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May 5, 2015

April Honaker, Executive Director
Shared Light Foundation
1009 Light Brigade Ln
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Ms. Honaker:

The Shared Light Foundation exhibits a genuine desire to invest in the future. As an undergraduate student in civil engineering, I share your desire and hope my research brings long-term positive changes.

Upon receiving funding from the Shared Light Foundation, I have conducted research on the feasibility of slip-lining. The research conducted abided by the budget plan and task schedule presented in my research proposal. My research found slip-lining as a method of trenchless technology to be feasible when existing structural support is sufficient. This method offers a promising solution to sewage pipe restoration by preventing corrosion and saving the public from negative externalities. I recommend the funding of research into stronger materials for slip-lining.

The enclosed report summarizes my analysis. Thank you for your devotion to improving the future, and I hope you find this research project was a worthy investment. If you have any questions or comments, please contact me at the above email address or phone number.

Sincerely,

Madeline Carlisle

Enclosure (1): The Feasibility of Slip-lining

THE FEASIBILITY OF SLIP-LINING

Shared Light Approved Research Project

Prepared by Madeline Carlisle, Independent Researcher

Prepared for SLF Board of Directors

HNRS 303 - Technical Writing

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ABSTRACT

Many aging pipelines are experiencing corrosion, threatening pipes to leak or collapse. Sewage pipes are especially vulnerable due to the chemicals contained in wastewater. The traditional pipe restoration method, the dig-and-bury method, imposes negative externalities on the public and requires excessive labor and machinery. Trenchless technology offers an alternate approach to pipe repairs. This research focused on the slip-lining method for sewage repair. The feasibility of slip-lining was measured by the following criteria: social benefit, pipe reliability, labor requirements, equipment requirements, installation time, and application versatility. Because dig-and-bury is adequately feasible, its score was considered a minimal requirement to maintain feasibility. When compared to dig-and-bury, slip-lining proved to be thoroughly superior in all criteria except pipe reliability. The lining used in slip-lining lacks structural support and flexibility for tight curves or loops. Overall, slip-lining offers improvement to urban sewage restoration. Further research could offer improvements to the integrity of the pipeline materials.

KEY WORDS: ACID.CORROSION.DETERIORATION.DIG-AND-BURY.EXTERNALITIES.FEASIBILITY.OPEN-TRENCH.PIPE.RENEWAL.REPAIR.REPLACEMENT.RESTORATION.SEWAGE.SLIPLINE.WASTEWATE.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures

Tables

EXECUTIVE SUMMARY

Numerous methods for replacing pipes are being used today. Trenchless technology has begun to gain prominence; it is used in about 70 percent of sewage pipe repairs, specifically. However, dig-and-bury has continued to be used in many scenarios. This report addresses the feasibility of the slip-lining method of trenchless technology for sewage restoration projects.

PROBLEM

Cities across America have aging sewage systems facing severe corrosion. In 2009, the American Society of Civil Engineers estimated restorations will cost $390 billion over the following 20 years. In 2012, the American Water Works Association estimated costs to be one trillion dollars over the following 25 years. These cost estimates are increasing because sewage pipes are deteriorating faster than they are being restored. This high demand calls for action and improvements in the restoration process.

METHOD

To gauge the feasibility of slip-lining, the process was evaluated against the dig-and-bury method. They were compared using the following criteria:

- *Social benefit*
- *Pipe reliability*
- *Labor requirements*
- *Equipment requirements*
- *Installation time*
- *Application versatility*

These criteria were explored to determine the feasibility of slip-lining in urban regions.

FINDINGS & CONCLUSIONS

Research revealed that slip-lining, as many trenchless technology methods, requires sophisticated labor and equipment, but reduces many social costs. Also, slip-lining cannot be used on tight bends or loops in pipelines. The lining used in this method does not provide structural support for the existing pipe. Though lacking in material superiority, slip-lining proves to be cost-effective and useful for many sewage pipe replacements. All disruptions to the public are avoided due to its simplicity.

RECOMMENDATIONS

I recommend the use of slip-lining as a method of trenchless technology for future urban pipe replacements when the existing pipe is not in need of additional structural support.

INTRODUCTION

The feasibility of slip-lining for pipe replacements will be discussed. This report presents research findings and offers recommendations to the Shared Light Foundation, researchers, and engineers concerning slip-lining development.

