Integrated cost comparative framework for trenched and trenchless techniques in the Netherlands

Master's Thesis Internship – Master Water Sciences and Management

Guillaume Cardon de Lichtbuer

KWR
Watercycle Research Institute

Universiteit Utrecht

Master thesis report
Author: Guillaume Cardon de Lichtbuer – student 5498988
Student number: 5498988
Date: July 31st 2016
Location: Nieuwegein

Company
KWR Watercycle Research Institute
Groningenhaven 7,
Postbus 1072
3430 BB Nieuwegein

Company supervisor
Mirjam Blokker
Mirjam.Blokker@kwrwater.nl

University supervisor
Aat Barendregt
a.barendregt1@uu.nl

Contact
Guillaume Cardon de Lichtbuer
Julianaweg, 5
3525 VA Utrecht
06-26460096
g.cardondelichtbuer@students.uu.nl

Preface

It is with great pride and satisfaction that I present this report that describes the process and results of my thesis research: *Integrated cost comparative framework for trenched and trenchless techniques in the Netherlands.* The research has been performed at KWR Watercycle Research Institute and marks the end of my Water Sciences and Management Master at Utrecht University.

KWR Watercycle Research Institute is a Dutch organization gathering a wide range of professionals of water related fields. It is owned by Dutch water companies and aims at improving and creating technology and scientific knowledge for water management. Within the broad range of research fields, KWR is composed of the water infrastructure section, held by the principal scientist Mirjam Blokker, who graciously accepted to be my supervisor at KWR.

This research has been carried out in relation with the TKI project aiming at improving the technology of rehabilitation and replacement techniques in drinking water piping network. The choice made on the integrated cost assessment has been entirely related to my own interests. Although performing this research was an epic journey, I am very satisfied of the knowledge gained in research processes as well as the knowledge gained in the topic of this research.

By this preface, I would like to thank both of my supervisors who help to get insights in research processes. I am very satisfied as they both could frame my work when needed and were available as much as I wanted. Special thanks also to all the experts of the fields at KWR and Vitens who dedicated some time for interviews and site visits.

Guillaume Cardon de Lichtbuer,
Nieuwegein, July 2016

Summary

There is a large number of techniques available for rehabilitation and replacement in drinking water pipes in the Netherlands. Among the rehabilitation and replacement techniques, decision-makers can choose whether to use trenched or trenchless techniques. The choice of the technique is however limited by the variety of site-specific conditions.

When choosing to dig or not to dig a trench, social and environmental concerns are considered by decision-makers although it is observed that economic concerns are prioritized. The trade-off between social, environmental and economic is a complex algorithm.

Hence, the current research aims at providing a framework to calculate the economic, social and environmental costs of a technique and supporting decision-makers in the selection of the appropriate technique. After performing a meaningful literature review and discussions with experts, a description of the topic is proposed, followed by the formulation of hypotheses. The framework is applied to two trenched and two trenchless techniques, so that the hypotheses can be validated or invalidated.

A general observation is that the cost of techniques varies highly from one site to another site. Out of four hypothesis, three have been confirmed through the use of the framework.

The total costs vary between 174 819 € and 195 744 € for trenched techniques and between 250 158 € and 423 644 € for trenchless techniques.

Trenchless techniques have proved to provide social and environmental benefits varying between 11 000 € and 44 000 €. It has been identified that urban areas increase significantly the difference between direct-indirect costs and socio-environmental manly due to the costs associated to the technology of the techniques. The price of the technology for trenchless techniques is strongly impinging on the direct-indirect costs, explaining the fact that capital costs, i.e. direct and indirect costs, are more considered in the decision-making processes. The valuation methods used for the accounting of environmental costs have shown to be adequate in this topic although have shown to be highly dependent on the perceptions and values of people on the environment. Social accounting methods are adequate although some weaknesses appear in the consideration of stakeholders.

Table of contents

Chapter 1: Introduction

Water is a crucial element needed for both Humanity and Earth. Available fresh water can be found in the lakes, the rivers, the reservoirs and underground sources. Available fresh water accounts only for 3 percent of the global water availability while the remaining 97 percent is salted water (Gleick & Palaniappan, 2010). Fresh water has the property to be directly usable for human consumption and more specifically for agricultural, domestic and industrial purposes.

One way of improving water availability is the improvement of the water supplies (Boucherie et al., 2012). Water supplies can refer to the natural resources but also to the infrastructures that protect and provide water to the users. Phenomena such as the failures of pipes (also called mains) in the distribution networks occurs because of the ageing processes. The observed increase in pipes rate failures arise challenges for decision-makers who needs to undertake appropriate actions to repair the failures.

In any water distribution network, the ageing of the pipes requires attention from the water companies as a result of the increased phenomena of failures that the ageing processes involve. Leakages in the pipes represent an enormous amount of water wasted. Such in the Netherlands, water loss caused by leakages represents 6 percent of the total water production while this phenomenon represents 16 percent in United Kingdom (Rosario-Ortiz et al., 2016).

As a result of increasing concern for water scarcity induced by pipes failures, the efficiency of pipes renovation and rehabilitation techniques becomes a challenge. Numerous techniques are available for pipes replacement or rehabilitation, however the economic requirements are often a barrier. Within the range of rehabilitation and replacement techniques, distinction between trenched and trenchless technologies exists and the current opinion of experts highlights the increasing capacity of trenchless techniques (Beale et al., 2013). Especially in urban areas where the water demand is higher, the consideration for adapted techniques is even more crucial.

Problem identification

Decision-makers are confronted in selecting the appropriate way of extending the life time of a pipe line after failure. Rehabilitation and replacement techniques are available, however the selection of the appropriate technique involves economic and operational constraints. The decision-maker aims at finding the most cost-effective alternative.
Researchers in the Netherlands are currently investigating the underlying reasoning behind the selection of a technique. As the responsibility of the safe and effective drinking water supply of a specific region lies with the water company, methods and means for the selection of the technique is entirely left to the water company. In fact, the method and criteria that are applied are economically based. An applicative study led by Bottero and Peila (2005) investigated the influence of economic, social and environmental criteria on the selection of either trenched or trenchless techniques. The study observes that trenchless techniques are adopted when social and environmental criteria are considered.
The complex task of decision-makers is to comply with a large amount of criteria. There are regulative, economic and operational constraints for each site-specific condition which provide barriers to decision-makers (Marlow et al., 2015). On top, the involvement of stakeholders adds supplementary difficulties to the decisions, especially in urban areas where the higher density of the population causes higher number of involved parties such as the residents of the area and the owners of other underground infrastructures.

The evaluation of costs is often neglecting the social and environmental aspects in the decision-making processes. The significance of those aspects seems not being recognized by decision-makers as a result of difficulties associated to their quantification, even more when considering their conversion into monetary terms (Haab et al., 2013). Studies have been done on the life-cycle assessment of construction projects such as trenched and trenchless techniques although none have attempted to establish the total budget estimation integrating economic, social and environmental aspects (Strogen et al., 2016; Petit-Boix et al., 2016; Akhtar et al., 2015).
The cost quantification of social and environmental impacts is difficult to conduct because of the occurrence of multiple direct and indirect consequences of anthropogenic activities caused by multiple chemical and physical natural reactions (Bonamente, 2016). The lack of adaptive methods arises difficulties to estimate environmental damages, and even more in long-term considerations.

A distinction between trenched and trenchless techniques needs to be established as a result of unawareness of their total costs component; the real issue is that decision-makers are mainly focused on capital costs to select the appropriate technique. When examining the use of trenched and trenchless techniques and their relevance in renovation and replacement, it is important to consider the life-cycle cost of the technique as some cheaper rehabilitation techniques may require additional cost for maintenance (Morisson et al., 2013).
The current practice is the use of trenchless techniques in most of the rehabilitation work while trenched techniques are used for both replacement and rehabilitation work. However, the application of trenchless techniques to most of rehabilitation works are not always technically or economically feasible (Beale et al., 2013). It is agreed that the installation of a new pipe provides better services than a rehabilitated one although each site has specific

conditions and adaptive measures must be considered. A consensus must differentiate in which case replacement or rehabilitation needs to be undertaken.

Objectives and research questions

The main aim of this master thesis is to undertake a cost analysis of trenched and trenchless techniques in the Netherlands using a framework. The term of 'framework' is used as a result of the establishment of a specific set of criteria.

Sub-objectives of this research are:

-Identify the current considerations and practices of trenched and trenchless techniques in the Netherlands.

-Provide and apply an integrated framework capable to assess the total cost of a technique.

-Discuss the environmental and social consideration and their pertinence in the context of trenched and trenchless techniques.

The main research question of this thesis is:

What are the current total costs in euros - including direct, indirect, social and environmental costs - of trenched and trenchless techniques in the Netherlands?

Sub-questions are:

What are the current social and environmental benefits of trenchless techniques in the Netherlands?

How the Dutch conditions can affect the costs of those two types of techniques?

While considering direct-indirect costs and socio-environmental costs between trenched and trenchless techniques, do those costs present a significant difference and appeal to consider one more than the other?

Are the methods of environmental and social accounting adequate when considering stakeholders involvement?

Organization of the research

The current research has been performed using various sources of information including a literature review, the knowledge of experts and field observations. Statistical database for the Netherlands such as CBS is used as a source of data for the calculation of social costs. The overall process of this research is based on the validation or invalidation of hypotheses using a framework applied to case studies.

Step 1: a literature review and interviews with experts lead to a meaningful introduction to the topic. This introductory work on the topic allows the determination of hypotheses.

Step 2: the theoretical framework is built. The details of the parameters to include are collected from knowledge of experts and a literature review. The framework aims to be applied to four case studies including two trenched and two trenchless projects.

Step 3: once the theoretical framework is applied to the four case studies, the costs are calculated and the hypotheses are validated or not. Discussion, conclusion and recommendations are deduced from the results.

The figure 1-1 summarizes the process of the research.

