QATAR UNIVERSITY

COLLEGE OF ENGINEERING

RESIDENTIAL INFRASTRUCTURE OPTIMIZATION: FOUL SEWER NETWORK CONSTRUCTION APPROACHES AND RELATIVE EFFICIENCIES

BY

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ABSTRACT

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Ensuring urban communities stay clean and functional relies heavily on effective sewer systems. However, building these networks in neighborhoods with existing residents comes with unique challenges like noise and traffic disruptions. This project examines different methods used in sewer network construction, emphasizing the need to boost efficiency to minimize disruptions and maximize effectiveness. Based on research into pipe-laying technologies, this project thoroughly evaluates the efficiency of various methods using Data Envelope Analysis (DEA), focusing on both trenchless techniques and traditional approaches. The results of the analytical study revealed significant differences in efficiency. Strategies to enhance efficiency in both trenchless and conventional methods are suggested, including reducing the workforce and implementing noise reduction measures. The analysis highlights the importance of adopting trenchless methods more widely in sewer network construction and offers valuable insights for improving construction processes in urban settings. The sustainability scores for the open-cut method at one and the trenchless method at 7.698 indicate a notable contrast in performance between the two methods. Overall, the trenchless method significantly outperforms the open-cut method in sustainability. By proposing enhancements, this study aims to streamline construction practices, cut down on resource wastage, and enhance overall system efficiency, benefiting both current and future projects in the field

DEDICATION

My master's project is dedicated to my parents and friends, whose consistent support and patience have been invaluable since my journey towards obtaining this degree began.

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CHAPTER 1: INTRODUCTION

1.1 Background

To maintain the thriving of urban communities, it is crucial to view foul sewer systems as an integral component of infrastructure, essential for providing a hygienic environment for residents. Foul sewers play a pivotal role in ensuring the sustainability and resourcefulness of these communities. Constructing foul sewer networks in occupied residential areas poses unique challenges. Residents' presence must carefully consider factors such as noise and traffic disruptions. The construction process, involving excavation and installation of sewer infrastructure, can generate considerable noise, potentially causing disturbances to the residents. Additionally, managing traffic flow in densely populated residential zones requires strategic planning to minimize disruptions and ensure the safety of both construction workers and community members. Balancing the essential infrastructure development with the need to maintain a livable environment for residents underscores the complexity of implementing foul sewer networks in inhabited areas. Several pipe-laying technologies of foul sewer networks exist, each defined by distinct application conditions and technical parameters (Zwierzchowska, 2018). A comprehensive evaluation of process efficiency for each of these methods or approaches will be conducted to determine the most suitable method for a particular situation and to improve the process efficiency of the less efficient approach.

1.1.1 Process Efficiency

Process efficiency refers to the ability of a system, operation, or process flow to achieve its objectives while conserving resources and reducing waste. It measures how well a process delivers desired outcomes in business operations and manufacturing. An efficient process accomplishes its goals in time and with fewer resources resulting in cost savings and improved performance. To achieve process efficiency, organizations often streamline operations, minimize waste, establish procedures, and use data-driven metrics to monitor and optimize the process (Ndedi, 2016). Efficient processes are crucial for businesses aiming to stay competitive by maximizing productivity and allocating resources while meeting customer demands.

1.1.2 DEA-based Measuring Process Efficiency

Data Envelopment Analysis (DEA) is a nonparametric method to assess decision-making units' relative efficiencies (DMUs). The DEA measures how efficiently these units convert inputs into outputs. DMU performances are usually evaluated from an optimistic standpoint, in which each DMU identifies a set of weights that maximize its efficiency. The DEA assigns efficiency scores, where 1 signifies efficiency and is called DEA efficient, while lower scores indicate inefficiency and are called DEA non-efficient (Azizi, 2013). The most efficient DMU can be used as a benchmark to enhance the less efficient units. This approach proves valuable in sectors without practice or when complex input and output relationships enable performance assessment and improvement across various industries. The DEA was introduced in the journal literature by Charnes, Cooper, and Rhodes in 1978. DEA was developed as a tool for assessing the performance of activities within individual units or organizations. Researchers from various fields soon recognized DEA as an outstanding methodology for modeling operational processes (Malik, 2018).

1.1.3 Improvement of Process Efficiency

Improving the efficiency of processes is a dynamic effort. It involves optimizing workflows, starting with identifying and eliminating bottlenecks and unnecessary steps.

This helps make operations smoother. Moreover, automation can greatly reduce tasks. Minimizing errors while standardizing procedures ensures consistency. Keeping track of performance metrics and regularly monitoring indicators helps measure progress and identify areas for improvement. Continuous improvement methodologies, employee training, and the use of technology are all aspects of this pursuit. Collaboration, benchmarking, and maintaining a customer focus also play roles. Ultimately, reaching optimal process efficiency is a journey that requires refinement and adaptation to ensure resource utilization and consistent improvement of results (Konokh, 2019).

1.1.3 Process Efficiency VS. Sustainability

Sustainability practices are focused on the preservation of resources. Reducing their impact on the environment. The aim is to achieve sustainability by optimizing processes to minimize waste and use resources. Process efficiency plays a role in reaching this goal as it ensures that operations are resource friendly. Process efficiency optimizes workflows and resource utilization to boost productivity and cut costs. It aims to streamline operations, achieving more with resources, ultimately leading to increased profitability and competitiveness. On the other hand, sustainability takes a perspective that emphasizes the long-term well-being of society, the environment, and the economy. When organizations integrate sustainability with process efficiency, they can develop practices that improve productivity. This combination is crucial for long-term success in our interconnected world.

The connection between process efficiency and sustainability is rooted in efficient processes frequently aligning with sustainability objectives. By decreasing resource usage and minimizing waste, efficient processes can impact the environment. Additionally, they can bolster the stability of sustainability endeavors by reducing expenses and enhancing profitability, thereby making it more viable for organizations to embrace practices (Konokh, 2019). Nevertheless, it is critical to understand that although process efficiency may align with sustainability goals, it does not assure their achievement. Sustainability encompasses an approach that considers ethical, social, and environmental factors and economic efficiency. Organizations must incorporate these considerations into their core principles and decision-making procedures to genuinely embrace sustainability rather than focus on operational optimization (Solvang, 2008) (AI tool).

1.1.4 Sustainability Assessment

A sustainability assessment assesses how an organization or project impacts the environment, society, and the economy. The main objective is determining if the entity operates responsibly, maintains fairness, and remains economically viable. This evaluation involves gathering and analyzing resource usage, emissions, social impacts, and financial performance data. The collected information is then used to measure the entity's sustainability performance, identify areas for improvement, and develop strategies for enhancing sustainability. Conducting sustainability assessments is crucial for organizations that aim to integrate practices into their operations while meeting requirements (Bond, 2012). Additionally, these assessments help organizations align with growing expectations from consumers and stakeholders regarding behavior (Haywood, 2009).

1.2 Aims and Objective

The paper aims to evaluate methods used in constructing foul sewer networks and to enhance the efficiency of the chosen construction process. The objective is to analyze identified inefficiencies to propose improvements and refinements to the existing approach. These enhancements are intended to streamline the construction of sewer networks by minimizing resource waste, reducing impact, and ultimately improving the system's overall effectiveness. The findings from this evaluation and improvement process benefit this project and provide valuable insights for advancements in best practices and methodologies within the broader field of sewer network construction.

1.2 Research Question

This study will focus on answering two research questions. These are

Question One: How can foul sewer networks be constructed most effectively in a project?

Question Two: what are the criteria to consider when deciding the most appropriate approach, and under what conditions?

1.4 Methodology

This research attempts to evaluate methods used in constructing foul sewer networks using DEA and improving the efficiency of the least efficient approach. Figure 1 presents the proposed methodology. Foul sewer networks evaluation methodology started with identifying the decision-making units (DMUs) that will be evaluated. Then, the inputs and outputs relevant to the efficiency evaluation will be defined. Followed by collecting data on the chosen inputs and outputs for each DMU. Next, the formulation of a linear programming model is used to evaluate the efficiency of each DMU. Calculating their efficiency and then based on the efficiency scores, DMUs are classified into efficient and inefficient. Once the inefficient approach is determined, areas of improvement are suggested.