Scope

Many pipelines are installed with trenchless technology, such as gas lines, water mains, and oil pipelines (Pugh 122). Additionally, there are many types of trenchless technology methods, such as pipe splitting, pipe pulling, and slip-lining (Boyd). However, this report will focus on the analysis the slip-lining method as it pertains to the rehabilitation of sewage systems.

Background

Many sewage systems across the United States are in need of repair (Azeez 656). Until these systems are repaired, sewage lines and the streets above them are in danger of collapsing (Lamson 18). Additionally, these sewage systems leak and contaminate groundwater (Cooper). Currently, the "average rate of system renewal and upgrades in the USA cannot keep pace with increasing quality demands, and continually deteriorating systems" (Selvakumar 118). Most deterioration is caused by corrosion (Cooper). The affected cities need efficient pipe replacements which minimize costs, installation time, and public disturbance while still solving the problem of deterioration. For further background, see Appendix C.

Sources

The research conducted for this report is primarily based on online scholarly journals and a few articles. The types of sources used are:

- *Analytical research based secondary sources*
- *Studies based on primary research or experimentation*
- *Applied research for modelling data*
- *Articles reporting examples of pipe replacements*

Additionally, an informal meeting with a civil engineer served as a primary source for the research presented. All sources used are credible. A variety of viewpoints and subject matter was explored to prevent biases.

Though many sources were explored, most lacked applicable quantitative information that could be used to execute an exact comparison of slip-lining and dig-and-bury methods.

Such information is lacking because many factors must be considered for each pipe replacement, such as:

- *length of replacement*
- *level of corrosion*
- *size of pipe*
- *depth of pipe*
- *available replacement options*
- *infrastructure*

The complexity of each situation makes specific installation time and costs difficult to relate to each other with values. Situations would need to be normalized for at least each of the above factors. For this reason, secondary sources mainly relayed qualitative information to express the efficiency of slip-lining or dig-and-bury. Some sources based this on studies and research while others based this on a particular pipe replacement.

Trenchless technology such as slip-lining is commonly considered an advancement in pipe replacements. Scholarly research reflects it as the preferred choice when feasible for a given situation. Therefore, researchers focus on trenchless technology in efforts to advance the practice. So, research on the old-fashioned method of dig-and-bury was limited.

Findings

Slip-lining imposes negligible disturbances to the public while dig-and-bury imposes many. The pipes used in both methods are corrosion resistant, but slip-lines do not offer structural support. Slip-lining installation requires little labor, unlike dig-and-bury. Slip-lining requires sophisticated equipment. Installation time is decreased significantly with this method in urban areas. Slip-lining can be used in a variety of situations.

Conclusions

My research proved slip-lining to be a feasible method for pipe replacement. This method offered decreases social costs, installation time, equipment requirements, and labor requirements when compared to traditional methods of sewage repair.

Recommendations

I recommend further research to improve the material used in slip-lining. In the meantime, I recommend its use in urban regions where the existing pipe still offers structural support.

Report Contents

This report contains methodology, results, conclusions, and recommendations. Reference information follows.

METHODOLOGY

The goal of this research project was to determine the feasibility of slip-lining for sewage repairs. Listed below are the ordered tasks completed for the research project.

1. Evaluated pipe corrosion & dig-and-bury issues

The growing need for replacements and proposed solutions were first presented to me at a meeting with a civil engineer, Rusty Cooper. In this meeting, we discussed the significant corrosion of sewage lines in the city of Shreveport, Louisiana and the possible methods of replacement. The traditional method, dig-and-bury, involves digging a trench along the sewage line.

External pipe corrosion is common in nearly all underground pipes. This research focused on sewage lines particularly because of their unique situation – internal corrosion. After reading credible online articles and journals, I found this sewage corrosion to be a prominent issue. In 2009, the American Society of Civil Engineers gave the United States' wastewater system a failing grade of D–, and the Environmental Protection Agency estimated restorations to cost $390 billion over the following 20 years (Azeez 656). In 2012, the American Water Works Association estimated restoration to cost one trillion dollars over the following 25 years (Bauers). This growing issue requires immediate attention and advancement.

2. Identified slip-lining as a solution to corrosion & existing dig-and-bury issues

Slip-lining offers a pipe replacement method that does not disturb the above ground infrastructure. In researching pipe replacement alternatives, slip-lining seemed most efficient, both economically and socially.