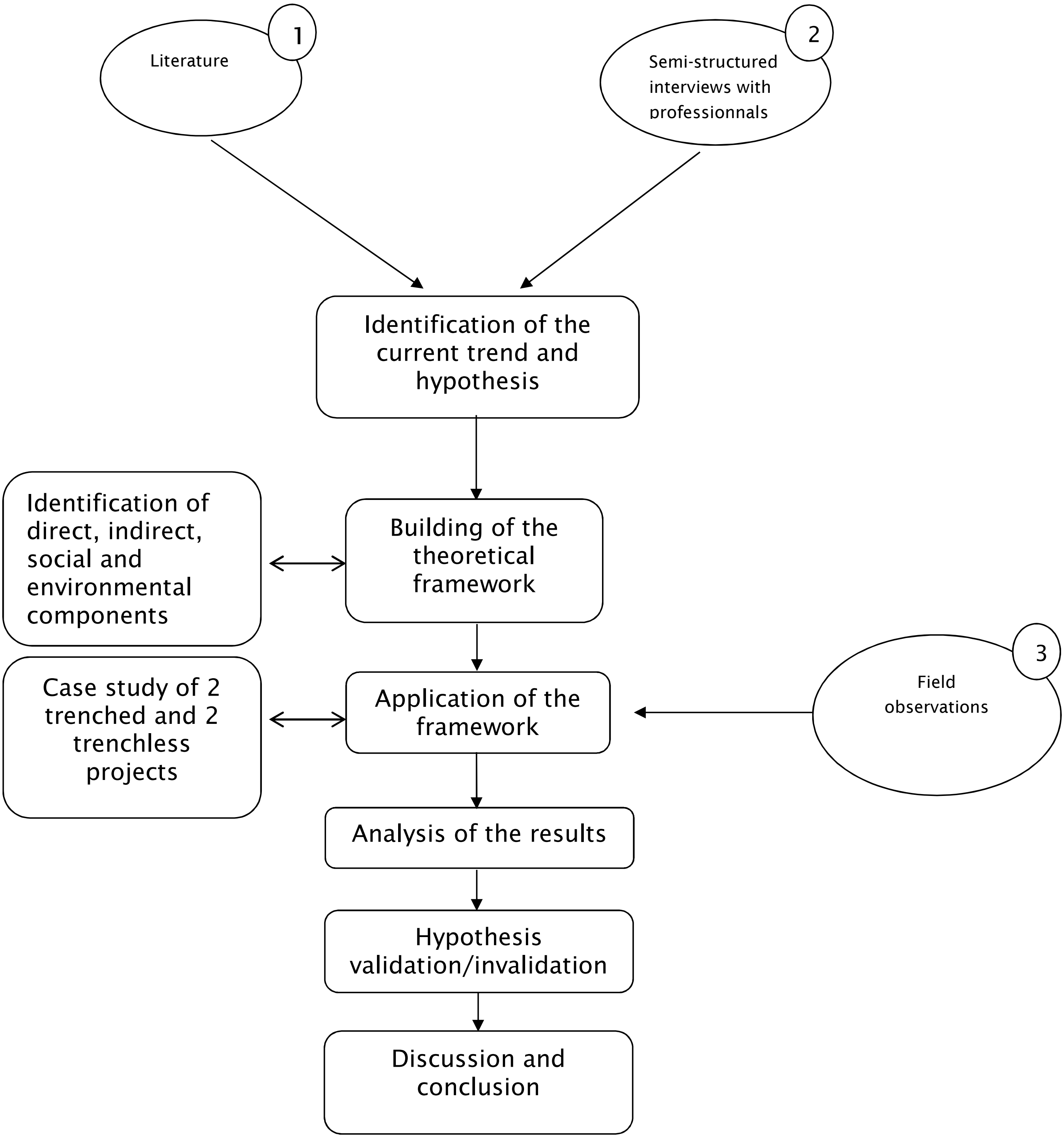

Figure 1-1 : Scheme of the research

Chapter 2: Observations and hypotheses

This section aims at identifying the current trends in the use of trenched and trenchless techniques and their costs based on the available literature and the interviews with experts. The outcome of this section is the formulation of hypotheses that are verified through the use of a framework described in the next chapter.

A general observation revealed that trenchless techniques have been widely considered and approved by water companies and contractors during the last decades although trenched techniques are still more often used. Even though the economic constraints plays a crucial role in the decisions, the choice of the technique needs also to take into account the social and environmental aspects.

Terminology and definitions

This section aims at clarifying concepts and terms used in this research. Multiple and diverse technical terms may be encountered in this current thesis, that need to be primarily explained.

Trenched and trenchless techniques

Trenched technique

The trenched technique is also called the traditional method or the open-cut excavation method. As shown in Figure 2-1 , it requires the removal of the soil of all the section to repair, replace or install. It involves excavating down and exposing the existing pipe to possible reparation, replacement or installation and lead to laborious trenching work.

The advantage of trenched technique is that the pipe is entirely visible and a proper analysis of the problem can be performed.

Figure 2-1: Open-cut for installation, replacement or rehabilitation

Trenchless techniques

Historical research have reported the first use of trenchless techniques in the 1860's (Ariaratnam, 1994). However, the use of trenchless techniques in the sector of drinking water is quite recent and further research are needed because of lack of knowledge of this type of technique (Ariaratnam et al., 2013). Only one specific trenchless technique, so-called pipe bursting or cracking, is available for replacement and is performed by pulling the new pipe into the old pipe causing its cracking. However many issues and uncertainties remain on this type of technique (Lapos et al., 2007; Cholewa et al., 2009). The table 2-1 presents an overview of the current trenchless techniques for rehabilitation.

Table 2-1: Current trenchless techniques used in rehabilitation of drinking water and wastewater piping network (Morisson et al., 2013)

Trenchless techniques	**Specifications**
Spray-On Linings	Cement Mortar Lining Epoxy Lining Polyurea Lining Polyurethane
Slip-lining	Segmental Sliplining Continuous Sliplining
Cured-in-Place Pipe	Insitu Main Aqua Pipe Nordipipe Starline
Inserted Hose Lining	Thermopipe Primus Line
Close-Fit Lining	Fold and Form Close-Fit Liners Symmetrical Reduction/Reduced Diameter Pipe
Service Line Rehabilitation	Nu Flow Technology Flow-Liner Neofit Process Deposition of Calcite Lining

Within the broad range of trenchless techniques, some are more used than others. The followings enlist the rehabilitation techniques that are mostly used:

Slip-lining: this technique is considered the simplest technique as the straightforward process involves the insertion of a new pipe into an existing pipe. The different pieces of the new pipe are assembled in the manhole and pushed forward along the section to repair. The space between the new and old pipe is then filled with grout allowing a reinforcement of its resistance. Figure 2-2 illustrates the process of slip-lining.

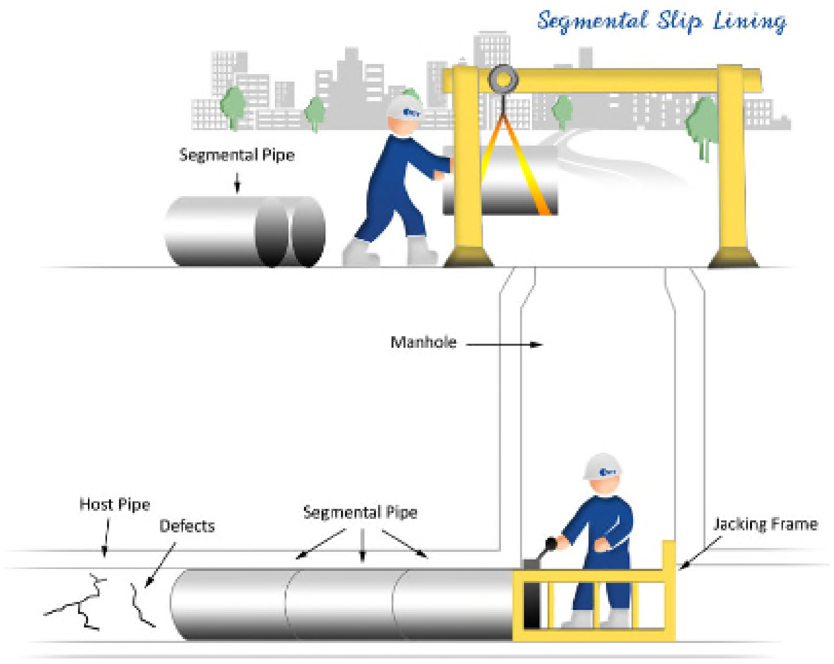

Figure 1-2: Slip-lining process

Spray-On Linings: the principle of this technique lies in the recovery of the inside of the pipe using a specific material (see Figure 2-3). Also named coating, the product that is sprayed can for instance consists of a mix of epoxy and polyurethane which can prevent corrosion to the interior surface. The spraying process can improve the flow stream of the pipe, but is not adding additional strength to the existing pipe.

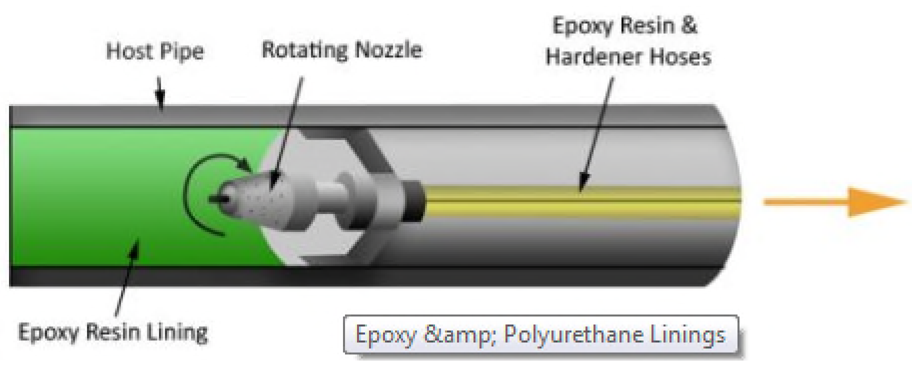

Figure 2-3: spraying process using Epoxy and Polyurethane Resin

Close-fit lining: this technique refers to the introduction of a thin-wall thermoplastic liner by reducing its diameter. As shown in Figure 2-4 , the initial shape of the liner is folded so that it can be introduced in the section under rehabilitation. After pulling the liner, a chemical reaction induced by water or heat allows the pipe to closely fit the existing pipe. Compared to slip-lining process, close-fit lining allows the use of larger diameter pipe.

Figure 2-2: Close-fit lining pipe (white one) before heating

Cured-in-place (CIPP): the process involves the insertion of a liner impregnated in a resin either by air, water inversion or pulled into place with a winch . Once the liner is positioned in the pipe to rehabilitate, a chemical reaction triggered with water or pressure gives a new material formed from the resin and the liner. The technique is fully constructive as it is closely sticking to the wall of the existing pipeline. There are currently many variants of the technique that depend on the resin type, the installation methods, the curing methods and tube construction. Figure 2-5 illustrates two variants of CIPP processes.

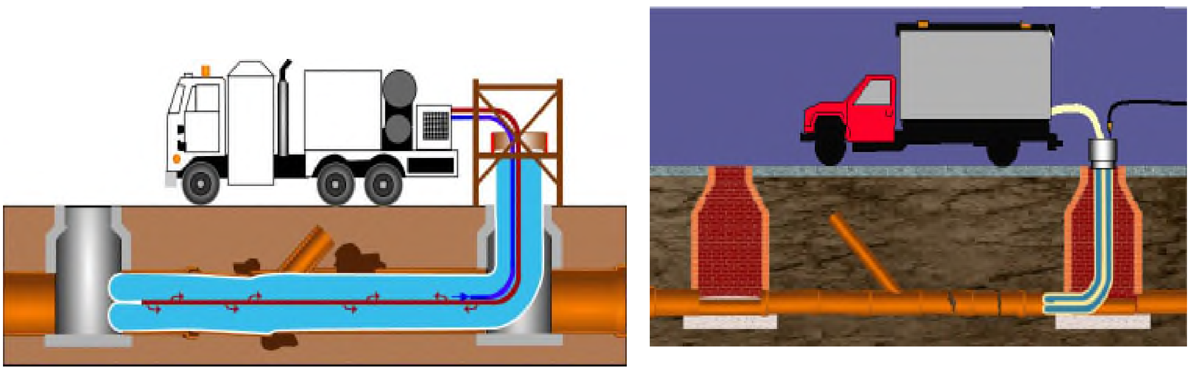

Figure 2-5: two variants of CIPP technique - left: water inversion process ; right: hot water circulation and curing

Rehabilitation and replacement

Rehabilitation

The rehabilitation or reparation of a pipe involves all the work aiming at extending the use of an existing pipe.