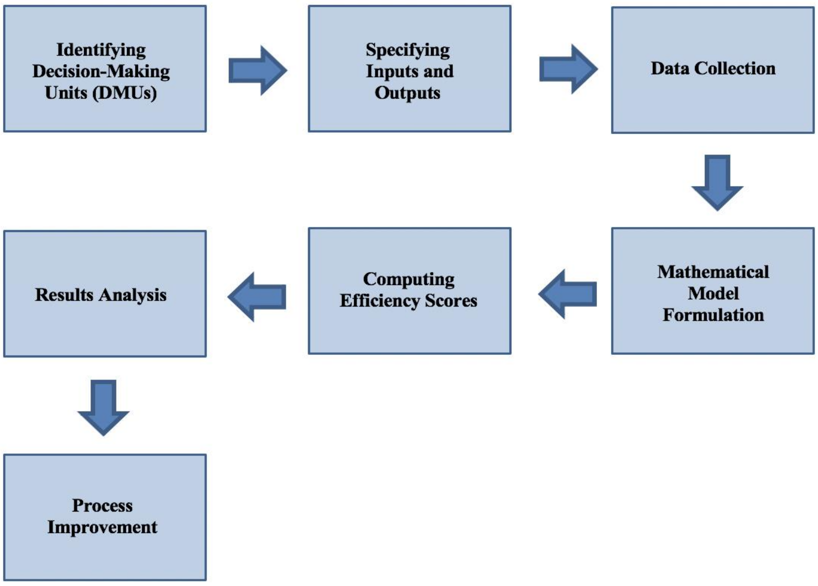

Figure 1 Project Methodology Overview

1.5 Report Outline

Following the introduction chapter, the project report comprises the following chapters: Chapter two provides an overview of recent literature on various topics, including Measuring Process Efficiency, DEA Applications for Measuring Process Improvement, Sustainability Assessment, and Foul Sewer Network Construction Methods. Subsequently, Chapter 3 elaborates on the data analysis, detailing the process of data collection, computation of efficiency, and analysis of results. Moving forward, Chapter 4 delves into process improvement strategies for the chain cutter and jackhammer techniques. Chapter 5 represents environmental sustainability assessment. Finally, chapter 6 concludes the report and outlines future work for the project.

The report starts by carefully identifying the decision-making unit for foul sewer network approaches, making sure we understand its parts clearly. Then, it describes what goes into making decisions and what comes out of them, so we have a good plan for our analysis. After that, we collect data from different places using different methods to get all the necessary information. Next, we make a math model to show how inputs relate to outputs in the decision-making process. We use this model to determine efficiency scores to see how well the decision-making unit performs. Then, we look at these scores to find trends or places where things could improve. Finally, we suggest ways to improve the decision-making process based on what we find.

CHAPTER 2: LITERATURE REVIEW

The section reviews existing literature that is the basis for this study on process efficiency. The chapter will demonstrate methods and strategies utilized to gauge and enhance efficiency.

2.1. Measuring Process Efficiency

Before selecting a specific technology for a particular project, a critical step involves assessing the available technologies and their capabilities. These papers provide different perspectives on measuring process efficiency. (Tavassoli, 2014) proposes a new method for assessing the relative efficiency of decision-making units based on process capability indices. (Verbruggen, 2019) introduces the concept of Process Efficiency, a metric that can objectively measure and compare teams' performance in an Agile environment. (Fei, 2016) focuses on measuring the efficiency of a two-stage production process, considering both desirable and undesirable outputs. (Denkena, 2021) explores measures for energy-efficient process chains, highlighting the importance of optimizing process parameters and considering base load-reducing measures for minimizing energy demand.

2.2.DEA Applications for Measuring Process

Data Envelopment Analysis (DEA) was introduced in the journal literature by Charnes, Cooper, and Rhodes in 1978. DEA was developed as a tool for assessing the performance of activities within individual units or organizations. Researchers from various fields soon recognized DEA as an outstanding methodology for modeling operational processes (Malik, 2018). These papers collectively suggest that DEA can be applied to measure the efficiency performance of construction organizations. (Lee, 2014) highlights the limited application of DEA in the construction industry and proposes a methodological scheme for performance measurement. (Hu, 2016) proposes a globally applicable relational two-stage DEA methodology designed specifically for analyzing the profitability performance within Australia's construction industry. (Zhang, 2018) investigates the impact of environmental regulation on the efficiency of the regional construction industry using a 3-stage DEA model. Overall, these papers demonstrate the potential of DEA applications for measuring process efficacy in the construction field.

2.3. Improvement of Process Efficiency

The papers collectively suggest several methods for improving process efficiency. (Agrahari, 2015) discusses adopting Lean Manufacturing principles within a small-scale manufacturing sector, reducing process time and increasing cycle efficiency. (Kovács, 2018)

highlights simulation, Lean methods, and layout design as effective tools for improving production and logistical processes. (Klabusayová, 2014) emphasizes using Lean Manufacturing principles, such as Value Stream Mapping (VSM) and Overall Equipment Efficiency (OEE), to reduce waste and increase labor productivity. (Aman, 2017) focuses on using Overall Equipment Effectiveness (OEE) as a performance measurement tool to identify areas of process improvement and increase production efficiency. These papers collectively provide insights and methodologies for improving process efficiency in various industries.

2.4.Sustainability Assessment

These papers collectively highlight the importance of sustainability assessment in the construction industry. (Goh, 2013) emphasizes the role of sustainability assessment systems in delivering sustainable construction and providing transparent metrics for evaluating sustainable performance. However, it also points out the need to focus on post-occupancy evaluation and soft issues to achieve a more comprehensive assessment approach. (Ujene, 2017) focuses on evaluating main contractors' project delivery practices for sustainability, highlighting the need to strengthen their inclination towards sustainable construction practices. (Sitepu, 2020) discusses the sustainability assessment process in construction industry supply networks, emphasizing the need for different indicators at each stage of the supply network. (Cuadrado, 2016) introduces the Integrated Value Model for Sustainable Assessment (MIVES) and its application to industrial buildings, demonstrating its reliability in evaluating sustainability in construction.

2.5.Foul Sewer Network Construction Methods

The construction of a foul sewer network pipe includes several techniques, strategies, and skills applied within foul sewer systems. The choice of network construction method can significantly impact the success of a sewer system project. Therefore, a thorough understanding of the available options and selecting the most suitable one, considering the specific project requirements and conditions, is crucial to a successful project. The most widely used approaches are open-cut chain cutter, open-cut jackhammer, and trenchless technology. The open-cut method is the most widely used underground utility construction due to its approach. A trench is excavated, a pipe is installed, and the excavation is backfilled (Onsarigo, 2020). A chain cutter is considered a heavy-duty digging machine with a sharp-toothed chain. It is used to dig trenches for the installation of pipes, cables, and other important components of a network. Jackhammers are used in construction to break, chip, and demolish hard materials like concrete, asphalt, and rock. It is made up of a handle, a motor, and an attachment that resembles a chisel. The trenchless approach is a method of pipeline construction that requires minimal excavation or zero excavation (Lu, 2020). It is engineered to achieve precise, on-grade accuracy while simplifying some challenging steps in other installation techniques (Vermeer). Its characteristics include not affecting traffic and low noise.

These papers collectively provide insights into the methods utilized in constructing foul sewer networks. They emphasize the advantages of trenchless technology compared to open-cut approaches, including minimizing disruptions, ensuring safety, reducing impacts, and offering cost-effective alternatives. (Kumar, 2019) explores the design criteria and decision-making process for selecting the trenchless construction method based on project-specific requirements. (Ariaratnam, 2011) focuses on highlighting the benefits associated with trenchless technologies, such as reduced emissions and environmental impact compared to open-cut excavation. (Orlov, 2014) discusses the strategic planning of sewer network renovation and presents a program package based on mathematical algorithms for choosing priority pipe sections. Overall, these papers emphasize the advantages of trenchless technology in terms of sustainability, reduced environmental impact, and efficient construction methods for foul sewer networks.