3. Established criteria needed to maintain feasibility

The feasibility of slip-lining was measured based on the following criteria:

- *Social benefit*
- *Pipe reliability*
- *Labor requirements*
- *Equipment requirements*
- *Installation time*
- *Application versatility*

These criteria were used to compare slip-lining to the dig-and-bury method.

4. Researched slip-lining process

I conducted secondary research with online articles and journals. To begin with, the causes of pipe corrosion and the sustainability of different pipe materials were investigated. Then, the details of the slip-lining process were considered. Finally, the process requirements for slip-lining and dig-and-bury were individually evaluated.

5. Weighed process requirements against criteria

The feasibility of slip-lining was determined by organizing the results of each criteria into a decision matrix for both the slip-lining and dig-and-bury methods. The criteria were given different weights to stress importance. Each method's rating for each criteria was evaluated relative to each other and based on the research results.

6. Determined feasibility of slip-lining

The results of the decision matrix for slip-lining versus dig-and-bury were then compared. Because dig-and-bury is feasible, its score was considered a minimal requirement for slip-lining in order to prove feasibility.

7. Summarized results in a technical report

Pipe corrosion, pipe materials, the slip-lining process, and the criteria analysis is summarized in the "Results" section of this report. The feasibility of slip-lining is presented in the "Conclusions" section. Finally, my recommendations for the Shared Light Foundation, researchers, and engineers are presented. This report was submitted to the Shared Light Foundation on May 5, 2015.

RESULTS

In this section, pipe corrosion, pipe materials, and the slip-lining process are presented. Next the results of slip-lining and dig-and-bury processes are summarized by criteria.

Pipe Corrosion

The deterioration of sewage pipes is primarily caused by corrosion (Shan). This corrosion is actually initiated by the wastewater itself. This corrosion process involves the following steps:

1. Sulfur in urine and fecal material decomposes into sulfates (Harris).
2. Sulfates convert to sulfides (Harris).
3. Sulfides are released as hydrogen sulfide gas (Fan 196).
4. Hydrogen sulfide oxidizes into sulfuric acid (Fan 196-197).
5. Sulfuric acid corrodes the walls and crown of the pipe (Fan 196-197).

Corrosion varies for different materials.

Pipe Materials

Corroded steel pipes are directly exposed to soil. Corroded concrete pipes are weakened and then crack, eventually directly exposed to soil (Nnadi 1355). These exposed pipes then leak wastewater into the groundwater supply (Lamson 18; Cooper). Additionally, the friction caused by corroded pipes slows down the flow of wastewater (Lamson 18).

Plastic, such as polyvinyl chloride (PVC), does not corrode like steel and concrete. Most sewage lines experiencing corrosion are made of these materials (Cooper). For this reason, renewed sewage systems are often using plastic piping (Boyd). In one study, PVC showed no deterioration after 15 years of sewage use (Whittle 311). Additionally, PVC causes less friction than steel and concrete, allowing for improved flow of wastewater (Lamson 18). During slip-lining, a plastic lining is placed inside the existing corroded pipe, while dig-and-bury involves a full replacement of the existing pipe with a PVC pipe.

In using either method of pipe replacement, corrosion should no longer occur.

SLIP-LINING PROCESS

Slip-lining involves the following steps:

1. Dig two access pits (Boyd). One slip-lining project reported pits which were "10-12 feet wide, 25 feet long and 15-20 feet deep," as seen in Figure 1 (Lamson 19).

Figure 1: Slip-lining Access Pit
Source: Lamson, 18

2. Destroy entry to pipe, and remove debris (Lamson 19).
3. Slip a smaller pipe or lining into the existing pipe (Abusaoud).
4. Push the pipe or lining through with compressed air (Boyd).

WEIGH METHOD AGAINST CRITERIA

This section presents the research results for each criteria: social benefit, pipe reliability, labor requirements, equipment requirements, installation time, and application versatility. Both the slip-line and dig-and-bury methods are addressed for each criteria.

Table 1 shows some properties of the two methods. This qualitative data is based on an articles comparing pipe replacement technologies.

Table 1: Comparing Technologies

Technology	Constraints	Effects on Customers	Qualitative Cost Comparison
Open trench[1]	Surface conditions, soils, other utilities	High (traffic, noise)	Wide range
Slip lining	Pipe conditions	Moderate	Low-moderate

Source: Based on Boyd, "Selecting Lead Pipe Rehabilitation and Replacement Technologies"

Constraints, as presented in Table 1, will be discussed as application versatility and pipe reliability. Effects on customers will be discussed as social benefit. Cost comparisons will be discussed within the application versatility section.