Replacement

The replacement of a pipe involves the removal of the existing pipe and the insertion of a new one. In some cases, the new pipe is installed next to the existing pipe to avoid the removal process.

Total cost

The concept of total cost as used in this research involves the direct, indirect, social and environmental costs. Those four aspects are described in detail in the framework provided in this research (see Chapter 3). Since those concepts are mentioned before the elaboration of the framework, it is relevant to mention them here.

Direct and indirect costs involve all the expenses that need to be paid directly. They involve the costs related to the "physical" work for the construction processes as well as the costs for the material used for example. Indirect costs account for all the costs that are not included in the direct costs but is part of the budget of the contractors such as the costs related to the risks of delay.

Social and environmental costs are involved during any trenched or trenchless techniques. They represent the monetary value of social and environmental consequences that might occur during a project.

Technology and technique

In this current report, the terms used for the techniques and the technologies can be confusing as the term "technology of a technique" is used. Therefore, this section attempts to differentiate those two terms in order to have a clear idea.

A definition of technique is the "body of specialized procedure and methods used in any specific field"(The Random House Dictionary, 2016). The term "technique" is a conceptual approach referring to the steps leading to a wanted outcome.

The term "technology" refers to the area of "knowledge that is dealing with the creation and use of technical means and their interrelation with life, society, and their environment" (The Random House Dictionary, 2016). In the context of trenched and trenchless techniques, the "technology" is a concrete and specific approach focused on elements such as the type of materials, the tools, the machinery used.

Applied to the topic of this current study, the "technology of the techniques" is associated to the specificity of the technique. Important elements involving the technology of the techniques are the materials used and their specific function in the process of the technique. The technology also refers to the level of expertise that the technique requires.

Sustainability

Environmental concerns in the field of construction project such as trenched and trenchless techniques is an increasing matter of concerns (Thewes and Bielecki, 2007). Historically, the main goal of projects is to minimize the costs and maximizing the quality. Behavioral enhancement towards more sustainable practices is a concept that can change the model of selection of techniques. The significance in the context of this research is that trenchless techniques are well in line with the concept of sustainability as their impacts on the environment and society has proved to be diminished.

Trends in the adoption of trenched and trenchless techniques

The “tried and true” technique

Contractors and water companies are relying on trenched techniques and their use remains nowadays higher than trenchless techniques as a result of the “tried and true” attribute of trenched techniques and their proven reliability and efficiency (Beale et al., 2013). While the conventional excavation technology is mostly used in the replacement of pipes, trenchless techniques facilitate practices for rehabilitation. Only the pipe bursting technique, also called pipe cracking, is used to replace a pipe without digging trenches.

Trenchless techniques are continuously developed and refined, more specifically in the range of their applicability such as the size of the pipe, the accuracy and their ability to work deeper in the water table (UNEP, 2001). The preferential use of trenched techniques has decreased during the last decades mainly caused by the increase of environmental and social pressure in urban areas. Consequently, it is likely that trenchless market will increase in the next years (Damvergis, 2014).

With trenchless techniques, a recurrent operational problem is the management of the joints. The rehabilitated pipe needs indeed to be properly connected with the existing network and issues occur when the repaired pipe is reconnected (Chapman et al., 2007b). Beyond the operational issues occurring with trenchless techniques, intrinsic problem seems to be the slow recognition of the high potential of those techniques induced by a lack of knowledge. Uncertainty with respect to trenchless techniques suggests further research on applicability and cost of those technique in a particular situation (Chapman et al., 2007a). The achievement of appropriate knowledge and use of trenchless techniques in rehabilitation would allow an extension of useful lifetime of the existing pipes, reducing considerably the expenses on a long-term run (Selvakumar et al., 2002). Difficulties occur in estimating the potential of rehabilitation techniques to extend the useful lifetime of pipes as it depends on factors such as the used technique, the material and the size of the pipe. Typically, spraying methods with epoxy lining can extend the useful lifetime of small pipes from 40 to 60 years (Deb et al., 2006).

The forgotten social and environmental aspects

Trenched operations in urban area generate social and environmental disturbances. Despite the slow progress, environmental and social impacts in heavy construction works are increasing concerns for decision-makers (Oliveira, 2014; Oliver-Sola, 2009).

The social aspect

As mentioned by authors and experts, social disturbances have a significant impact on the total costs of the operations (Boyce et al., 1998; Islam et al., 2014). In fact, the social parameter is rarely considered by decision-makers. Typically, a management strategy considering the use of trenchless techniques would significantly reduce the traffic congestion in urban areas (Beale et al., 2013). Typically, this current research is aiming to prove the marginal and significant contribution of social factors in the total budget of a technique and therefore, should be considered.

The environmental aspect

A similar approach is observed for environmental impacts, i.e. a low consideration by the decision-maker for damages to natural resources and public health (Fea et al., 2000). It is worth noting that public health is considered in this current study as an environmental damage; while some experts would not include humans as being part of the environment, the approach of this research sees humanity as being fully part of the natural environment. One possible mean to mitigate the environmental impacts is to develop strategies incorporating more trenchless techniques that are able to significantly reduce the carbon emission and the ecosystem disturbances. Typically, the use of trenchless techniques reduces the greenhouse gas emissions from 78 to 100 percent compared to traditional open-cut excavation explained by the lower time spent on site and reduced traffic congestion (Rehan and Knight, 2007).

Investments in the techniques should consider not only the direct and indirect components but also the social and environmental aspects. Although the latter components are rarely considered, the conversion into monetary terms should prove their legitimacy in the decision-making processes, and more specifically for urban areas where larger savings are possible. The best alternatives in the choice of the techniques must be the result of the combination of all the costs, which can make the trenchless techniques the most economical choice (Jung and Sinha, 2007).

Trenched and trenchless techniques in the Dutch situation

In this section, the review aims at analyzing the influence of external conditions on the cost of trenched and trenchless techniques in the Netherlands. As the current research focuses on the total costs of the techniques, the section enlists the specific Dutch characteristics that can impinge on the total costs. When considering the differences between trenched and trenchless techniques, it is probable that the Dutch conditions affect more the costs of trenched techniques than trenchless techniques.

Potential of trenchless techniques in Dutch urban areas

The type of environment (urban or rural) is an important matter of interest as it can influence the type of rehabilitation or replacement strategy to adopt. Both types of environment can affect largely on the use of either trenched or trenchless techniques, depending on the proportion of urban areas within a country. In urban area, a higher number of parameters needs to be taken into account in the analysis. Trenchless techniques in cities can reduce significantly the social and environmental costs and their advantages can be considerable in complex environment such as an urban area.

In trenchless techniques, the financial savings are mainly caused by the limited removal and recovering processes. In the presence of asphalt, those processes can be costly.

Savings on social costs are related to the decrease of the traffic congestion that can be avoided with the use of trenchless techniques. The mitigation of traffic congestion are even more important considering the increasing growth rate of the population in major cities of the Netherlands. Figure 2-6 displays the population growth of Amsterdam (CBS, 2011).

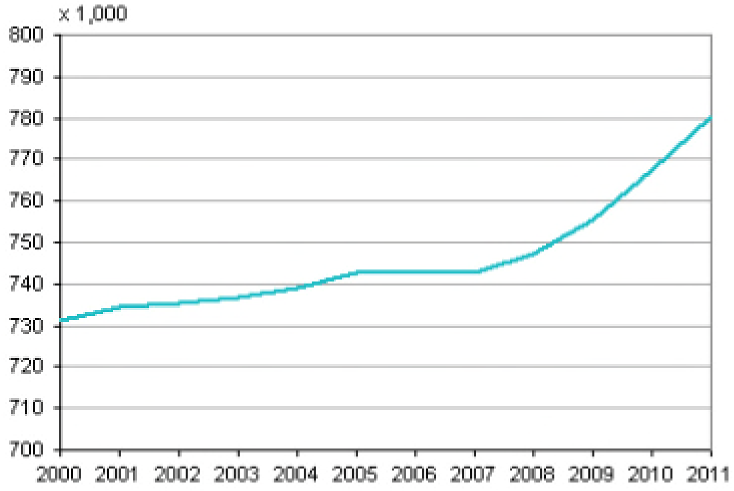

Figure 2-6: Amsterdam population growth between 2000 and 2011 (CBS, 2011)

Soil properties consideration

Dutch soil has a recognized specific geologic conditions that can be an issue in constructions sector (Van der Hoop, 2013). When analyzing the geological settings of the Netherlands, the

Dutch specificities are likely to stem from the fact that most of the country is located beneath the sea level and results in a high proportion of sandy soils. The Netherlands also present a peat soil region located in the western part of the country and represents 9% of the total area of the country.

By definition, trenchless techniques limit the excavation of the soil. In contrast, trenched techniques are characterized by a high dependency on the level of pollution as well as the quality of the soil as heavy metals and oil-like substances might be present. The cleaning process involves the removal, transport and treatment of the soil and refers to the removal of unwanted soil elements such as coarse granular. The cleaning processes of the soil can require the replacement of the original soil by an adequate type of soil that allows a uniform compaction and increases the life expectancy of the buried pipe.

The increase of the direct costs can be engaged in case of poor soil quality and unclean soil. In the context of construction projects, the main qualitative aspect of the soil is the stability in which stable and unstable soils are distinguished. Issues arise in unstable soil when the pipe sinks down into the water table, limiting the life-time of a renovated pipe. In the Netherlands, sand, clay and peat soils are mostly present and have different values of stability. Typically, peat soil has the lowest value of stability leading to a field mudslide down varying between 20 and 30 centimeters per year (Van der Akker, 2010). Generally, sandy and clay soils have respectively mildly and high values of stability and usually have limited impacts on pipe settlements.

In trenched techniques, direct costs can also be involved as a result of the control of the archeologist and ecological conditions of the soil. They are preventive measures because unexpected temporary break or cancellation of the project would lead to considerable financial waste.

Groundwater level influence

The eastern part of the Netherlands presents a groundwater located at several tens of meters beneath the surface. In the western part of the Netherlands, the level of groundwater can be between 0.5 and 1 meter below the surface. During an excavation work, the high proximity of the groundwater to the subsurface may causes the need for dewatering. The inconvenience related to the dewatering processes is the lowering of the groundwater table around the excavation. Dewatering might affect other facilities near the excavations, therefore an assessment of the adverse consequences needs to be carried out prior to the work (Wong, 2003).