2.6.Conclusion

In conclusion, the literature review provides comprehensive insights into various aspects related to process efficiency, encompassing measurement techniques, improvement methodologies, sustainability assessment, and specific construction methods for foul sewer network projects. The section discusses different methodologies for measuring process efficiencies, such as process capability indices, process efficiency, and DEA models. These methods offer distinct perspectives on evaluating and comparing the performance of processes and organizations. Furthermore, the review highlights the application of Data Envelopment Analysis (DEA) in assessing the efficiency performance of construction organizations, underscoring its potential as a valuable tool in the construction industry. Data Envelopment Analysis (DEA) is a prominent tool for measuring efficiency performance, especially in construction organizations. These papers collectively suggest the effectiveness of DEA in assessing performance within construction industries. Efforts to improve process efficiency are discussed next, with Lean Manufacturing principles, simulation techniques, and Overall Equipment Effectiveness (OEE) highlighted as effective tools. Insights into how these methodologies can be applied to various industries to reduce waste, increase productivity, and identify areas for improvement. Moreover, sustainability assessment is crucial, particularly in the construction industry. These papers stress the importance of incorporating sustainability metrics into construction practices to achieve long-term environmental and social goals. Lastly, the section discusses foul sewer network construction methods, highlighting the advantages of trenchless technology over traditional open-cut approaches. The benefits of trenchless technology include reduced environmental impact, increased efficiency, and improved sustainability. Overall, the literature reviewed provides valuable insights and methodologies for assessing, improving, and sustaining process efficiency across various industries, particularly in construction and infrastructure development.

CHAPTER 3: DATA ANALYSIS

Data Envelopment Analysis, DEA, compares multiple service units of the same type by examining their inputs (resources) and outputs. The outcome is represented by an efficiency index, where the most efficient entity, characterized by consuming fewer resources while producing more, achieves an efficiency score of $E = 1$. Conversely, less efficient entities register an $E < 1$.

3.1 Identifying Decision-Making Units

In this study, three processes are selected: DMUs. These are 1) the open-cut chain cutter, 2) the open-cut jackhammer, and 3) the trenchless technology. The open-cut method stands out as the most commonly employed approach for underground utility construction, owing to its widespread use and effectiveness in this field.

3.1.1 Criteria of Selection

The primary criterion for evaluating these DMUs is efficiency. This study will assess how efficiently each method performs network construction tasks for installing underground utilities.

3.2 Specifying Input and Output:

Achieving the optimal index necessitates considering both inputs and outputs of the entities. In DEA, output variables should be assessed on a scale where "more is better," while input variables should be gauged on a scale where "less is better." This methodology ensures a comprehensive efficiency evaluation, guiding decision-makers toward optimal resource utilization and process enhancement.

3.2.1 Input Factors Relevant to Decision-Making

When evaluating decision-making in underground utility construction, several input factors play a crucial role in determining the efficiency of the chosen methodology. One such factor is the number of Workers involved in the construction process. The way labor resources are allocated can have an impact on project timelines and overall productivity. Another factor to consider is the noise level generated by construction activities in areas or densely populated neighborhoods where noise regulations and community concerns may be relevant. Furthermore, the availability of Sufficient Working Space can influence the choice of construction method, as some techniques may require more room for equipment and operations than others. The duration needed for completion is another factor that directly impacts project schedules and budgets. Many utility projects aim to minimize construction time while ensuring high-quality standards. By assessing these factors, decision-makers can make informed decisions about selecting construction methods leading to optimized project outcomes and resource management

3.2.2 Output Metrics to Evaluate Efficiency

When evaluating the efficiency of decision-making units (DMUs) using Data Envelopment Analysis (DEA), it's important to consider various output metrics that reflect the performance of chosen methodologies One key measure is the public satisfaction score, which measures the level of satisfaction among stakeholders, including residents, businesses, and government entities, affected by the construction project. A high satisfaction score means the DMU meets public needs well, fostering community relationships and project success. Another crucial measure is overall productivity, which covers aspects like output per input unit, labor efficiency, and resource use in construction performance. A high overall productivity score indicates that resources are used effectively to meet project goals affordably. Moreover, the incident rate score shows how well the DMU handles safety and risk management by tracking incident frequency and severity during construction work. A lower incident rate score suggests that the DMU prioritizes safety and implements measures to minimize risks to workers and the public. By considering these output measures, decision-makers can understand DMU's efficiency levels in network construction projects to make informed decisions for process enhancements.

3.3 Data Collection

3.3.1 Sources of Data

The data used in this study was sourced from a construction company operating in Qatar, specifically engaged in constructing foul sewer networks in the Al-Khaisa area. As a prominent player in the construction industry, this company offers valuable insights into the practices and performance metrics associated with underground utility construction projects in the region. Collecting data directly from a company actively involved in similar projects is important to ensure the relevance and reliability of the information gathered. This data provides a firsthand perspective on the challenges, opportunities, and best practices in constructing foul sewer networks, enabling a comprehensive analysis of decision-making processes and efficiency evaluation. Additionally, collaborating with a local construction company enhances the applicability of findings to the specific context of Qatar, facilitating targeted recommendations and solutions for optimizing construction processes and project outcomes in the region.

3.3.2 Data Collection Techniques

Meetings with the engineer responsible for overseeing these construction projects were arranged to gather information for the project. During these meetings, interviews and discussions with the project engineer were conducted, allowing for a structured and in-depth exploration of various decision-making processes and efficiency factors in underground utility network construction. These interactions collected valuable insights, data, and firsthand perspectives on project timelines, resource utilization, productivity metrics, and incident rates. By engaging directly with a key stakeholder involved in the construction projects, this data collection approach ensured access to relevant and reliable information, enhancing the credibility and validity of the study's findings.

3.3.3 Challenges and Solutions

The interview with the project engineer revealed challenges with the technical complexity of construction projects and gathering the required information. To overcome this, preparation was made in advance by conducting background research on underground utility construction methods and terminology. This enabled me to ask targeted and informed questions, facilitating clearer communication and comprehension of the engineer's responses. Another challenge was the limited availability of the project engineer due to their busy schedule and on-site responsibilities. The interview must be scheduled in advance to mitigate this challenge, accommodate the engineer's availability, and ensure adequate time for a comprehensive discussion. These strategies ensured a successful interview and effective data collection for the study.

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3.4 Mathematical Model Formulation

The mathematical model formulation for the DEA involves developing a linear programming model to assess how efficiently decision-making units operate. The DEA model is designed to evaluate the performance of multiple units, such as organizations or processes, by comparing the relationship of their inputs and output. Essentially, the model aims to determine the efficiency scores of each unit based on its ability to transform inputs into outputs effectively. Mathematically, the DEA model requires setting up constraints that reflect the production possibilities of each unit, considering their inputs and outputs. These constraints ensure that each unit operates within its feasible region while maximizing its efficiency score. Moreover, the model includes weight restrictions to account for the relative importance of inputs and outputs. Solving the DEA model calculates efficiency scores for each unit, allowing for comparisons and identification of best practices. The mathematical formulation of the DEA model provides a framework for evaluating and enhancing the efficiency of decision-making units across various sectors and industries.

3.4.1 Variables and Parameters

The following are the variables and parameters of the data envelope analysis,

where K stands for the number of operating units;

K: #Operating units (DMUs) k= 1,……,K

and N stands for the number of inputs.

N: #imputs i=1,…,N

and M stands for the number of outputs.