[1] Another term for "dig-and-bury"

Social Benefit

Most of the advantages in using slip-lining over dig-and-bury are based on social costs. Figure 2 shows a dig-and-bury pipe replacement in a residential area. The following issues arise when a pipe is replaced in a populated area with the dig-and-bury method:

- Traffic disruption (Davis; Table 1)
- Sewage service interruption (Davis)
- Environmental/infrastructure damage (Davis; Figure 2)
- Disruptions to merchants (Azeez 661)
- Noise pollution (Noor; Table 1)

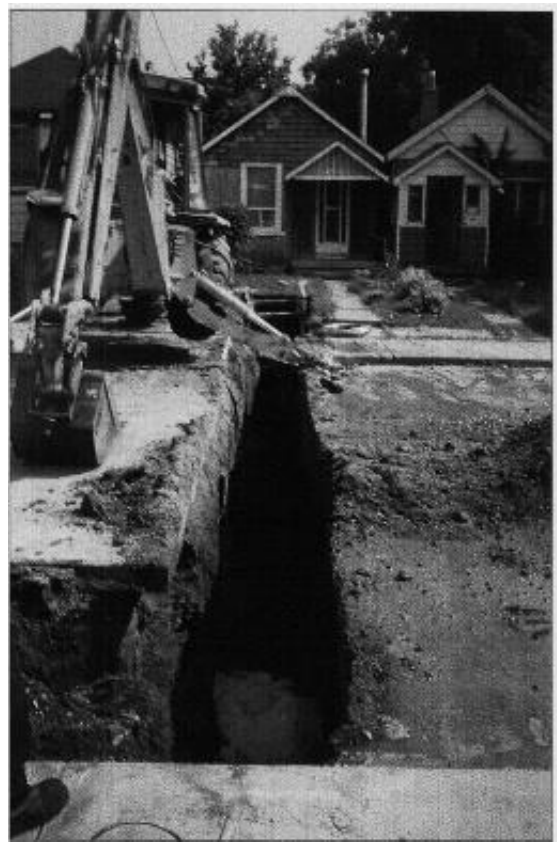

Figure 2: Dig-and-Bury
Source: Boyd, "Selecting Lead Pipe Rehabilitation and Replacement Technologies"

Slip-lining does not cause these issues. The access pits needed for slip-lining cause minimal disruption to the public (Reagin). Also, sewage can continue flowing while slip-lines are being placed (Reagin). For this reason, slip-lining is becoming common in urban areas (Sperio 51). According to Table 1, the effects on customers are "moderate."

Pipe Reliability

Both slip-lining and dig-and-bury offer a non-corrosive plastic pipe. The pipe inserted in the slip-lining process, however, must be smaller than the existing pipe. Therefore, the pipe's sewage capacity is reduced (Abusaoud). However, this reduction is generally marginal (Abusaoud). According to Greg Strudwick, owner of Line One, Inc., the flow rate actually increases when a slip-line is installed because the plastic pipe causes less friction than the corroded pipe (Lamson 19).

Lining used for slip-lines cannot provide much structural support (Boyd). According to Table 1, slip-lining can only be used under certain pipe conditions. New pipes used in dig-and-bury replacements, however, have few pipe limitations. As seen in Figure 2, the new pipe is simply lowered into the trench.

As mentioned by Azeez, "Despite the extensive research conducted by previous investigators, the [life cycle cost] analysis of various methods of new installation or rehabilitation using trenchless technologies is not sufficiently covered" (656).

Labor Requirements

Implementing a slip-line requires well-trained operators, while digging a trench requires little skill (Boyd). According to Roy O'Donnell, owner of Pipeline Trenching, Austin, TX, the dig-and-bury method is traditional and therefore widely known to workers (Griffin 20). Dig-and-bury workers, who usually dig, would need to be taught the slip-lining process, such as how to operate air compressors for pushing the new pipe through the existing pipe.

While dig-and-bury is easier to understand, digging such long trenches requires a "considerable amount of labor" (Sperio 51). Such an exhausting process also requires more vehicle operating costs (Noor). Also, before the existing pipe is even removed, it has to be pumped dry (Noor).

Equipment Requirements

Slip-lines require high capital costs for its more sophisticated equipment (Boyd). Such equipment may include air compressors and machinery dig access pits. Slip-lining and dig-and-bury both require large excavators (Griffin 21). Figure 3 shows an excavator digging an access pit for a slip-line.