The costs involved in the influence on the groundwater level are direct and environmental. Direct costs include the various consequences to other infrastructures near the excavation. The adverse effects of dewatering are mainly affecting sensitive structures, i.e. old buildings on shallow foundations, busy roads, gas and water mains, etc.

Environmental impacts include the effects on the soil. Potential effects of excessive dewatering are (WQPN, 2012):

- Contamination of water used for agricultural or domestic water supplies

- Turbidity and sedimentation in urban surface water nearby the excavation

- Harm on the nearby ecology and vegetation

- Reduction of dissolved oxygen in waterways

Summary

While comparing trenched and trenchless techniques in Dutch settings, the impacts mainly concern trenched techniques and point out their main disadvantage that is their high dependency to the surrounding environment.

The description of the three typical conditions considered above concludes that the urban conditions in urban areas highly encourage the use of trenchless techniques. The consideration for social and environmental factors plays an important role in the cost calculation. The following table 2-2 summarizes the costs and parameters that are affected by the Dutch situation. From the table, it can be readily identified that the type of environment, e.g. urban or rural, affects primarily the variety of impacts and prices as direct, social and environmental impacts are observed.

Table 2-2: Cost-impact evaluation of the Dutch situation

Dutch situation factor	Type of cost influenced	Involved parameters
Dutch urban area	Direct	Recovering processes (high cost of asphalt)
	Social	Traffic congestion
	Environmental	GHG emission from machineries
Soil properties	Direct	Depollution processes
Groundwater level	Direct	Dewatering processes Archeologist and ecological control
	Environmental	Consequences on the surrounding infrastructures Ecological consequences of dewatering

Hypotheses

The previous section has attempted to explore the current knowledge on the costs of trenched and trenchless techniques. From those observations, hypotheses can be stated and verified using the framework described in Chapter 3.

Hypothesis 1: trenchless techniques have higher direct costs than trenched ones.

Accounted in the direct costs aspects, the technology used in the realization of trenchless techniques is observed to be much more developed. The state of the technology is constantly evolving and opportunities might give rise to cheaper product as a result of more adequate services. The hypothesis tends to verify whether the direct costs of trenchless techniques is still higher because of the level of technology.

Hypothesis 2: trenched techniques have higher social and environmental costs than trenchless ones.

A large part of the costs of trenched techniques is associated to their social and environmental costs. However, uncertainties arouse on the quantification of those impacts as well as on the method used. Using a specific method of quantification, the current hypothesis wants to quantify the social and environmental cost differences between trenched and trenchless techniques.

Hypothesis 3: the total costs of trenchless techniques in urban areas are higher than the total costs of trenched techniques in urban areas.

In the Netherlands, the high proportion of urban areas favors the use of trenchless techniques as a result of their high cost-benefit. There is a need to evaluate the current trend of the price of trenchless techniques if proper predictions or recommendations in the technology of the techniques want to be identified. The hypothesis aims at evaluating which extends the costs of trenchless techniques are.

Hypothesis 4: the values for social and environmental costs are higher than those for direct and indirect costs.

A significant difference between socio-environmental and direct-indirect costs is a matter of interest when taking decisions. Typically, the hypothesis aims at evaluating the order of magnitude existing between the costs of socio-environmental and direct-indirect impacts so that a decision-makers take them into consideration in their assessment of conditions.

Chapter 3: Building of the theoretical framework

This section aims at building the model for the evaluation of the total cost of the two types of techniques studied in this research (see Annexe A). As the model is applied in the next chapter, it is important to warranty its feasibility. In this section, the list of the observations for each type of costs are set and developed. Direct, indirect, social and environmental considerations are evaluated, converted into monetary value and summed. The framework attempts to consider all the aspects that are required when a complete cost assessment needs to be implemented. It is important to consider the framework as a common set of criteria that are most of the times observed although certain site-conditions might require the addition or the removal of criteria. Therefore other parameters might be incorporated, depending on the site specificities.

A comprehensive review of the current literature combined with semi-structured interviews has been undertaken in order to build a theoretical framework. In the body of literature, no study performing an integrated assessment of costs has been found. It is often noticed that only one or two aspects of the costs (either social and/or environmental) are treated.

Direct costs estimation

An estimate of the direct costs in trenched and trenchless techniques involves a wide range of parameters contributing to the construction work and giving rise to the budget for the execution of the project. Direct costs include all the expenses associated with the construction work involved in the “physical” work. The accounting depends largely on the task specified as a result of the site-specific conditions differing from one site to the other (Arends et al., 2004; Oreste et al., 2001). Typically, externalities such as a high surrounding infrastructure or the presence of subway are likely to alter the direct costs of the techniques.

The "office-work" component

An exhaustive list of the direct costs includes the executive work as well as the preparation work that is not necessarily associated with the "physical" work. It is indeed important to consider the time that is spent for administrative requirements. The preparation phase of a construction project is usually intensive and requires documentation and surveying. Those types of activities require time, management and effort from the water companies and contractors. They include the engineering work for planning, the tender procedure, the contract proposal etc. The following list describes the various additional aspects that are included in the administrative work:

- Construction supervision and project management
- Costs of recording the status of structures and trees, plant etc.
- Surveying work
- Requirements of any approvals

While considering trenched and trenchless techniques, it is likely that the administrative work is similar and therefore, differences cannot be readily observable. Considering the goal of this current study, it is important to mention them as they can be included in the total costs estimation of the two types of techniques studied.

The "physical-work" component

The executive work includes the activities associated to the installation of the pipe and the excavation and recovering of the soil. Those activities require the use of specific machineries and the price of the pipe that are included in the direct costs.

The installation of pipe usually involves the technology that is associated to the technique. Trenched techniques usually involve limited technology as the section to repair is open-air. In contrast, trenchless techniques involve a higher level of technology as the pipe is not visible. As described in the previous chapter, trenchless techniques require a certain type of equipment that is more costly than the traditional machineries used in trenched techniques.

The recovering of the soil is part of the preparation processes as a pipe will be buried and is significantly influenced by the quality of the soil. The proper preparation of the soil ensures the avoidance of unexpected longitudinal and cross-sectional strains and stresses in the pipe. The performance of the pipe depends largely on the quality of the compacted fill in the embedment zone (see Picture 3-1). Typically, the denser the fill, the more likely gravity loads of surcharge will be pushed away from the pipe.

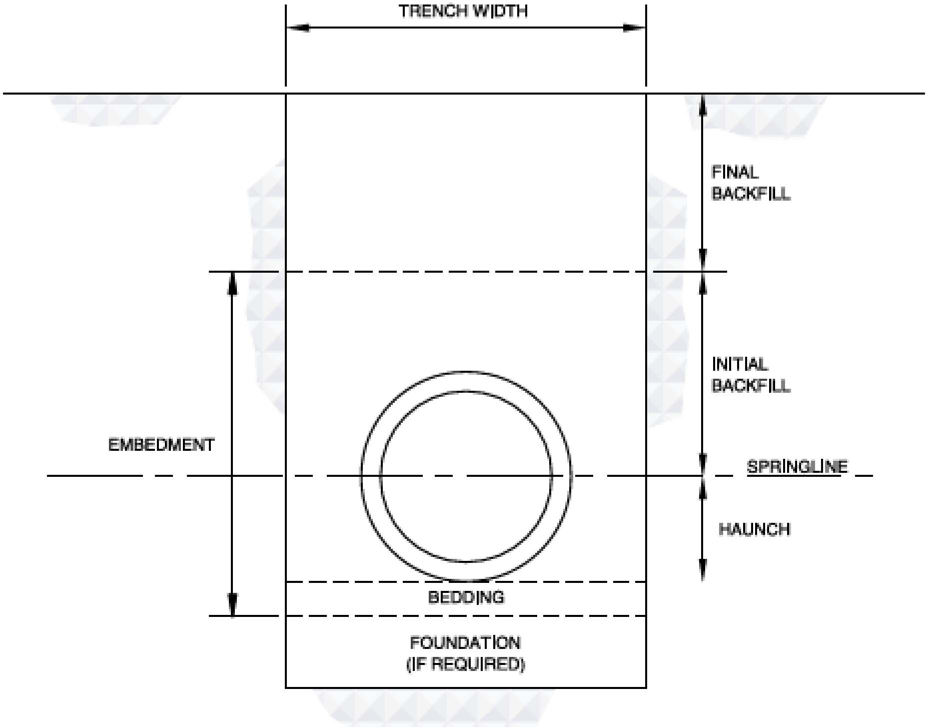

Figure 3-1: Used trenched terms

Insurances

The cost associated to the insurances of delay or collapse of the project, machineries breakages and equipment needs also to be considered in the framework. Although they are important to consider, they represent a small part of the budget.

Indirect costs estimation

The distinction between direct and indirect costs is often confused in the body of literature, as well as the distinction between indirect and social costs. It is recognized that the contribution of indirect costs depends mainly on the size of the site (Read, 2004). The current analysis defines two main features for the parameter to be eligible to the integration in the framework:

- The parameter must differ between trenched and trenchless techniques.
- The parameter is expressed as a monetary value.

An adequate approach of the definition of indirect costs is the incorporation of the monetary costs that are not attributed to the specific costs (Jan, 2013).

In this analysis, the accounting of the indirect costs includes the insurance fees of the construction projects, the consumed power and the cost of the labor as they contribute to the budget while they are not associated to a specific expense.

Consumed power

Typically, construction projects require power to operate all the necessary steps leading to the accomplishment of the project. The means of providing the energy and the related financial costs are evaluated. Typically, the energy requirements vary between trenched and trenchless techniques.

Note that power consumption have also some indirect impacts on the environment. The next section of this chapter aims at elucidating those aspects.

Labor

On a construction site, the cost of labor is eligible for its integration in the framework. For trenched and trenchless techniques, the amount of working hours differs. The calculation gives a monetary value and the accounting takes into consideration the number of workers, the market wage per hour and the duration of the project.

Social costs

Definition of social costs and approach

Also called ‘costumer impact’, the social costs differ from one technique to the other and remain higher in the case of trenched techniques as the excavation of a road produces more disturbances to externalities than trenchless techniques. On construction sites, social costs refers to the externalities caused by the interactions between the area of construction and the socio-economic activities surrounding the area (Gilchrist and Allouche, 2005). Decision-makers are in need of reliable means of quantifying social impacts of trenched and trenchless construction sites. Reliance on direct and indirect costs only is not enough if a true estimation of the total cost is required. Current literature provides methods to estimate social costs although it is recognized that those methods need to gain in accuracy, especially for heavy above-ground conditions (Matthews and Allouche, 2010). It is assumed that the higher the amount of infrastructures surrounding the site, the higher the social cost.

Social parameters

A common set of parameters is observed for construction sites and developed by Matthews *et al.* (2015). This list of six common parameters is presented below. This list can be extended upon the specificities of the site.

