Replacement Essentials

Optimization of Essent Netwerk's infrastructure replacement

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Executive summary

The majority of the Dutch gas and electricity infrastructure is already in operation for decades and will need replacement soon. Since many of the assets are constructed during a relatively short period, their failure is also expected to occur in a condensed period. As one of the largest network operators in The Netherlands, Essent Netwerk faces this new issue of expected upcoming large-scale replacements. Essent Netwerk recently started with the creation of replacement policies for its electricity and gas assets and is now wondering whether its current approach might be improved. The purpose of this research was to recommend Essent Netwerk whether it should continue its current track or should adopt a new approach. The research question to be answered was *"What is the optimal approach for Essent Netwerk to the replacement of its regulated and aged gas and electricity assets such that goals and constraints of long-term network operation are maximally fulfilled?"*

For answering the main research question the question was divided into 6 sub questions concerning (1) the current approach, (2) the goals and constraints of long-term network operation and the relevant performance indicators, (3) the available alternative approaches, (4) the evaluation of alternative approaches, (5) the application of the optimal approach and (6) the organizational implications stemming from implementing this approach. The research was demarcated to the gas service lines, gas mainlines, low voltage (LV) service cables and LV main cables of Essent Netwerk, located in densely populated areas.

It was found that the current approach of Essent Netwerk to the replacement of its aged and regulated assets is characterized by optimization per asset type. Currently, a strategy and tactic is developed for each asset type separately. Thereafter for this specific asset type, plans are concretized and finally the replacement of the asset type is executed by the Infra Services department. This stand-alone approach finally results in the replacement of one asset type at a time. Considering the expected replacement wave, this might result in inefficient situations in which streets are excavated multiple times in a short period, which is likely economically inefficient and results in inconvenience to residents.

By conducting a stakeholder and network analysis and by reviewing the company values Essent Netwerk currently uses as its decision-making framework, goals and constraints of long-term network operation are derived:

- Maximal safety of long-term network operation
- Maximal quality of supply of long-term network operation
- Minimal costs of long-term network operation
- Maximal reputation of long-term network operation
- Be compliant with relevant rules and regulations

The replacement approach should be such that it maximally fulfills these goals and meet the constraint. It thereby aims at reaching the overall optimum in an integrated manner. By decomposing the goals and constraint, the relevant performance indicators were found that were used to evaluate the replacement approaches.

Multiple alternative approaches were discussed. It was found that a promising alternative approach to the replacement of aged assets was a coordinated approach in which multiple existing asset types are considered during replacement planning. Instead of focusing solely on one asset type at a time, this approach

considers the totality of existing asset types and when beneficial prescribes to replace these multiple asset types simultaneously.

To find out whether Essent Netwerk needs to adopt the alternative approach or should stay with its current approach, it was researched whether combining replacement of asset types *can* be beneficial as compared to separate replacement. This was done by applying a quantitative and qualitative analysis. A calculation model determined for five cases the combination advantage for different combination options of asset types. Although some results showed a negative combination advantage (e.g. separate replacement turned out to be cheaper), for others the combination advantage was positive; it even led to a saving of almost 30% in one of the cases. Moreover, analysis showed that changed conditions, as in the level of street restoration costs, the length of connections and the configuration of the main net can increase the obtainable combination advantage.

It was estimated that with adopting the coordinated approach, and thus with choosing to combine replacements if this is cheaper, a total saving of at least 100 million Euros on the replacement spending can be obtained. Since the total replacement value of the demarcated infrastructure was estimated at 1.7 billion Euros, this saving is substantial.

In addition, the qualitative evaluation showed that in some situations combined replacement is the only option for Essent Netwerk to not be in violation with municipal rules and it showed that combining replacements results in fewer inconvenience to residents; especially where inconvenience effects of replacements are large, such as in shopping streets and through streets.

This research derived decision criteria indicating when to combine replacements (e.g. indicating when combined replacement is more beneficial than separate replacement considered from the goals and constraint of long-term network operation). The quantitative decision criteria give maximal differences in optimal replacement moments of the asset types and specific conditions at which combined replacement is cheaper than separate replacements. Because the maximal differences are secure lower limits, they are rather generally applicable to the demarcated system.

Since it turned out that combined replacement *can* result in substantial cost savings, is compliant with municipal rules in situations where separate is not and since it results into less inconvenience, combined replacement is in certain situations better able to fulfill the goals and constraint of long-term network operation than separate replacement. As the alternative coordinated approach, oppositely to the current approach, considers the multiple existing asset types and thus the possibility for combined replacement, this approach therefore better fulfills the goals and constraint of long-term network operation. After all, with considering the possibility to combine replacements, constantly the optimal choice with regard to the goals and constraint of long-term network operation is made. Therefore this research advises Essent Netwerk to adopt the coordinated approach as the new and optimal approach to the replacement of its aged assets.