M: #outputs j=1,…,M

and Ojk stands for observed level of output j from DMU k

Similarly, Iik stands for observed level of input i from DMU k

Model variables are v_i and u_j, where

v_i is the weight on input i

u_j is the weight on output j

3.4.2 Mathematical Representation of Decision-making Process

E_k is the efficiency of the DMU and it is calculated by the following formula

$$E_k = \frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}}$$

To evaluate a given unit, e, choose a nonnegative weight to solve…

Max E_e

$$such\ that\ E_k \leq 100\% \qquad\qquad k = 1, \dots\dots, K$$

which can formulate max $\sum_{j=1}^{M} u_j O_{je}$

such that $\sum_{i=1}^{N} v_i I_{ie} = 1$

$\sum_{j=1}^{Mk} u_j O_j \leq 1$*$\sum_{i=1}^{N} v_i I_{ik}$, $\qquad k = 1, \dots\dots, K$

$u_j \geq 0, \qquad j = 1, \dots\dots, M$

$u_j \geq 0, \qquad j = 1, \dots\dots, N$

Output analysis

λ_k dual variable associated with DMU k

$\lambda_k > 0 \rightarrow DMU\ k\ is\ the\ refrence\ set\ of\ DMU\ e$

These dual variables can be used to construct an efficient hypothetical composite unit (HCU) with

$$\hat{O}_j = \sum_{k=1}^{K} \lambda_k O_{jk}\,, \qquad j = 1, \dots., M \qquad Output\ j\ of\ HCU$$

$$\hat{I}_j = \sum_{k=1}^{K} \lambda_k i_{ik}\,, \qquad i = 1, \dots., N \qquad Input\ i\ of\ HCU$$

Satisfying

$$\hat{O}_j \geq O_{je}, \qquad j = 1, \dots, M$$

$$\hat{I}_i \geq I_{ie}, \qquad j = 1, \dots, N$$

HCU can be used to measure excess use of inputs and potential increase in outputs

$$\Delta Output = \hat{O}_j - O_{je} \geq 0, \qquad j = 1, \dots., M$$

$$\Delta Input = I_{ie} - \hat{I}_i \geq 0, \qquad i = 1, \dots., N$$

3.5 Computing Efficiency Scores:

Computing efficiency scores for the DMUs involves applying the Data Envelopment Analysis (DEA) methodology to evaluate their relative performance.

Efficiency scores represent the ability of each DMU to achieve maximum outputs given its inputs compared to other DMUs in the dataset. The DEA model is solved using linear programming techniques to compute these scores. First, the inputs and outputs of each DMU are normalized to ensure comparability across units. Then, the model is formulated with constraints representing the production possibilities of the DMUs, considering their input-output relationships. Solving this model generates efficiency scores for each DMU, indicating their efficiency relative to others. DMUs with efficiency scores 1 are considered efficient, while scores less than 1 denote inefficiency. Computing efficiency scores through DEA provide valuable insights into the performance of DMUs and identifies benchmarks for improvement, ultimately facilitating informed decision-making and resource allocation in various domains.

3.5.1 Calculating Efficiency Scores

The DMUs for the DEA for foul sewer network construction approaches are the following,

DMUs: Trenchless, Jack Hammer Open Cut, Chain Cutter Open Cut

DEA Inputs

Input 1 *(Number of Workers)*

Based on the data provided by the company, the trenchless approach requires a crew of 5 workers to execute the construction activities efficiently. In contrast, the chain cutter open-cut approach necessitates 5 workers for execution, 9 for pipelaying, and 13 for backfill activities, indicating a more labor-intensive process. The manpower requirements for the jackhammer open-cut method align with those of the chain cutter open-cut approach, with the same number of workers needed for execution. These workforce allocations reflect the diverse demands of each construction method, with trenchless technology potentially requiring a smaller crew due to its automated nature. At the same time, open-cut approaches rely on larger teams to manage various tasks such as excavation, pipelaying, and backfilling. Understanding these workforce requirements is essential for effective project planning and resource management, ensuring that personnel are allocated appropriately to meet project timelines and objectives.

Input 2 *(Noise Level)*

Aligning with Ashghal regulations regarding noise levels is crucial for construction projects to minimize disturbance to surrounding residents and adhere to environmental standards. Ashghal allows 55 decibels (dB) maximum during the daytime and 45 up to 75 dB during nighttime. According to the data provided by the company, trenchless technology maintains noise levels within the permissible range, with values ranging from 50 to 60 dB. This falls below the maximum limit of 55 dB set for daytime operations, ensuring compliance with regulations. In contrast, the jackhammer open-cut method exceeds regulatory noise limits, registering above 90 dB, posing potential challenges in noise management and community impact mitigation. Similarly, the chain cutter open-cut method also operates within a range of 70 to 90 dB, indicating the need for noise mitigation measures to align with regulatory requirements. By considering these noise level specifications, project managers can implement appropriate measures such as sound barriers, scheduling adjustments, and equipment selection to minimize noise disturbances and ensure compliance with Ashghal regulations, fostering harmonious relations with local communities and stakeholders.

Input 3 *(Working Space)*

According to the data obtained from the company, the space requirements for setting up construction activities vary significantly between different network construction methods. Trenchless technology demonstrates the most efficient use of space, requiring only 1.43 square meters per linear meter (m^2/lm) for setup. In contrast, due to the extensive excavation involved in this approach, the jackhammer open-cut method necessitates a larger working area, averaging 5 m^2 per linear meter. Similarly, the chain cutter open-cut method also requires considerable space, requiring 4 m^2 per linear meter for setup. These space requirements highlight the logistical considerations involved in selecting the appropriate construction method, as the availability and allocation of space can significantly impact project planning and execution. By understanding these spatial constraints, project managers can effectively plan for equipment placement, material storage, and site logistics to ensure smooth project progress and timely completion.

Input 4 *(Duration of Completion)*

Based on the productivity rates of each construction method and their allocated working hours, the duration required to complete a 100 linear meter objective can be calculated. The allocation of working hours for different construction methods reflects a strategic consideration of minimizing disruptions while maximizing productivity. With its quieter operation, Trenchless technology allows for longer working hours of 20 hours per day, seven days a week, enabling workers to implement double shifts efficiently. This extended timeframe optimizes project progress without disturbing residents or surrounding environments. Conversely, jackhammer open-cut and chain cutter open-cut methods are restricted to 10 hours per day, from 5 am to 5 pm. This limitation is imposed by constraints set by Ashghal to mitigate noise disturbances and respect community regulations. By adhering to these defined working hours, construction activities can proceed with minimal disruption to residents' daily lives, ensuring a balance between project advancement and community well-being. Overall, allocating working hours reflects a strategic approach to optimizing construction efficiency while mitigating potential impacts on the surrounding environment and stakeholders. Furthermore, based on data obtained from the company, the productivity rates required to complete 100 linear meters (lm) vary significantly across different construction methods. Trenchless technology proves to be the most efficient, with a productivity rate of 1.5 lm per hour. This method allows for rapid progress while minimizing surface disruption, making it a favorable option for projects requiring swift execution. In contrast, the jackhammer open-cut method demonstrates a lower productivity rate, averaging 0.25 lm per hour. Despite its slower pace, this method remains viable for specific scenarios where trenchless technology may not be feasible or cost-effective. Similarly, the chain cutter open-cut method exhibits a moderate productivity rate of 0.5 lm per hour, balancing efficiency and practicality. The comparison of productivity rates underscores the importance of selecting the most suitable construction method based on project requirements, site conditions, and constraints. By considering these factors, project managers can optimize efficiency and effectively streamline the completion of linear meter objectives.

Hence,

Trenchless: 1.5 lm/hour working 20 hours a day.

Jack Hammer Open-Cut: 0.25 lm/hour workings 10 hours a day.

Chain Cutter Open-Cut: 0.5 lm/hour workings 10 hours a day.