Travel Delay

Travel delay (or traffic delay) is explained by the increase of travel time spent due to lane closures or complete road closures. It is a significant parameter as it can represent more than

50 percent of the total social costs (Kirmeyer et al., 2000). For example, utility work in the UK causing traffic disruption can cause £2 billion per year (Brady et al., 2001).

An equation can be used as a reference to calculate the cost for travel delay:

$$DC_t = VT * N_v * ITT * D_h$$

where DC_t is the delay costs for traffic [€]; *VT* is the value of time [€/h]; N_v is the number of vehicles [vehicles/h]; *ITT* is the increased travel time [h/vehicle]; and D_h is the project duration [h].

Of the components mentioned above, the concept of value of time per person defined as the monetary value that a person would pay for the reduction of a unit of time and depends on a certain number of factors such as the socio-economic condition of the traveler, trip purpose, the condition of travel (Khan and Islam, 2013). For instance, ten minutes of relaxing trip on a comfortable seat cost less than the same amount of time standing in a crowded bus. The trip purpose is also an important variable as one day a traveler might enjoy a recreational walk while another day, the same person might pay generously for a faster travel to have an important meeting. Those parameters have consequences on the value of time and therefore should be taken into account in the analysis.

Vehicle operating costs

The vehicle operating costs include the costs caused by the 'stop-and-go' behavior of the vehicles resulting from the construction work. Typically, this type of costs refers to the increase of fuel consumption involved. Budhu and Iseley (1994) reported an extra-fuel consumption of 55 Liters when repeating 1000 times the same process of speed change from 80 km/h to 24km/h and back to 80km/h. The following expression is used in order to calculate the vehicle operating costs:

$$VOC = ITD * OCA * N_v * D_h$$

where *VOC* = vehicle operating costs [€]; *ITD* = increased travel distance [km/vehicle]; *OCA* = operating cost allowance [€/(km vehicle)]; N_v = number of vehicles [vehicles/h]; and D_h = project duration [hours].

The concept of operating cost allowance is used in the formula and refers to the property of the vehicle. The concept refers to the expenses associated to the costs of fuel and the additional running costs for the tire, oil, repair and maintenance (Akcelik and Besley, 2004).

Decreased road surface value

As a result of the anticipated damages caused by the excavation of the road while digging a road, it is relevant to consider the decrease of the road surface value. This value is calculable through the proposed equation:

$$RSV = L_s * C_{rsv}$$

where *RSV* = decreased road surface value; and L_s = length of excavation [m] and C_{rsv} is the decreased road coefficient.

Lost Business revenues

The parameter considers the financial loss associated with the decrease of accessibility to various businesses caused by congested traffic. The loss of customers choosing a more convenient place needs also to be considered. The lost business revenues can be expressed as:

$$LBR = TW * D_w$$

where *LBR* = lost business revenue [€]; *TW* = turnover per week [€/week]; and D_w = project duration [weeks].

Loss of parking revenues

In an urban area, trenched site constructions are likely to reduce the number of parking spaces and is likely to be a source of financial loss. The calculation of the financial loss can be made through the calculations of the possible loss of parking fine (LPF) and the loss of parking meters (LPM):

$$LPM = NPS * MR * O * D_h$$

$$LPF = TF * FOT * D_h$$

where *NPS* = number of lost parking spaces; *MR* = meter rate [€/h]; *O* = % of occupancy; *TF* = ticket fine [€/ticket]; and *FOT* = frequency of ticketing [tickets/h].

Cost of dust control

The accounting of cost for dust control results from the fact that any construction site produces noise and is likely to disturb the population. The presence of dust leads to inconvenience such as the additional cleaning time. The equation that is associated to the cost of dust control is:

$$CDC = AC * WR * D_w CDC=AC*WR*Dw$$

where *CDC* = costs of dust control [€]; *AC* = additional cleaning time [h/week]; *WR* = wage rate [€/h]; and D_w = project duration [weeks].

Environmental costs estimations

The estimation of environmental costs gathers all the related economic consequences of environmental damages (Enshassi et al., 2014). An infinite number of direct and indirect effects exist on a short-term and long-term time frame. Evaluating the economic impacts of the degradation of the environment requires an infinite range of parameters to consider. Difficulties arise in the predictions of indirect effects of environmental impacts such as the effects of the secondary pollutants in the atmosphere. The assessment of environmental costs is proposed through the use of valuation methods. Quantitative as well as qualitative techniques to measure the monetary values of environmental damages are proposed in this framework.

The following paragraphs develop the two-steps procedure proposed by the World Bank report (1998) determining the monetary value of environmental degradation. Firstly, an environmental impact evaluation is conducted by enlisting the major effects of trenched and trenchless construction projects on the environment. Secondly, the valuation methods are described.

Environmental impact assessment

Air and noise pollution

The consideration of air pollution is explained by the use of machineries and energy releasing a high number of pollutants in the atmosphere such as the greenhouse gases (GHG). Emitted from tailpipes, fuel supply systems and clutch plates of construction equipment, the presence of GHG in the atmosphere causes the production of secondary pollutants.

Dust pollution can be part of the environmental and social impact as it affects not only the quality of life but also human health. The use of heavy machineries in earthworks have strong impacts on the local air quality as aerosols and particles smaller than 10 microns, known as PM10, are emitted. The process of asphalt sawing for instance emits predominantly coarse mineral dust particles and generates a high level of local pollution (Faber et al., 2015). Those elements can easily affect the respiratory system of humans and cause chronic diseases.

Noise, defined as “unwanted sound” causes typical public health damages such a hearing problems, high blood pressure, sleep disturbances and increased stress (Stansfeld and Matheson, 2003). Typically, the daily exposure to continuous environment beyond 85 to 90 dBA is likely to lead to the complete loss of hearing. Further investigation stated that the noise produced by combined sounds has more impacts on annoyance than the noise produced by individual sounds (Lee et al., 2015). Hence, the noise induced by heavy machineries can have consequences on public health and generates additional non-negligible costs.

Soil degradation

In general, urban construction projects have limited impacts on the ecosystem as a result of many years of past urbanization (Gilchrist & Allouche, 2005). An important exception in trenched and trenchless techniques is the surface and/or subsurface disruption. Typical consequence of surface and/or subsurface disruption in urban area is the removal of a tree because of the presence of roots disturbing the trenched or trenchless operation. Consequences on the value of habitat are measurable.

In rural areas, construction projects affect the soil characteristics. The results of the research led by Shi *et al.* (2014 and 2015) have shown a change of chemical and physical properties of the soil during pipeline construction. The study discovered that pipeline installation has significant effects on the nitrogen content, soil organic matter and pH. The authors also identified the alteration of the soil restoration cycle that may take several years before entirely recovering from the disturbances.

Valuation into monetary values

The valuation of all the environmental impacts cited above imply the consideration for numerous natural processes. Methods exist for their quantification, however a large amount of data and assumptions would lead to exaggerate and inadequate values. Therefore, the application of environmental cost valuation takes only into consideration the direct impacts generated by the trenched and trenchless operation techniques. The impacts on air, water and soils require a long-term impact assessment and only health and habitats are considered in this research as direct impacts. The current research use the two types of valuation methods for environmental impacts:

- Illness and human capital analysis

Numerous environmental impacts are affecting human health. The costs due to air, noise and dust pollution are determined through the analysis of cost of illness and human capital. Effects of exposure to outdoor and indoor pollutants represent an economic burden at a country scale as a result of an approximate 600,000 deaths and diseases per year caused by air pollution (Salvi and Brickman, 2015). In this framework, the environmental costs due to air pollution is calculated by considering the costs of health insurance fees. The risks associated to accidents and injuries during construction operations can represent 6.5 percent of the total cost of the project (Everett and Frank, 1996). A statistical database from the United States has recorded 60 workers killed each year in the construction sector while trenched constructions increase the number of accidents by 112 percent (Jung and Sinha, 2007).

An illness or death does not only cost in insurances but also generates additional non-negligible expenses such as the loss of production or output, the loss of quality of life resulting from the pain, the costs related to the administration costs (e.g. the application for social security payments or reporting on a workplace accident) (Weerd et al., 2013).
While assessing the applicability of those different costs related illnesses components, it is recommended to include them in a sub-category of expenses as they are indirect effects of an illness or death.

- Hedonic analysis

The hedonic pricing method has been practiced since the 1960's and implies the willingness-to-pay of people for environmental amenities that are likely to improve their well-being (Cekanavicius et al., 2011). In this method, a major assumption is made based on the fact that people are willing to invest for a public good such a green space in an urban area. More than 30 studies provided the evidence (Wolf, 2007). The method usually undertakes a survey or questionnaire measuring people consideration for a particular environmental facility. In the context of trenched and trenchless techniques, the value of a green entity such a tree is taken into account to measure the ecosystem disturbances. The framework considers the change in value of a house. More applicable to urban areas, the economic loss refers in this case to the reduction of the value of a property because of the removal or degradation of the surrounding green area.
Note that the hedonic analysis relies on the values and beliefs of people. Particular attention needs to be paid to the analysis of the data as differences might occur in the value that people are giving to a public good (de Vries and Petersen, 2009). This is a consideration of high importance as ecologists for instance might give a higher value to have a tree in front of his/her house than an engineer as a result of differences in values and beliefs.

A significant notice in the consideration of those valuation methods is their multi-applicability as both can be used to quantify the same impact. It is indeed observed that the cost of a specific impact can be estimated using two different techniques of valuation and a double counting might not be adequate. For example, it is possible to evaluate the cost of noise and dust pollution by evaluating the costs caused by the medical expenses and the loss of working days while it is also possible to estimates those costs using an hedonic analysis. The former method implies the calculation of the medical expenses and the loss of working days while the latter method estimates the willingness-to-pay of people to avoid illnesses and death resulting from the air and dust pollution. Considering the aspect of "multi-applicability" of the methods, differences can arise in the method that is used for a particular environmental impact. The choice made in this current analysis is based on the feasibility of the method to the studied impact. Table 3-1 summarizes the methodology used in this research for the impacts that are considered.

Table 3-1: Environmental economic applied to trenched and trenchless techniques activities

Direct Environmental Impacts	**Application**	**Illness and human capital analysis**	**Hedonic Analysis**
Health effects	Health insurances fees	✓	
Habitat	Change in property value		✓

Chapter 4: Application of the framework, results and discussion

This section aims at validating/invalidating the hypotheses through the use of the framework. By selecting two trenched and two trenchless projects, the framework is applied and the hypotheses verified. The projects imply a certain number of assumptions that are identified in this current section. The data are collected from fields observations and information collected from project leaders of KWR and Vitens. Their experiences are useful in the estimation of important missing data.

Description of the projects

Project 1: trenched technique in urban areas

The project 1 considers a trenched technique in urban areas with an excavation of 200 meters for the installation of a PVC pipe.

Project 2: trenched technique in rural area

The project 2 involves the excavation of the soil in rural area in order to install a concrete pipe of 500 meters.

