	1	1.82035	
At Mall Entrance	N. Main at Mall	Plan 4 - two lanes closed	0.075	8580	8	56.35	40.25	1	1.141711	
Total									**9.93408**	
Cold Batches, steel plates and signs										
	N. Main	No Plan	0.765	4390		56.35	40.25	137	**816.3079**	
Gross Total (Gallons)						**Final fuel consumption**			**1089.83**	Fuel cons. (Gallons)
						Excess CO2 (Pounds)			**21447.86**	

Figure 35. Total excess CO_2 emission by traffic during the open-cut process