The completion duration for the trenchless method is

$$Trenchless = 1.5\,\frac{\text{lm}}{\text{hr}} \times 20\,\frac{\text{hr}}{\text{day}} = 30\ lm/day$$

$$= 100\ lm\ \div 30\frac{\text{lm}}{\text{day}} = 3.33\ day$$

$$Jack\ Hammer\ Open - Cut = 0.25\frac{\text{lm}}{\text{hr}} \times 10\frac{\text{hr}}{\text{day}} = 2.5 lm/day$$

$$= 100\ lm\ \div 2.5\frac{\text{lm}}{\text{day}} = 40\ day$$

$$Chain\ Cutter\ \ Open - Cut = 0.5\frac{\text{lm}}{\text{hr}} \times 10\frac{\text{hr}}{\text{day}} = 5\ lm/day$$

$$= 100\ lm\ \div 5\frac{\text{lm}}{\text{day}} = 20\ day$$

DEA Output

Output 1 *(Public satisfaction score)*

The public satisfaction score, as indicated by the data gathered from the company, serves as a crucial metric in assessing community perceptions and acceptance of construction activities. In this context, trenchless technology emerges as the most favored option, boasting a satisfaction score of 5 out of 5. This high score reflects the community's positive reception towards trenchless methods, potentially attributed to its lower noise levels and reduced disruption compared to other construction techniques. Conversely, the jackhammer open-cut method received a markedly lower satisfaction score of 1, indicative of significant dissatisfaction among the public. The elevated noise levels associated with jackhammer operations likely contributed to this discontent, highlighting the detrimental impact of noise pollution on community well-being. Meanwhile, the chain cutter open-cut method obtained a moderate satisfaction score of 3, suggesting a mixed response from the public. The correlation between noise levels and public satisfaction underscores the importance of prioritizing community engagement and implementing noise mitigation strategies to enhance project acceptance and foster positive relationships with stakeholders.

Output 2 *(Overall Productivity)*

Based on data from the company, the productivity levels for completing 100 meters (lm) vary significantly depending on the construction method used. Trenchless technology is the choice, with a productivity rate of 1.5 lm per hour. This approach allows for progress while minimizing surface disruption, making it ideal for projects that require completion. On the other hand, the jackhammer open-cut method shows a productivity rate of just 0.25 lm per hour. Despite its pace, this method can still be suitable for situations where trenchless technology is not feasible or cost-effective. Likewise, the chain cutter open-cut method demonstrates a productivity rate of 0.5 lm per hour, balancing efficiency and practicality. These insights into productivity rates are valuable for planning projects and allocating resources effectively, helping construction firms choose the method based on project needs and limitations.

Output 3 *(Incident Rate score)*

The incident rate score reflects the level of safety and risk associated with different construction methods, as observed in the data collected. Trenchless technology, characterized by its automated processes and minimal human interaction, boasts an incident rate score of 5, indicating the lowest incidence of accidents and safety concerns. With reduced exposure to noise due to its quieter operations, trenchless methods prioritize worker safety and minimize the likelihood of incidents, earning it the highest score. In contrast, the jackhammer and chain cutter methods, which involve more human interaction and higher noise levels, receive incident rate scores of 2. The increased presence of workers and the louder operating environment contribute to a higher risk of accidents and safety incidents than trenchless technology. These findings underscore the importance of prioritizing safety measures and adopting technologies that minimize worker exposure to hazards, ultimately promoting a safer work environment and reducing the incidence of workplace incidents.

3.5.2 Interpretation of Efficiency Scores

After considering all input and output values, we have compiled the following table:

Table 1 Input and Output of Trenchless, Jack Hammer, Chain Cutter Approaches

Approach	Outputs			Inputs			
	x1	x2	x3	y1	y2	y3	y4
Trenchless	5	1.5	5	5	55	1.43	3.33
Jack Hammer	1	0.35	2	27	90	5	40
Chain Cutter	3	0.9	2	27	80	4	20

where,

Input 1 (y1) = Number of Workers

Input 2 (y2) = Noise Level

Input 3 (y3) = Working Space

Input 4 (y4) = Duration of Completion

Output 1 (x1) = Public satisfaction score

Output 2 (x2) = Overall Productivity

Output 3 (x3) = Incident Rate score

- The efficiency of trenchless is calculated using the following formula

$$E_k = \frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}} = \text{Z= Efficiency}$$

Max E_e

Such that Z $\leq 100\%$

which can formulate max $\sum_{j=1}^{M} u_j O_{je}$

such that $\sum_{i=1}^{N} v_i I_{ie} = 1$

$\sum_{j=1}^{Mk} u_j O_j \leq 1 * \sum_{i=1}^{N} v_i I_{ik}, \qquad k = 1, \ldots\ldots, K$

$u_j \geq 0, \qquad j = 1, \ldots\ldots, M$

$u_j \geq 0, \qquad j = 1, \ldots\ldots, N$

Using DEAFrontier software, the efficiency for each method was calculated:

- Trenchless Efficiency:

$$E_{Trenchless} = \frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}} = 1 = 100\% = Z$$

The efficiency is equal to 1, thus the trenchless approach is efficient relative to other approaches.

- Open-Cut Jack Hammer Efficiency:

$$E_{JackHammer} = \frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}} = 0.244 = 24.4\% = Z$$

The efficiency is less than 1, thus the Open-Cut Jack Hammer approach is inefficient relative to other approaches.

- Open-Cut Chain Cutter Efficiency:

$$E_{ChainCutter} = \frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}} = 0.4125 = 41.25\% = Z$$

The efficiency is less than 1, thus the Open-Cut Chain Cutter Efficiency approach is inefficient relative to other approaches.

3.6 Result analysis:

Table 2 DMU's Efficiency Score and Rank

No.	DMU	Score	Rank
1	Trenchless	1	1
3	Chain Cutter	0.4125	2
2	Jack Hammer	0.2444	3

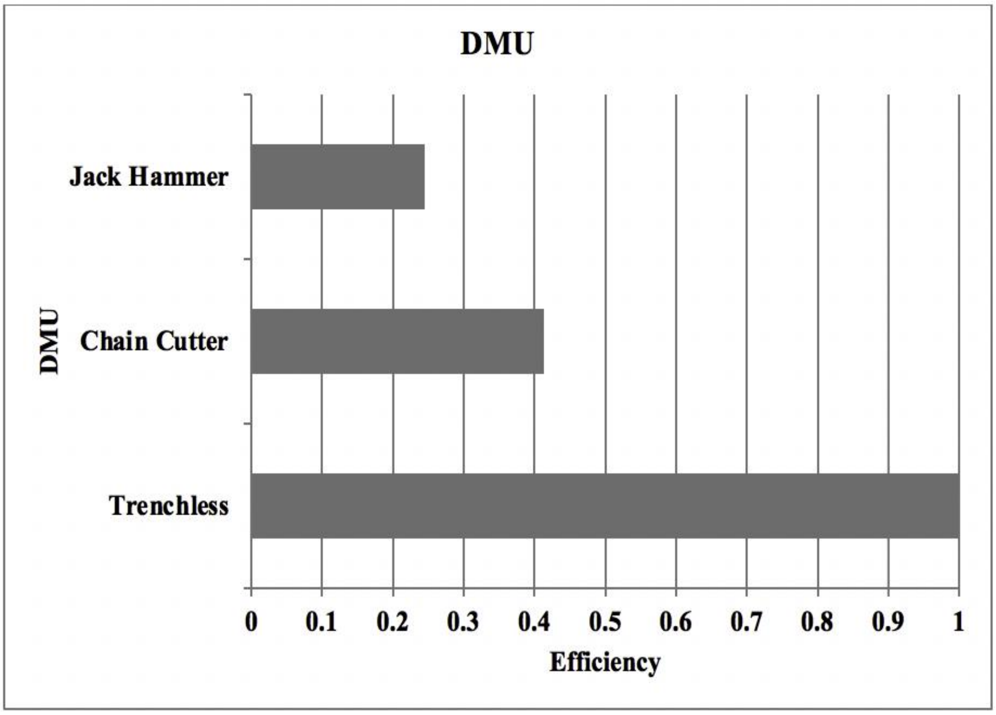

Figure 2 DMU's Efficiency Graph

The analysis reveals stark differences in efficiency between trenchless methods and traditional approaches. Table 2 and Figure 2 show that Trenchless technology boasts a remarkable 100% efficiency, indicating its ability to complete tasks without excavation, thereby minimizing disruption and costs. In contrast, the jackhammer exhibits a 24.4% efficiency, likely due to its labor-intensive and time-consuming nature and potential damage to surrounding structures. The chain cutter fares better at 41.25% efficiency, suggesting its moderate effectiveness in cutting through materials, albeit with some limitations. These findings underscore the advantages of trenchless methods over conventional techniques, highlighting the need for widespread adoption in various industries.