Project 3: trenchless technique in urban area

The project considers a slip-lining technique in urban area to rehabilitate a 100 meters pipe.

Project 4: trenchless technique in rural area

The fourth project is the rehabilitation of a 100 meters pipe using a cured-in-place technique.

Assumptions in the calculations

- Statistical databases estimate the average operating cost in 2014 to be 0.06 dollar per mile or 0.08 euro per kilometers (American Automobile Association, 2015).
- A value of time has been identified at 9 € per hour per car for the Netherlands, considering all types of trip purposes (Significance, 2013).
- 110 is suggested by Kolator (1998) as a coefficient associated to the decrease of the road surface value.
- The presence of a tree in a street tree is reported to worth an increase of sale price of $7 130 or 6 380 € (Thomas, 2010)
- The wage average is assumed to be the Dutch standard of 16 € per hour.

Cost calculations

Project 1: costs estimations (see Annexe B)

Table 4-1: Detailed costs estimation for project 1

	Value	Percentage
Direct costs [€]	152 440	87
Indirect costs [€]	320	0
Social costs [€]	22 000	13
Environmental costs [€]	59.2	0
Total cost [€]	**174 819**	**100**

Project 2: costs estimation (see Annexe C)

Table 4-2: Detailed cost estimation for project 2

	Value	Percentage
Direct costs [€]	140 350	72
Indirect costs [€]	320	0
Social costs [€]	55 000	28
Environmental costs [€]	74	0
Total cost [€]	**195 744**	**100**

Project 3: costs estimations (see Annexe D)

Table 4-3: Detailed cost estimation for project 3

	Value	Percentage
Direct costs [€]	412 250	97
Indirect costs [€]	320	0.1
Social costs [€]	11 000	3
Environmental costs [€]	74	0
Total cost [€]	**423 644**	**100**

Project 4: costs estimations (see Annexe E)

Table 4-4: Detailed cost estimation for project 4

	Value	Percentage
Direct costs [€]	239 000	96
Indirect costs [€]	128	0
Social costs [€]	11 000	4
Environmental costs [€]	29.6	0
Total cost [€]	**250 158**	**100**

Hypotheses validation/invalidation

Validation/invalidation of the hypothesis 1

The results for the projects 3 and 4 showed a higher value in direct costs than those for the projects 1 and 2. Those results are 152 440 € and 140 350 € for the direct costs of trenched projects; for trenchless projects, the direct costs are 412 250 € and 239 000 € for the trenchless projects.

The hypothesis 1 is validated.

Validation/invalidation of the hypothesis 2

Especially remarkable for social costs, the trenched techniques are more expensive socially. The accounting of the social and environmental cost for projects 1 and 2 are respectively 22 059.2 € and 55 074 €. Those results for projects 3 and 4 are respectively 11 074 € and 11 029.6 €.

The hypothesis 2 is validated.

Validation/invalidation of the hypothesis 3

The results of the calculations conclude that trenchless techniques in urban area is 2.4 times more expensive than the use of trenchless techniques in rural areas.

The hypothesis 3 is validated.

Validation/invalidation of the hypothesis 4

Table 4-5: Differentiation of direct-indirect and socio-environmental costs

	Project 1	Project 2	Project 3	Project 4
Direct and indirect costs	152 760 €	140 670 €	412 570 €	239 128 €
Socio-environmental costs	22 059 €	55 074 €	11 074€	11 030€

From the table 4-5 , it can be concluded that the reverse phenomenon is observed. Capital costs show higher values than socio-environmental.

The hypothesis 4 is not validated.

The table 4-6 displays the summary of the hypotheses testing method.

Table 4-6: Table summary of the hypotheses testing method

	Validation	Invalidation
Hypothesis 1	✓	
Hypothesis 2	✓	
Hypothesis 3	✓	
Hypothesis 4		✓

Discussion

The current study wants to determine the current integrated price of trenched and trenchless techniques considering direct, indirect, social and environmental costs in the Dutch situation. The method used in the research enables the reader to have a critical overview of the price of a technique considering not only capital (i.e. direct and indirect) costs but also social and environmental costs, allowing the research questions to be answered.

Although the method of this research is appropriate, the results are exploitable for the current researches, although they are not exploitable for further researches. Firstly, the results cannot be used as a result of inaccurate data related to the projects. Secondly, the data of the projects does not readily highlight the specificities of the Dutch situations and the importance of stakeholders as mentioned in the sub-questions. The reasons associated to these observations are identified latter in this section. In order to gain in accuracy of the results, the projects should be well defined with an appropriate availability of data.

The current research contributes to the practice and theory of the use of trenched and trenchless techniques as the costs assessment method may improve the decision-making processes. When considering the reproducibility of the method for further scientific findings, the research process is readily doable for any other types of techniques and may suggest a good adaptability.

The analysis of the results confirmed the fact that technological improvements are recommended in trenchless techniques. For example, the direct costs of trenchless techniques have proved to be higher when analyzing the hypothesis 1. The high value of the direct costs of trenchless technique is mainly due to the high cost per meter of the lining processes. The technology of trenchless techniques is a point of improvements when considering more sustainable strategies.

Unexpected results and limitations

The integrated calculation is a relevant method to estimate the total costs although some weaknesses need to be stated. The followings points enlist those weaknesses:

- Environmental implications in construction projects are part of the current concerns in the society and should have proved to amount for a significant monetary value, as expected with the hypothesis 4. The observations of the results for environmental costs have been observed to be critically low compared to the other costs considered. The unexpected results may be associated to the missing data for the number of houses. Those seem to count for a large monetary value when considering the change property value.

- It is remarkable that a certain number of data is missing in the framework. Their presence would avoid the proportion of indirect and environmental costs to be almost nulle in the four projects. Although those data represent a large amount of expenses, the framework remains a tool that is usable for the appreciation of the results of the research. A recurrent observation made during the data collection processes is that either the required data is too specific, either the parameter is not applicable in the project. The application of the framework requires the identification of detailed and specific information. The quantification of some direct parameters requires a high level of expertise and surveying in order to get the cost of this specific parameter. For example, the costs for the office-work components are difficult to quantify, even though they are comprised in the direct costs components.

- As mentioned earlier, the environmental costs analysis considers the value of the direct environmental impacts. A complete overview of the environmental aspects should incorporate the damages to the environment such as the quality of air, water and soil. A complete environmental impact assessment requires long-term considerations as most of the natural processes are relatively slow. A weakness of the approach used in the current research is that only “on-site” or direct environmental impacts are taken into account. An exhaustive listing of environmental impacts is complex and may generate exaggerate values.

- A clear distinction between environmental and social impacts needs to be set as confusion between both concepts might occur. When building the framework, the choice and selection of the criteria require judgment on the type of impact. As an example, the costs of noise can be both an environmental and social degradation but also a disturbance for the surrounding inhabitants because the noise can affect the environment as well as the society.

Chapter 5: Conclusion

A general remark on the topic highlights that decision-makers rely on the advantage of traditional techniques. Broadening the consideration for social and environmental considerations is likely to open the market for trenchless techniques even faster than it is nowadays. The implication of a variety of conditions is constraining the decision-making processes to choose trenched techniques as they can be used in any situations, in contrast with trenchless ones.

The current research focused on various aspects of trenched and trenchless techniques. Some important points are enlisted below:

1- The case studies on trenched and trenchless techniques have identified the total cost varying between 174 819 € and 195 744 € for trenched techniques and between 250 158 € and 423 644 € for trenchless techniques. When considering the distribution of those costs, it is noticed that trenchless techniques have higher direct cost than trenched techniques as a result of the high cost of the technologies involved.

2- Trenchless techniques have been used a while after trenched techniques. The interviews from experts have concluded that trenched techniques are still greatly appreciated caused by their multi-applicability and easiness. The current research revealed that the environmental and social benefits of trenchless techniques are significant. This benefit varies between 11 000 € and 44 000 €.

3- Three major Dutch features have been identified as factors influencing the use of trenched and trenchless techniques including the high proportion of urban areas, the relative high instability of the soil and the high level of groundwater. The main effect associated to those three Dutch characteristics is the increase of direct costs of trenched techniques. It appeared that the high proportion of urban areas in the Netherlands tends to have the most diversity of impacts on the total costs as direct, social and environmental costs are identified. The results of the hypothesis 4 confirm the trend that urban areas increase significantly the cost difference between direct-indirect costs and socio-environmental for both trenched and trenchless techniques.

4- When assessing the difference between the direct-indirect and the socio-environmental costs is "peanuts or big money" and may constitute a matter of interest in the decision-making processes, the results have shown that the direct-indirect costs are much higher than the socio-environmental costs. This difference is even more significant for trenchless techniques, explained by a high cost of the technology implied. According to our results, the notion of integrated cost in trenched and trenchless techniques is mainly implying the assessment of the direct-indirect costs. This observation is confirmed by the difference of percentage observed in the total costs.

5- The methods of valuation for environmental impacts needs to consider the involvement of other parties. More explicitly, the impacts induced by the pollution of air is also affecting the health of citizens in the area. Such a problem in environmental management is the understanding of the concept of common good, that considers the effects of a specific group of humans on all the humans of a society.

A similar observation is made on the social accounting. This type of cost involves not only the contractors and water companies but also the third parties. Typically, the third parties can be the drivers who are paying the additional fuel consumption in the case of traffic delay, or the neighborhood of the construction sites for example as they are directly disturbed by the construction work.

The accounting methods for environmental costs are valuable in the case of a typical cost accounting. However, it is not valuable in the case of an impact assessment as a result of the importance of stakeholders involvement. The high dependency on the values and opinions of stakeholders can modify significantly the appreciation of a common good.

References

Akcelik & Besley. (2004). *Operating cost, fuel consumption, and emission models in aaSIDRA and aaMOTION*. Paper presented at the 25th conference of Australian Institutes of Transport Research, Adelaide, South Australia.

Akhtar, S., Reza, B., Hewage, K., Shahriar, A., Zargar, A., & Sadiq, R. (2015). Life cycle sustainability assessment (LCSA) for selection of sewer pipe materials. [Article]. *Clean Technologies and Environmental Policy, 17*(4), 973-992. doi: 10.1007/s10098-014-0849-x

Akker, J. J. H. V. d., & Pleijter, M. (2010). *Subsurface infiltration via submerged drains to limit subsidence and GHG emissions of Agricultural peat soils in the Netherlands*. Finland.

American, Automobile, & Association. (2015). Your driving costs Retrieved 7/10, 2015, from http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_03_17.html

Arends, G., Bielecki, R., Castle, J., Drabek, S., Haack, A., Nedbal, F., . . . Sterling, R. (2004). Risk Budget management in progressing underground works: International Society for Trenchless Technology (ISTT) and International Tunnelling Association (ITA) Joint Working Group Report. *Tunnelling and Underground Space Technology, 19*(1), 29-33. doi: http://dx.doi.org/10.1016/j.tust.2003.08.004

Ariamalar Selvakumar, R. M. C., and Sivaganesan, M. (2002). Costs for water supply distribution system rehabilitation. *Environmental Protection Agency, 600*, 1-16.