Figure 3: Slip-lining Excavator
Source: Lamson, 19

Digging trenches, when compared to digging two pits, requires a "considerable amount... of materials and equipment" (Sperio 51).

The dig-and-bury method also requires pumps for removing the wastewater from the pipelines (Noor). Slip-lines also require small costs like hammers for destroying the entry pipe (Lamson 19).

Installation Time

Restoration of infrastructure, in addition to the digging of a whole trench, must take place during dig-and-bury pipe replacements (Boyd). This requires extra time, in comparison to the refilling of the two slip-lining access pits.

Application Versatility

Both slip-lining and dig-and-bury are applicable to many settings. Both can be used for a variety of soils and surface conditions (Boyd). In addition to sewage, both methods can also be used in replacing oil, gas, and water main pipes (Pugh 122; Griffin 20).

Dig-and-bury becomes more cost-efficient in open, rural areas (Griffin 22). This is due to the elimination of infrastructure restoration. The most cost effective method is different for every situation, depending on the length of the pipe, the depth of the pipe, and the significance of the infrastructure above the pipe. So, in urban areas infrastructure complications must be especially considered, unlike that of open fields. Thus, as Table 1 addresses, the costs of implementing the dig-and-bury method vary.

According to Table 1, dig-and-bury is limited by utilities and above ground conditions. Though possible, the dig-and-bury method is very difficult for areas with infrastructure, but slip-lining can easily be applied to sewage pipes going under rivers, through canyons, and beneath buildings (Griffin 22). Slip-lines, however, are more difficult to implement in loops or tight bends (Boyd). Materials used cannot be forced to curve with just compressed air. Figure 4 shows the difficult curve attempted in a slip-lining project.

Figure 4: Slip-lining a Curve
Source: Sperio, 51

The zoomed-in photo in the corner of Figure 4 shows a segment of the slip-line. For curves, many short segments of slip-lining must be used (Sperio 51).

CONCLUSIONS

Slip-lining's adherence to each criteria measures the feasibility of slip-lining. Because dig-and-bury is feasible, its score can be considered a minimal requirement to maintain feasibility.

Figure 5 shows my interpretation of each method's adherence to the criteria.

		Slip-line		Dig-and-Bury	
Criteria	*Weight*	*Rating*	*Score*	*Rating*	*Score*
Social Benefit	5.0	100%	5.0	0%	0.0
Pipe Reliability	5.0	60%	3.0	100%	5.0
Labor Requirements	-2.0	50%	-1.0	100%	-2.0
Equipment Costs	-2.0	60%	-1.2	100%	-2.0
Installation Time	-3.0	30%	-0.9	100%	-3.0
Application Versatility	4.0	100%	4.0	80%	3.2
			8.9		**1.2**

Figure 5: Decision Matrix

The following discussion explains the weight of each criteria, the ratings for each method, and the implications of the overall scores.

How were the weights distributed?

The magnitude of each criteria represents its importance. The weights are multiplied by the ratings to determine the scores; thus, for a given rating, criteria with higher weights result in higher scores[2]. Social benefit and pipe reliability are weighted most because they directly solve the proposed issues. Labor requirements and equipment requirements are weighted least because these are one-time expenses for each restoration project. Application versatility and installation time are given mediocre weights because versatility encourages business, but cities offer a promising market, and installation time can impose negative externalities but is negligible if construction is minor.

How were the weights' signs chosen?

The sign of each criteria's weight is representative of whether it's a positive or negative quality. Furthermore, social benefit, pipe reliability, and application versatility are positive qualities for a pipe replacement method, so they add to overall scores.

[2] "Higher" refers to magnitude.

However, labor requirements, equipment requirements, and installation time are negative qualities which we hope to minimize, so they deduct from the overall scores.

How were negative criteria assessed?

Each criteria was evaluated objectively. For example, dig-and-bury received a 100% for installation time because this method requires a long time to install a pipe. This rating is not desirable for a pipe replacement; hence, its score for this criterion is negative. So, the whole three points are deducted from the overall score for dig-and-bury.

How were the ratings calculated?

Because only two methods are being compared, the ratings were chosen relative to each other and based on the results of research:

Social Benefit

Slip-lining imposed no obvious social costs on society, so it received a perfect rating in social benefit while dig-and-bury imposed many, earning a rating of zero percent.