3.6.1 Identification of Efficient and Inefficient Units

- Efficient Unit:

- Trenchless technology: With a reported efficiency of 100%, trenchless technology stands out as the most efficient unit. It completes tasks without excavation, minimizing disruption and low noise level, making it the optimal choice for various applications, especially residential areas.

   - Inefficient Units:

- Jackhammer: With an efficiency of only 24.4%, the jackhammer is the least efficient. Its low efficiency likely stems from its labor-intensive and high noise level, incident rate score and duration of completion.

- Chain Cutter: While more efficient than the jackhammer, the chain cutter still falls short compared to trenchless technology. With an efficiency of 41.25%, it demonstrates moderate effectiveness in cutting through materials but is less efficient than trenchless methods.

CHAPTER 4: PROCESS IMPROVEMENT

Several process improvement strategies can be considered to improve the efficiency of both the chain cutter and the jackhammer.

4.1 Chain Cutter Open-Cut

Jackhammer is producing overcutting by 30%

reducing the number of workers for the backfilling activity of chain cutter by 30%

new number of workers = 13*0.7= 9 works

Several process improvement strategies can be implemented to improve the chain cutter's efficiency from a construction perspective. One approach is to minimize the workers required for the backfilling and excavation activities. The chain cutter carves out trenches 80 centimeters wide and 3 meters deep, whereas the jackhammer necessitates a wider 1.2 m cut due to its larger surface area requirements (Revolution of Cutting, n.d.). With this difference in width, both techniques employ the same number of workers. Since the chain cutter requires a smaller excavation space of only 0.8 meters compared to the 1.2 meters needed by the jackhammer, there is potential to reduce the workforce. Since the chain cutter often leads to production by overcutting by 30%, there is room to optimize its usage and reduce the need for extra workers. Moreover, by streamlining the backfilling activity, potentially reducing it by 30%, the overall workforce required for both activities can be decreased. By implementing these strategies, such as reducing the number of workers needed for excavation and backfilling, the efficiency of using chain cutters can be significantly enhanced, leading to cost savings and improved productivity on construction sites. By decreasing the number of workers involved in the backfilling activity of the chain cutter by 30%, the revised workforce totals 9 individuals instead of the initial 13. After process improvement, number of workers from 27 will be 23, using DEA solver, the result of efficiency is

$$E_{ChainCutter\_before}=\frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}}= 0.4125 = 41.25\% = \mathrm{Z}$$

$$E_{ChainCutter\_after}=\frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}}= 0.4125 = 41.25\% = \mathrm{Z}$$

$$\text{Percentage increase}=\left(\frac{after-before}{before}\right) \times 100$$

$$\text{Percentage increase} \approx 0$$

The percentage remains the same. Despite a 30% alteration in the number of workers, overall efficiency remains unchanged.

4.2 Jack Hammer Open-Cut:

The jackhammer generates noise levels reaching up to 90 dB, which can be excessively loud. However, this noise can be reduced using noise reduction curtains, which help mitigate the disruptive effects of high noise levels, particularly for workers spending extended periods in noisy environments and for the residents. The Echo Barriers, specifically the Echo H9 model, serve as high-performance noise barriers. Extensively tested, the H9 has demonstrated the ability to reduce noise by up to 45 dB, providing significant relief from noise exposure.

$$E_{JackHammer\_before}=\frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}} = 0.244 = 24.4\% = Z$$

after process improvement, noise level from 90 will be 45, using DEA solver, the result efficiency is

$$E_{JackHammer\_after} = \frac{\sum_{j=1}^{M} u_j O_{jk}}{\sum_{i=1}^{N} v_i I_{ik}} = 0.489 = 48.9\% = Z$$

$$\text{Percentage increase} = \left(\frac{after - before}{before}\right) \times 100$$

$$\text{Percentage increase} = \frac{48.9 - 24.4}{24.4} \times 100$$

$$\text{Percentage increase} \approx 100.4\%$$

The percentage increases by 100.4%, meaning the original value has doubled. This massive rise underscores the effectiveness of noise reduction curtains in mitigating the disruptive effects of high noise levels. Particularly beneficial for workers enduring extended periods in noisy environments and for residents alike, these curtains offer substantial relief.

4.3 Insights from Result Analysis

Table 3 Efficiency Score and Rank After Improvement

No.	DMU	Score	Rank
1	Trenchless	1	1
2	Jack Hammer	0.4889	2
3	Chain Cutter	0.4125	3

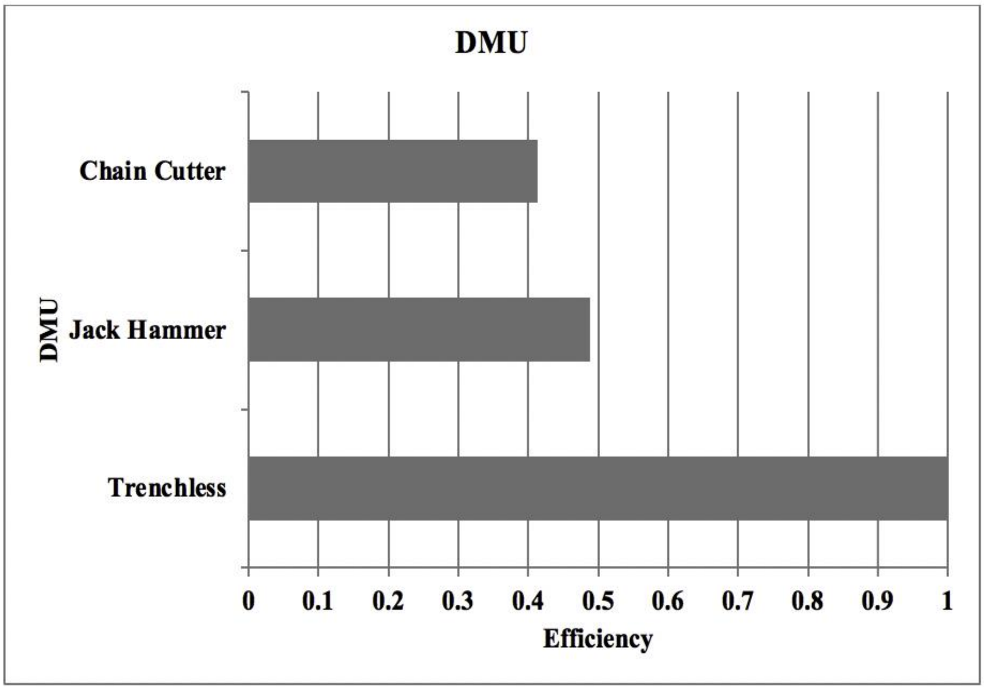

Figure 3 Efficiency Score and Rank After Improvement

Several strategies can enhance the efficiency of both the chain cutter and jackhammer. Table 3 and Figure 3 show that the jackhammer is more efficient after improvement than the chain cutter. Strategies for the chain cutter involve reducing the workforce for excavation and backfilling, leveraging its narrower trench dimensions compared to the jackhammer. Despite a 30% reduction in the workforce, efficiency remains unchanged. Noise reduction curtains, such as the Echo H9 model, offer relief from the jackhammer's loud noise levels, reducing noise pollution by 100.4%. These curtains particularly benefit workers and residents in noisy environments, fostering quieter and more conducive surroundings.

CHAPTER 5: ENVIRONMENTAL SUSTAINABILITY ASSESSMENT

5.1 Environmental Sustainability:

Environmental sustainability is about managing resources wisely so that natural ecosystems stay healthy and productive for future generations. It means reducing pollution, conserving water, and using renewable energy sources. When businesses and communities prioritize environmental sustainability, they can create a balanced relationship with the planet, ensuring economic growth doesn't harm our ecological health. This is crucial for tackling big challenges like climate change, biodiversity loss, and resource depletion. Ultimately, it’s about aiming for a future where people and the environment can thrive together.