Ariaratnam, S. (1994). *Sustainable development through Innovative Underground Infrastructure Construction Practices*. (PhD), Arizona State University, Tempe.

Ariaratnam, S. T., Piratla, K., Cohen, A., & Olson, M. (2013). Quantification of Sustainability Index for Underground Utility Infrastructure Projects. [Article]. *Journal of Construction Engineering and Management, 139*(12). doi: 10.1061/(asce)co.1943-7862.0000763

Beale, D. J., Marlow, D., & Cook, S. (2013). Estimating the Cost and Carbon Impact of a Long Term Water Main Rehabilitation Strategy. *Water Resources Management, 27*(11), 3899-3910.

Bonamente, E., Scrucca, F., Rinaldi, S., Merico, M. C., Asdrubali, F., & Lamastra, L. (2016). Environmental impact of an Italian wine bottle: Carbon and water footprint assessment. [Article]. *Science of the Total Environment, 560*, 274-283. doi: 10.1016/j.scitotenv.2016.04.026

Boucherie, D., Huron, J., Sauersapfe, S., Richard Mas, Laetitia Chassefiere, Haberlah, D., . . . Dubreuil, C. (2012). Towards a way to improve the situation. In W. W. Council (Ed.), *Water crisis*.

Boyce, G., Brinckerhoff, P., & Bried, E. (1998). Social costs accounting for trenchless projects. *No-Dig*.

Brady,K., Burtwell, M., & Thomson, J. (2001). Mitigating the disruption caused by utility street works. In T. L. r. n. 516 (Ed.). UK.

Budhu, G. & Iseley, D. (1994). The economics of trenchless technology vs. the traditional cut and fill in high-density–activity urban corridors — a research concept in a real-world environment *No-Dig, Dallas, TX, North American Society for Trenchless Technology*. Arlington, VA.

CBS (2011). *Population growth rate major cities above average*. Retrieved from: https://www.cbs.nl/en-gb/news/2011/28/population-growth-rate-major-cities-above-average

Cekanavicius, L., Semeniene, D., Oosterhuis, F., & Ierland, E. v. (2011). Chapter 19. The cost of Pollution *Environmental Economics*.

Chapman, D. N., Ng, P. C. F., & Karri, R. (2007). Research needs for on-line pipeline replacement techniques. *Tunnelling and Underground Space Technology, 22*(5–6), 503-514. doi: http://dx.doi.org/10.1016/j.tust.2007.05.004

Chapman, D. N., Rogers, C. D. F., Burd, H. J., Norris, P. M., & Milligan, G. W. E. (2007). Research needs for new construction using trenchless technologies. *Tunnelling and Underground Space Technology, 22*(5–6), 491-502. doi: http://dx.doi.org/10.1016/j.tust.2007.05.003

Cholewa, J. A., Brachman, R. W. I., Moore, I. D., & Take, W. A. (2009). Ground Displacements from a Pipe-Bursting Experiment in Well-Graded Sand and Gravel. [Article]. *Journal of Geotechnical and Geoenvironmental Engineering, 135*(11), 1713-1721. doi: 10.1061/(asce)gt.1943-5606.0000117

Damvergis, C. N. (2014). Sewer systems: Failures and rehabilitation. *Water Utility Journal, 8*, 17-24.

de Vries, B. J. M., & Petersen, A. C. (2009). Conceptualizing sustainable development: An assessment methodology connecting values, knowledge, worldviews and scenarios. *Ecological Economics, 68*(4), 1006-1019. doi: http://dx.doi.org/10.1016/j.ecolecon.2008.11.015

Deb, A. K., McCammon, S. B., Snyder, J., & Dietrich, A. (2010). *Impacts of Lining Material on Water Quality*. Paper presented at the Water Research Foundation, Denver.

Deb, A. K., Snyder, J. K., Hammel, J. O., Tyler, E., Gray, L., & Warren, I. (2006). *Service Life Analysis of Water Main Epoxy Lining*. Paper presented at the Awwa Research Foundation, Denver.

Enshassi, A., Kochendoerfer, B., & Rizk, E. (2014). An evaluation of environmental impacts of construction projects. *Revista Ingenieria de construccion, 29*(3). doi: http://dx.doi.org/10.4067/S0718-50732014000300002

Everett, J., & Frank, P. (1996). Costs of Accidents and Injuries to the Construction Industry. *Journal of Construction Engineering and Management, 122*(2), 158-164.

F.Read, G. (Ed.). (2004). *Sewers: Replacement and New Construction*. Oxford: Elsevier Butterworth-Heinemann.

Faber, P., Drewnick, F., & Borrmann, S. (2015). Aerosol particle and trace gas emissions from earthworks, road construction, and asphalt paving in Germany: Emission factors and influence on local air quality. [Article]. *Atmospheric Environment, 122*, 662-671. doi: 10.1016/j.atmosenv.2015.10.036

Fea, P., Gatti, F., Marchisio, L., Baldinelli, N., & Cori, C. (2000). Environmental and social costs evaluation for innovative dig techniques. *No-Dig*.

G.J.Kirmeyer, G. R. B., N.K.Tarbet, R.F.Serpente. (2000). Lead Pipe Rehabilitation and Replacement Techniques: AWWA.

Gilchrist, A., & Allouche, E. N. (2005). Quantification of social costs associated with construction projects: state-of-the-art review. *Tunnelling and Underground Space Technology, 20*(1), 89-104. doi: http://dx.doi.org/10.1016/j.tust.2004.04.003

Gleick, P. H., & Palaniappan, M. (2010). Peak water limits to freshwater withdrawal and use. *PNAS, 107*(25), 11155-11162.

Haab, T. C., Interis, M. G., Petrolia, D. R., & Whitehead, J. C. (2013). From hopeless to curious? Thoughts on Hausman's "Dubious to Hopeless" Critique of Contingent Valuation. *Applied economic perspectives and Policy* 1-20.

Hoop, G. W. v. d. (2010). *A new approach to Asset Management for Sewer Networks.* (Master), Delft University of technology.

Islam, A., Allouche, E., & Matthews, J. (2014). Assessment of social cost savings in trenchless projects. *No-Dig*.

Jan, I. (2013). Direct costs and Indirect costs. *Accounting Explained* Retrieved 25-05, 2016

Jung, Y., & Sinha, S. (2007). Evaluation of Trenchless Technology Methods for Municipal Infrastructure System. *Journal of Infrastructure and System, 2*(144), 144-156.

Khan, T., & Islam, R. (2013). Estimating cost of traffic congestion in Dhaka City. *International Journal of Engineering Sciences and Innovative Technology 2*(3), 281-289.

Kolator, R. (1998). *Soziale Kosten im Leitungs- und Kanalbau.* (PhD), Vienna University of Technology.

Lapos, B. M., Brachman, R. W. I., & Moore, I. D. (2007). Response to overburden pressure of an HDPE pipe pulled in place by pipe bursting. [Article]. *Canadian Geotechnical Journal, 44*(8), 957-965. doi: 10.1139/t0-036

Lee, S. C., Hong, J. Y., & Jeon, J. Y. (2015). Effects of acoustic characteristics of combined construction noise on annoyance. [Article]. *Building and Environment, 92*, 657-667. doi: 10.1016/j.buildenv.2015.05.037

Lehman, G. (1999). Disclosing new worlds: a role for social and environmental accounting and auditing. *Accounting, Organizations and Society, 24*(3), 217-241. doi: http://dx.doi.org/10.1016/S0361-3682(98)00044-0

Marlow, D., Gould, S., & Lane, B. (2015). An expert system for assessing the technical and economic risk of pipe rehabilitation options. *Expert Systems With Application, 42*, 8658-8668.

Matthews, J. C., & Allouche, E. N. (2010). *A social cost indicator for utility construction projects*. Paper presented at the No-Dig Show, Chicago, Illinois.

Matthews, J. C., Allouche, E. N., & Sterling, R. L. (2015). Social cost impact assessment of pipeline infrastructure projects. *Environmental Impact Assessment Review, 50*, 196-202. doi: http://dx.doi.org/10.1016/j.eiar.2014.10.001

Morisson, R., Sangster, T., Downey, D., Matthews, J., Condit, W., Sindha, S., . . . Selvakumar, R. (2013). State of Technology for Rehabilitation of Water Distribution Systems. In EPA (Ed.).

Oliveira, R. (2014). *Optimization of Large Civil Engineering Projects from an Environmental Point of View*. Cham: Springer Int Publishing Ag.

Oliver-Sola, J., Josa, A., Rieradevall, J., & Gabarrell, X. (2009). Environmental optimization of concrete sidewalks in urban areas. [Article]. *International Journal of Life Cycle Assessment, 14*(4), 302-312. doi: 10.1007/s11367-009-0083-7

Oreste, P. P., Peila, D., Marchionni, V., & Sterling, R. (2001). Analysis of the problem connected to the sinking of micro TMBs in difficult grounds. *Tunneling and Underground Space Technology, 16*(1), 33-45.

Petit-Boix, A., Roige, N., de la Fuente, A., Pujadas, P., Gabarrell, X., Rieradevall, J., & Josa, A. (2016). Integrated Structural Analysis and Life Cycle Assessment of Equivalent Trench-Pipe Systems for Sewerage. [Article]. *Water Resources Management, 30*(3), 1117-1130. doi: 10.1007/s11269-015-1214-5

Rehan, R., & Knight, M. (2007). Do Trenchless Pipeline Construction Method reduce Greenhouse Gas Emission? Waterloo, Ontario.

Shi, P., Huang, Y., Chen, H. B., Wang, Y. F., Xiao, J., & Chen, L. D. (2015). Quantifying the Effects of Pipeline Installation on Agricultural Productivity in West China. [Article]. *Agronomy Journal, 107*(2), 524-531. doi: 10.2134/agronj14.0023

Shi, P., Xiao, J., Wang, Y. F., & Chen, L. D. (2014). The effects of pipeline construction disturbance on soil properties and restoration cycle. [Article]. *Environmental Monitoring and Assessment, 186*(3), 1825-1835. doi: 10.1007/s10661-013-3496-5

Stansfeld, S. A., & Matheson, M. P. (2003). Noise pollution: non-auditory effects on health. *British Medical Bulletin, 68*(1), 243-257.

Strogen, B., Bell, K., Breunig, H., & Zilberman, D. (2016). Environmental, public health, and safety assessment of fuel pipelines and other freight transportation modes. [Article]. *Applied Energy, 171*, 266-276. doi: 10.1016/j.apenergy.2016.02.059

Thomas, L. (2010). Calculating the green in green: what's an urban tree worth? *Science Findings*(126).

UNEP. (2001). An Environmentally Sound Technology for the Installation, Maintenance and Repair of Underground Utility Services. In UNEP, DTIE, IETC & ISTT (Eds.), *Trenchless Technology Systems*.

Water Quality Protection Note. (2012). *Dewatering of soils at construction sites*. Western Australia: Government of Western Australia.