Pipe Reliability

Slip-lining received a mediocre rating for pipe reliability because slip-lines' lack of structural support could pose problems if the existing pipe deteriorates further, while dig-and-bury received a perfect rating because any pipe can be used.

Labor Requirements

Dig-and-bury requires much more labor than slip-lining, so it received twice the score of slip-lines in labor requirements.

Equipment Requirements

Due to the excessive excavation and manual repair required for dig-and-bury, its equipment requirements rating was very high. Slip-lining's rating was mediocre because it requires sophisticated machinery but at fewer locations.

Installation Time

The large gap in the two methods' installation time rating is based on the intense destruction required for dig-and-bury compared to the simplicity of digging two access holes for slip-lining. Slip-lining is much quicker in urban areas.

Application Versatility

The application versatility of both methods is acceptable, but slip-lining is applicable to more settings and terrains, so its rating is slightly higher.

What are the implications of these scores?

With the exception of pipe reliability, slip-lining received a higher score in each of the criteria. As a result, slip-lining's overall score is much larger than that of dig-and-bury. Slip-lining offers substantial improvement to pipe replacements, according to these criteria. By comparison with dig-and-bury, the slip-lining method proves to be feasible, and is a worthwhile consideration for pipe replacements, saving time, money, labor, and social costs.

RECOMMENDATIONS

Slip-lining is a feasible technique to employ when replacing a sewage pipe in urban areas. In open rural terrains, however, dig-and-bury should be considered. Recommendations for the Shared Light Foundation, researchers, and engineers are presented below.

Shared Light Foundation

Slip-lining has proven to be a viable topic in the future of urban pipe replacement. Slip-lining could afford further research. The lining used in this method lacks in structural support (Boyd). Also, the method is unreliable in areas with tight bends (Boyd). I recommend the funding of further research to improve the materials considered for slip-lining.

Researchers

Slip-lining is a prevalent topic today. Though it is a feasible method now, it is still in need of research and development. The lining used in this method lacks in structural support (Boyd). I recommend further research on the materials considered for slip-lining.

Engineers

The sewage systems in many cities across the United States are in need of renewal (Azeez 656). With this high demand, such an industry offers promising business. I recommend the use of slip-lining in these developed regions to achieve maximum efficiency and minimize the externalities imposed on citizens; however, I discourage the use of slip-lines when the existing pipe lacks structural support.

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APPENDIX A: BUDGET PLAN

Table 2: Budget Plan

Item	Quantity	Unit	Cost/Unit	Cost
Labor:	-	-	-	-
Research	10	hours	$ 14.00	$ 140.00
Technical Report	8	hours	$ 14.00	$ 112.00
Hardware:	-	-	-	-
Laptop	1	laptop	$ 300.00	$ 300.00
Printer	1	printer	$ 100.00	$ 100.00
Paper	1	ream	$ 8.00	$ 8.00
Ink	1	cartrige	$ 40.00	$ 40.00
TOTAL:				**$700.00**

APPENDIX B: TASK SCHEDULE

Task	4/2	4/6	4/12	4/20	4/24	4/28	4/30	5/5
1. Evaluate issues								
2. Identify solution								
3. Establish criteria								
4. Research								
5. Test criteria								
6. Determine feasibility								
7. Write technical report								

Figure 6: Task Schedule

APPENDIX C: CURRENT SITUATION

In many cities across the United States, sewage pipelines are corroding (Azeez, 656). Excessive corrosion causes pipes to leak. In the case of sewage, leakage is particularly dreadful as it allows waste water to infiltrate the surrounding soil and groundwater supply (Cooper).

As the situation has worsened, pipe replacement an industry in high demand. The traditional method of replacing pipes is called dig-and-bury. This involves digging a trench along the effected length of the pipe, removing the corroded pipe, inserting a new pipe, and restoring the above ground (Boyd). Such a method becomes difficult when the pipe passes under a road, building, or river. The inconvenience of closing roads or digging through the yards of residents inflicts a social cost on the public (Azeez, 661). The stench of sewage disrupts the effected community as well. The dig-and-bury method require many more hours of manual labor and high restoration costs (Azeez, 656). This method is strenuous on society and wasteful public funds.

Some pipe replacement companies have adopted trenchless technology methods. This field, however, needs more research to assess its feasibility (Azeez, 656). Without further research, some cities may not be able to afford sewage lines replacements in a timely manner. In addition to sewage problems, such municipal failures also result in federal fines (Cooper).