A sustainability assessment for a construction project evaluates its impact on the environment. This paper will focus on specific aspects such as carbon footprint, energy consumption, carcinogens, respiratory effects, and global warming.

5.1.1 Carbon Footprint:

Carbon footprint measures the greenhouse gas emissions contributing to climate change, usually expressed in terms of carbon dioxide equivalent (CO2e). Reducing carbon footprint is important for environmental sustainability because it helps mitigate global warming, protect ecosystems, conserve natural resources, and improve public health. Lowering emissions supports climate goals, compliance with regulations compliance, and ethical practices, contributing to a more sustainable future (Tavakoli,2017).

5.1.2 Carcinogens:

Carcinogens are substances that can cause cancer and are often found in pollution from industrial processes, transportation, and other activities. High levels of carcinogens in the environment can harm human health, wildlife, and ecosystems. It is essential to reduce carcinogen production for environmental sustainability because it protects public health and maintains the integrity of ecosystems. Controlling and minimizing it supports sustainable practices and regulations. Assessing the presence and release of cancer-causing substances helps ensure workers' and nearby areas' health and safety (Kaushal,2020).

5.1.3 Energy Consumption:

Energy consumption, in terms of diesel fuel usage, represents the amount of diesel fuel (measured in liters, L) utilized by a system, vehicle, or equipment over some time or for a specific task. This consumption indicates how much energy in the form of diesel fuel is used for operations such as transportation, power generation, or industrial projects. High diesel consumption increases operational costs and has a greater environmental impact, whereas lower consumption indicates efficiency or alternative fuel usage (Chorazy, 2024).

5.1.4 Respiratory Effects:

The health impacts caused by exposure to air pollutants such as particulate matter, ozone, and nitrogen dioxide are called respiratory effects. These pollutants usually result from activities such as transportation and industrial processes. Even though this category might fall under the classification of human health criteria pollutants, focusing on particulate matter, which comprises tiny atmospheric particles capable of adversely impacting human health, potentially causing illness and mortality. Minimizing respiratory effects is essential for environmental sustainability because it protects public health, reduces healthcare costs, and improves quality of life (Kaushal,2020).

5.1.5 Global Warming:

Global warming is the rise in average atmospheric and tropospheric temperatures near the Earth's surface, measured in kg CO2 equivalents. This phenomenon can alter worldwide climate patterns and is attributed to various factors, including natural processes and human activities. In everyday language, global warming typically denotes the heating effects resulting from heightened emissions of greenhouse gases stemming from activities like installing pipelines. Global warming, caused primarily by excess greenhouse gas emissions, leads to rising global temperatures and climate change. This disrupts the ecosystems, which will cause extreme weather events and will affect food and water security. Addressing global warming is essential for environmental sustainability because it helps protect the environment, protect natural resources. Reducing greenhouse gas emissions supports sustainability goals and mitigates the effects of climate change (Kaushal,2020).

A construction project can adopt sustainable practices that protect the environment, enhance public health, and contribute to a more sustainable future by assessing these aspects. This study will assess the environmental sustainability of the trenchless approach and the traditional open-cut method.

5.2 Normalization in Composite Index

Normalization in a composite index refers to the process of adjusting the data so that it can be compared across different indicators or variables. Normalization is a very important step in constructing a composite index because the various indicators often have different units, scales, and ranges. Combining these indicators would be problematic without normalization, as one indicator's range might overshadow another's, skewing the overall index.

Carbon footprint, energy consumption, carcinogens, respiratory effects, and global warming have different units, in which carbon footprint measured by tons of CO2 produced, energy consumption measured by Liters of diesel consumed, carcinogenic measured in comparative toxic units (CTU), respiratory effects measured in kg particulate matter (PM), and global warming measured in kg CO2 equivalents. Hence, normalization is required.

5.2.1 Normalization of Carbon Footprint

According to Tavakoli and Najafi (2017), the amount of CO2 produced in the trenchless approach is 887 U.S. tons, while for the open-cut method, it is 5379 U.S. tons.

Assuming the ideal carbon footprint is 500 U.S. tons, the linear scoring system will score each method on a scale of 1 to 10, where 10 represents the best outcome (i.e., the lowest emissions).

5.2.1.1 Deviation Calculation:

First, the deviation will be calculated to determine how much each method deviates from the ideal carbon footprint of 500 U.S. tons.

For Open-Cut Method:

$$\text{Deviation} = 5379 \text{ U.S. tons} - 500 \text{ U.S. tons} = 4{,}879 \text{ U.S. tons CO2e}$$

For the Trenchless Method:

$$\text{Deviation} = 887 \text{ U.S. tons} - 500 \text{ U.S. tons} = 387 \text{ U.S. tons CO2e}$$

5.2.1.2 Range Calculation:

The range of values is the difference between the highest and lowest CO2 measurements, which means the range from the ideal footprint to the maximum footprint.

5379 U.S. tons −500 U.S. tons =4897kg CO2.

5.2.1.3 Score Calculation

The score will be calculated based on the deviation from the ideal. The method with a smaller deviation will receive a higher score. A linear scale from 1 to 10 will be used, where 10 represents being very close to the ideal carbon footprint and 1 represents being far from the ideal.

$$Open\ Cut\ Score = 10 - (\frac{\text{Open } Cut\ Deviation}{Range} \times 9)$$

$$Open\ Cut\ Score = 10 - (\frac{4{,}897}{4897} \times 9) = 1$$

$$Trenchless\ Score = 10 - (\frac{Trenchless\ Deviation}{Range} \times 9)$$

$$Trenchless\ Score = 10 - (\frac{387}{4897} \times 9) = 9.29$$

So, the scores for each method on a scale of 1 to 10, with 10 being the best, are approximately 1 for the open-cut method and 9.29 for the trenchless method.

This provides a rough estimate of the comparison of the two methods based on the given carbon footprint values.

5.2.2 Normalization of Carcinogenic

A scoring system similar to the one previously described will be used to calculate the scores for each method based on the number of carcinogenic substances measured in CTUs (Carcinogenic Toxic Units), with the target value being 0 CTU (the ideal number of carcinogens).

According to Kaushal, V., & Najafi, M. (2020), the average amount of carcinogenic produced from trenchless is 25% less compared to open cut, with the open cut amount being 100 CTU, and the trenchless equals 75 CTU.

5.2.2.1 Deviation Calculation:

For Open-Cut Method:

Deviation = 100 CTU – 0 CTU = 100 CTU

For the Trenchless Method:

Deviation = 75 CTU – 0 CTU = 75 CTU

5.2.2.2 Range Calculation:

100 CTU – 0 CTU =100 CTU.

5.2.2.3 Score Calculation

$$Open\ Cut\ Score = 10 - (\frac{\text{Open}\ Cut\ Deviation}{Range} \times 9)$$

$$Open\ Cut\ Score = 10 - (\frac{100}{100} \times 9) = 1$$

$$Trenchless\ Score = 10 - (\frac{Trenchless\ Deviation}{Range} \times 9)$$

$$Trenchless\ Score = 10 - (\frac{75}{100} \times 9) = 3.25$$

The score for the open-cut method is 1, and the score for the trenchless method is 3.25. The trenchless method has a higher score, which means it is better in terms of carcinogenicity than the open-cut method.

5.2.3 Normalization of Energy Consumption:

According to Chorazy, T. and Hlavínek, P. (2024), trenchless method energy fuel consumption (diesel) equals 417.6 L and open cut method fuel consumption (diesel) 4896 L. Assuming 1000 L is the ideal amount of fuel consumption.