Weerd, M. d., Tierney, R., Duuren-Stuurman, B. v., Bertranou, E., Irastorza, X., & Elsler, D. (2013). Estimating the cost of accidents and ill health at work. In P. O. o. t. E. Union (Ed.), *European Agency for Safety and Health at Work*. Luxembourg.

Wolf, K. L. (2007). City trees and property values. *Arborist News, 16*(4), 34-36.

World Bank. (1998). Environmental Assessment - Source Book Update *Economic Analysis and Environmental Assessment*. Washington.

Web sources:

technique. (n.d.). *Dictionary.com Unabridged*. Retrieved July 06, 2016 from Dictionary.com website http://www.dictionary.com/browse/technique

technology. (n.d.). *Dictionary.com Unabridged*. Retrieved July 06, 2016 from Dictionary.com website http://www.dictionary.com/browse/technology

Annexe A: Standard framework for an integrated cost estimation

Input	Parameters	Data	Mathematical operation	Costs
Office-work component	Construction supervision [€]		Summation	
	Project management [€]			
	Surveying work [€]			
	Approvals requirements [€]			
Equipment	Pipe price [€/m]		Multiplication	
	Pipe length [m]			
Machinery	Rental fees [€/days]		Multiplication	
	Number of days			
Power use	Energy consumed [€]			
Soil conditions	Soil cleaning process [€]		Summation	
	Dewatering [€]			
Risks	Insurances [€/year]			
Labor	Duration of the project [days]		Multiplication	
	Number of workers			
	Wage average [€/hour]			

Travel delay	Value of time [€/hour]		Multiplication	
	Number of vehicle per hour			
	Increased travel time/vehicle [hours]			
	Duration of the project [hours]			
Vehicle operating costs	Increased travel distance [km]		Multiplication	
	Operating cost allowance [€/(km vehicle)]			
	Number of vehicles per hour			
	Duration of the project [hours]			
Decrease road surface value	Length of the excavation [m]		Multiplication	
	Decreased road coefficient			
Lost business revenues	Turnover per week [€/week]		Multiplication	
	Duration of the project [weeks]			
Loss of parking revenues	Number of lost parking spaces			
	Meter rate [€/h]			
	Ticket fine			

	[€/ticket]		Multiplication	
	Frequency of ticketing [tickets/h]			
Cost of dust control	Additional cleaning time [h/week]		Multiplication	
	Wage rate [€/h]			
	Duration of the project [weeks]			
Health impacts	Health insurance per worker [€]		Multiplication	
	Number of workers			
	Duration of the project [days]			
Ecosystem disruption	Change of property value [€/house]		Multiplication	
	Number of house			
Total cost [€]				

Annexe B: Integrated cost estimation for project 1

Input	Parameters	Data	Mathematical operation	Costs [€]
Office-work component	Construction supervision [€]	NC	Summation	60 000
	Project management [€]	NC		
	Surveying work [€]	NC		
	Approvals requirements [€]	NC		
Equipment	Pipe price [€/m]	2.2	Multiplication	440
	Pipe length [m]	200		
Machinery	Rental fees [€/days]	500	Multiplication	2000
	Number of days	4		
Power use	Energy consumed [€]	NC		
Soil conditions	Soil cleaning process [€]	NC	Summation	
	Dewatering [€]	NC		
Risks	Insurances [€/year]	90 000		90 000
Labor	Duration of the project [days]	4	Multiplication	320
	Number of workers	5		

	Wage average [€/hour]	16		
Travel delay	Value of time [€/hour]	9	Multiplication	
	Number of vehicle per hour	NC		
	Increased travel time/vehicle [hours]	NC		
	Duration of the project [hours]	96		
Vehicle operating costs	Increased travel distance [km]	NC	Multiplication	
	Operating cost allowance [€/(km vehicle)]	0.08		
	Number of vehicles per hour	NC		
	Duration of the project [hours]	96		
Decrease road surface value	Length of the excavation [m]	200	Multiplication	22 000
	Decreased road coefficient	110		
Lost business revenues	Turnover per week [€/week]	NC	Multiplication	
	Duration of the project [weeks]	0.6		
Loss of parking revenues	Number of lost parking spaces	NC		

	Meter rate [€/h]	NC	Multiplication	
	Ticket fine [€/ticket]	NC		
	Frequency of ticketing [tickets/h]	NC		
Cost of dust control	Additional cleaning time [h/week]	NC	Multiplication	
	Wage rate [€/h]	NC		
	Duration of the project [weeks]			
Health impacts	Health insurance per worker [€/day]	3.7	Multiplication	59.2
	Number of workers	4		
	Duration of the project [days]	4		
Ecosystem disruption	Change of property value [€/house]	6 380	Multiplication	
	Number of house	NC		
Total cost [€]				**174 819**

Annexe C: Integrated cost estimation for project 2

Input	Parameters	Data	Mathematical operation	Costs
Office-work component	Construction supervision [€]	NC	Summation	80 000
	Project management [€]	NC		
	Surveying work [€]	NC		
	Approvals requirements [€]	NC		
Equipment	Pipe price [€/m]	86.7	Multiplication	43 350
	Pipe length [m]	500		
Machinery	Rental fees [€/days]	1000	Multiplication	5000
	Duration of the project [days]	5		
Power use	Energy consumed [€]	NC		
Soil conditions	Soil cleaning process [€]	NC	Summation	
	Dewatering [€]	NC		
Risks	Insurances [€/year]	12 000		12 000
Labor	Duration of the project [days]	5	Multiplication	320
	Number of workers	4		

	Wage average [€/hour]	16		
Travel delay	Value of time [€/hour]	9	Multiplication	
	Number of vehicle per hour	NC		
	Increased travel time/vehicle [hours]	NC		
	Duration of the project [hours]	120		
Vehicle operating costs	Increased travel distance [km]	NC	Multiplication	
	Operating cost allowance [€/(km vehicle)]	NC		
	Number of vehicles per hour	NC		
	Duration of the project [hours]	120		
Decrease road surface value	Length of the excavation [m]	500	Multiplication	55 000
	Decreased road coefficient	110		
Lost business revenues	Turnover per week [€/week]	NC	Multiplication	
	Duration of the project [weeks]	0.7		
Loss of parking revenues	Number of lost parking spaces	NC		

	Meter rate [€/h]	NC	Multiplication	
	Ticket fine [€/ticket]	NC		
	Frequency of ticketing [tickets/h]	NC		
Cost of dust control	Additional cleaning time [h/week]	NC	Multiplication	
	Wage rate [€/h]	NC		
	Duration of the project [weeks]	0.7		
Health impacts	Health insurance per worker [€/day]	3.7	Multiplication	74
	Number of workers	4		
	Duration of the project [days]	5		
Ecosystem disruption	Change of property value [€/house]	NC	Multiplication	
	Number of house	NC		
Total cost				**195 744**

Annexe D: Integrated cost estimation for project 3

Input	**Parameters**	**Data**	**Mathematical operation**	**Costs**
Office-work component	Construction supervision [€]		Summation	40 000
	Project management [€]			
	Surveying work [€]			
	Approvals requirements [€]			
Equipment	Pipe price [€/m]	365	Multiplication	365 000
	Pipe length [m]	100		
Machinery	Rental fees [€/days]	250	Multiplication	1 250
	Duration of the project [days]	5		
Power use	Energy consumed [€]	NC		
Soil conditions	Soil cleaning process [€]	NC	Summation	
	Dewatering [€]	NC		
Risks	Insurances [€/year]	6 000		6 000
Labor	Number of working days	5	Multiplication	320
	Number of workers	4		

	Wage average [€/hour]	16		
Travel delay	Value of time [€/hour]	9	Multiplication	
	Number of vehicle per hour	NC		
	Increased travel time/vehicle [hours]	NC		
	Duration of the project [hours]	120		
Vehicle operating costs	Increased travel distance [km]	NC	Multiplication	
	Operating cost allowance [€/(km vehicle)]	NC		
	Number of vehicles per hour	NC		
	Duration of the project [hours]	120		
Decrease road surface value	Length of the excavation [m]	100	Multiplication	11 000
	Decreased road coefficient	110		
Lost business revenues	Turnover per week [€/week]	NC	Multiplication	
	Duration of the project [weeks]	0.7		
Loss of parking revenues	Number of lost parking spaces	NC		

	Meter rate [€/h]	NC	Multiplication	
	Ticket fine [€/ticket]	NC		
	Frequency of ticketing [tickets/h]	NC		
Cost of dust control	Additional cleaning time [h/week]	NC	Multiplication	
	Wage rate [€/h]	NC		
	Duration of the project [weeks]	0.7		
Health impacts	Health insurance per worker [€/day]	3.7	Multiplication	74
	Number of workers	4		
	Duration of the project [days]	5		
Ecosystem disruption	Change of property value [€/house]	6 380	Multiplication	
	Number of house	NC		
Total cost [€]				**423 644**

Annexe E: Integrated cost estimation for project 4

Input	Parameters	Data	Mathematical operation	Costs
Office-work component	Construction supervision [€]	NC	Summation	20 000
	Project management [€]	NC		
	Surveying work [€]	NC		
	Approvals requirements [€]	NC		
Equipment	Pipe price [€/m]	215	Multiplication	215 000
	Pipe length [m]	100		
Machinery	Rental fees [€/days]	500	Multiplication	1 000
	Duration of the project [days]	2		
Power use	Energy consumed [€]	NC		
Soil conditions	Soil cleaning process [€]	NC	Summation	
	Dewatering [€]	NC		
Risks	Insurances [€/year]	3 000		3 000
Labor	Duration of the project [days]	2	Multiplication	128
	Number of workers	4		

	Wage average [€/hour]	16		
Travel delay	Value of time [€/hour]	9	Multiplication	
	Number of vehicle per hour	NC		
	Increased travel time/vehicle [hours]	NC		
	Duration of the project [hours]	48		
Vehicle operating costs	Increased travel distance [km]	NC	Multiplication	
	Operating cost allowance [€/(km vehicle)]	0.08		
	Number of vehicles per hour	NC		
	Duration of the project [hours]	48		
Decrease road surface value	Length of the excavation [m]	100	Multiplication	11 000
	Decreased road coefficient	110		
Lost business revenues	Turnover per week [€/week]	NC	Multiplication	
	Duration of the project [weeks]	0.3		
Loss of parking revenues	Number of lost parking spaces	NC		

	Meter rate [€/h]	NC	Multiplication	
	Ticket fine [€/ticket]	NC		
	Frequency of ticketing [tickets/h]	NC		
Cost of dust control	Additional cleaning time [h/week]	NC	Multiplication	
	Wage rate [€/h]	NC		
	Duration of the project [weeks]	0.3		
Health impacts	Health insurance [€/day]	3.7	Multiplication	29.6
	Number of workers	4		
	Duration of the project [days]	2		
Ecosystem disruption	Change of property value [€/house]	NC	Multiplication	
	Number of house	NC		
Total cost				**250 158**