5.2.3.1 Deviation Calculation:

For Open-Cut Method:

Deviation = 4896 L – 1000 L = 3896 L

For the Trenchless Method:

Deviation = 417.6 L – 1000 L = -582.4 L

5.2.3.2 Range Calculation:

4896 L – 1000 L = 3896 L

5.2.3.3 Score Calculation

$$Open\ Cut\ Score = 10 - (\frac{\text{Open}\ Cut\ Deviation}{Range} \times 9)$$

$$Open\ Cut\ Score = 10 - (\frac{3896}{13896} \times 9) = 1$$

$$Trenchless\ Score = 10 - (\frac{Trenchless\ Deviation}{Range} \times 9)$$

$$Trenchless\ Score = 10 - (\frac{582.4}{3896} \times 9) = 11.34 \approx 10$$

Given that the score should not exceed 10, the trenchless score was round down.

This indicates that the trenchless method is much closer to the ideal fuel consumption of 1000 liters, while the open-cut method is farther away from the ideal.

5.2.4 Normalization of Respiratory Effects

According to Kaushal, V., & Najafi, M. (2020), respiratory effects (measured in kg particulate matter) for the trenchless method equals 20, and for the open cut method equals 100.

For Open-Cut Method:

Deviation = 100 PM – 0 PM = 100 PM

For the Trenchless Method:

Deviation = 20 PM – 0 PM = 20 PM

5.2.4.1 Range Calculation:

100 PM – 0 PM =100 PM

5.2.4.2 Score Calculation

$$Open\ Cut\ Score = 10 - (\frac{\text{Open}\ Cut\ Deviation}{Range} \times 9)$$

$$Open\ Cut\ Score = 10 - (\frac{100}{100} \times 9) = 1$$

$$Trenchless\ Score = 10 - (\frac{\text{Trenchless}\ Deviation}{Range} \times 9)$$

$$Trenchless\ Score = 10 - (\frac{20}{100} \times 9) = 8.2$$

It appears that the open-cut method has a significant deviation from the ideal, while the trenchless method achieves a relatively good score.

5.2.5 Normalization of Global Warming

According to Kaushal, V., & Najafi, M. (2020), global warming (measured in kg CO_2 equivalents) for the trenchless method equals 25, and for the open cut method equals 100.

For Open-Cut Method:

Deviation = 100 Kg CO_2 – 0 Kg CO_2 = 100 Kg CO_2

For the Trenchless Method:

Deviation = 25 Kg CO_2 – 0 PM = 25 Kg CO_2

5.2.5.1 Range Calculation:

100 Kg CO_2 – 0 Kg CO_2 =100 Kg CO_2

5.2.5.2 Score Calculation

$$Open\ Cut\ Score = 10 - (\frac{\text{Open}\ Cut\ Deviation}{Range} \times 9)$$

$$Open\ Cut\ Score = 10 - (\frac{100}{100} \times 9) = 1$$

$$Trenchless\ Score = 10 - (\frac{Trenchless\ Deviation}{Range} \times 9)$$

$$Trenchless\ Score = 10 - (\frac{25}{100} \times 9) = 7.75$$

This calculation indicates that the open-cut method significantly deviates from the ideal, whereas the trenchless method is much closer to the ideal amount of global warming. This suggests that the trenchless method is preferable from an emissions perspective.

5.3 Weighting

Equal weights will be assigned to all parameters (carbon footprint, energy consumption, carcinogens, respiratory effects, and global warming), each parameter to be equally important in assessing the environmental impact or sustainability of the construction methods. Equal weighting can help avoid potential biases that may arise from assigning higher weights to certain parameters based on personal opinions or beliefs. Hence, the parameters will weigh 0.20 each.

5.3.1 Calculate the Composite Index

$$\boldsymbol{Composite\ Index} = \sum \boldsymbol{weight} \times \boldsymbol{Factor}$$

Tables 4 and 5 represent the open cut and trenchless methods composite index, respectively.

Table 4 Composite Index for Open Cut Method

Open Cut			
Factor	Score (norm)	Weight	Final value
Carbon Footprint	1	0.2	0.2
Carcinogens	1	0.2	0.2
Energy Consumption	1	0.2	0.2
Respiratory Effects	1	0.2	0.2
Global Warming	1	0.2	0.2
Total			1

Table 5 Composite Index for Trenchless Method

Trenchless			
Factor	Score (norm)	Weight	Final value
Carbon Footprint	9.29	0.2	1.858
Carcinogens	3.25	0.2	0.65
Energy Consumption	10	0.2	2
Respiratory Effects	8.2	0.2	1.64
Global Warming	7.75	0.2	1.55
Total			7.698

5.4 Result Analysis:

Composite index scores for the open-cut method equal 1, and the trenchless method equals 7.698, suggesting a significant difference in performance between the two methods, with the trenchless method performing much better overall than the open-cut method.

A higher composite index indicates better overall performance across the various parameters (carbon footprint, energy consumption, carcinogens, respiratory effects, and global warming). The higher score suggests lower environmental impact and better sustainability and health standards adherence.

Given these scores, decision-makers might prefer the trenchless method over the open-cut method due to its better overall performance in terms of sustainability and health impact. These scores can guide policymakers, construction managers, and other stakeholders to favor the trenchless method in future projects, as it seems more sustainable and environmentally friendly.

CHAPTER 6: CONCLUSION AND FUTURE WORK

6.1 Conclusion

In conclusion, urban communities rely on the seamless operation of foul sewer systems, which serve as critical infrastructure components, ensuring a sanitary living environment for residents. However, constructing these networks in inhabited areas presents multifaceted challenges, necessitating careful consideration of noise and traffic disruptions. The construction process, involving excavation and installation, poses potential disturbances to residents and requires meticulous planning to manage traffic flow and ensure safety.

Various methods exist for constructing foul sewer networks, each characterized by distinct application conditions and technical parameters. To address the inefficiencies associated with these methods, this research endeavors to conduct a comprehensive evaluation and propose improvements to enhance construction processes. The study aims to optimize construction practices, minimize resource waste, and improve overall system efficiency by analyzing identified inefficiencies and suggesting improvements.

Adopting trenchless technology can be seen as a pivotal solution, showcasing remarkable advantages in minimizing disruption and costs compared to traditional techniques. To further enhance efficiency, strategies such as reducing the workforce and implementing noise reduction measures are proposed to optimize construction processes and mitigate adverse impacts on communities.

Data Envelopment Analysis (DEA) is a valuable tool for evaluating decision-making units (DMUs) in underground utility construction projects. By considering various input and output metrics, decision-makers can gauge the efficiency levels of different construction methodologies and make informed decisions to optimize project outcomes and resource management.

The collaboration with a Qatari construction company has provided invaluable insights and firsthand perspectives on the challenges and best practices associated with foul sewer network construction in the region. By leveraging this data, the study ensures relevance and reliability, facilitating targeted recommendations and solutions tailored to Qatar's specific context.

The composite index scores indicate a notable contrast in performance between the open-cut method, which scores 1, and the trenchless method, which scores 7.698. This suggests that the trenchless method outperforms the open-cut method considerably.

In conclusion, the findings underscore the imperative of adopting efficient construction methods and implementing process improvements to ensure the sustainability and resourcefulness of urban communities. Through collaborative efforts and strategic interventions, the construction industry can create healthier and more livable environments for residents, fostering sustainable urban development for generations to come.

6.2 Future Research Directions

Future work in this field could focus on several areas to further enhance the efficiency and sustainability of foul sewer network construction:

The next step could involve implementing the proposed improvements and refinements in construction projects. This would allow for the validation of their effectiveness in optimizing construction processes and improving overall efficiency.

Moreover, a longitudinal study assesses the long-term impact of the implemented improvements on construction projects. This could involve monitoring and evaluating efficiency metrics over an extended period to ascertain sustained improvements and identify potential challenges or areas for further enhancement.

Furthermore, comparative studies of foul sewer network construction practices and efficiency metrics across different countries and regions will be conducted to identify best practices, lessons learned, and opportunities for cross-border collaboration and knowledge exchange.

Additionally, the data were derived from a single company. The calculations and results would likely be more accurate if the data had been gathered from multiple companies.

By focusing on these areas of future work, researchers and practitioners can contribute to the continuous improvement and innovation of foul sewer network construction, ultimately promoting sustainable urban development and enhancing the quality of life for communities worldwide.

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