With regard to the implementation of the new approach, a decision-making moment to either combine replacements or not should be somewhere incorporated in Essent Netwerk's current processes. The best place to do so is the bottleneck-identification step at the regional Strategy Realization units. Implementation of the new approach implies that the job responsibilities and the way of working of asset engineer changes and that more cooperation between asset engineers is required. Implementation of the new approach moreover demands that, as long as there are no replacement policies for all asset types, a very clear and explicit framework should be made by the Strategy Development unit, which enables asset engineers to determine when these asset types need replacement. When freeing time for the additional work and adjusting the new procedures based on comments from the Strategy Realization units, adoption and acceptance of the new approach by these units is expected to be relatively easy.

The new approach additionally demands intensified cooperation of the different departments within the Infra Services units and the need for focus on replacement activities within these Infra Services units. Moreover, the monitoring and controlling process by Asset Management is expected to get more complicated with the new approach because of the more departments that are involved. A suggestion is to set up a separate replacement department within the Infra Services units. At least, enough attention should be paid to the adoption and acceptance of the new approach by the Infra Service units. Another practical implication for the Infra Services units is that they should search for more multidisciplinary contractors to execute combined replacements.

This research hence recommends Essent Netwerk to implement the new and coordinated approach which consistently considers the possibilities of combined replacement during the planning of replacements. Essent Netwerk can use the decision criteria derived in this research in its new approach but it can also decide to use the provided calculation model in making the choice for combined or separate replacement. This research furthermore recommends fine-tuning the decision criteria after the first combined replacements have been executed. For this purpose the calculation model can be used as well.

A reflection on the findings of this research showed that the expected outflow of personnel supports the need to adopt the new approach and it shows that findings of this research might also be relevant for other infrastructure operators.

Further research might be done on the extension of the new approach to other work streams within Essent Netwerk, on the possibility of cooperation with other infrastructure operators and on the planning of combined replacements on the longer term which thereby incorporates the development of personnel capacity.

Preface

With finishing this report my MSc education in Systems Engineering, Policy Analysis and Management at Delft University of Technology comes to an end. I experienced that carrying out this research was a valuable learning process to me. It offered me both the possibility to explore the ins and outs of working in a large company and to apply the things I have learned throughout my studies at the TPM faculty. It thereby contributed to my personal development.

I would like to thank my supervisors of the TPM faculty. I wish to thank Prof. Weijnen for her clear and straight forward comments during our meetings. I would like to thank Laurens de Vries for being my first supervisor, for always providing me with useful feedback and for giving me confidence in my work. I would like to thank my second supervisor, Mark de Bruijne, for his ever willingness to help me on the research subject in general and on the organizational part in specific.

I would also like to thank Han Slootweg, my company supervisor of Essent Netwerk. Thank you for very smoothly taking over the supervising task from Gabriël. And thank you for your ever practical contributions, which were always richly verbally illustrated.

I would like to thank Gabriël Clemens for being my supervisor during the first 2 months of my research. Furthermore I wish to thank Ype Wijnia and my colleagues of the Strategy Development unit and the Strategy Realization unit West-Brabant for their contributions and for providing a good atmosphere to work in.

Off course I also want to thank my family and friends for giving me the support that I needed. In specific, I want to thank my parents and sister. And obviously I wish to thank Berend Jan for tirelessly supporting me, being far away or close by, and for always showing me the positive side of things!

Eline Schapers

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1. Introduction

1.1 Background

For the distribution of gas and electricity to consumers very large utility networks are in use. Those networks are already in operation for decades. Some parts of the Dutch gas infrastructure were built 100 years ago and are still in operation (Wolters, 2004). The majority of the Dutch electricity and gas infrastructure, however, was built in the 1960s and 1970s to accommodate the rapidly growing demand for energy during that period (Jongepier, 2007). Although both the gas and the electricity networks are designed and built for large lifetimes varying from 40 to 80 years, they soon reach the age at which they cannot guarantee reliability and cannot meet the current safety standards any longer (Wijnia et al., 2006). To prevent outages, incidents and economic losses, these networks therefore have to be replaced in the near future.

The sheer scale of the replacement issue demands that network operators should take infrastructure replacement as a central element in the definition and execution of their policies. For energy network operators the issue of large scale infrastructure replacement is a new phenomenon. So far, replacement of assets was required only incidentally. Since a major part of both the gas and electricity network was installed during a short period however, it is expected that their failure and thus their need for replacement will also occur during a condensed period. This might result in a phenomenon which can be called a 'replacement wave'.

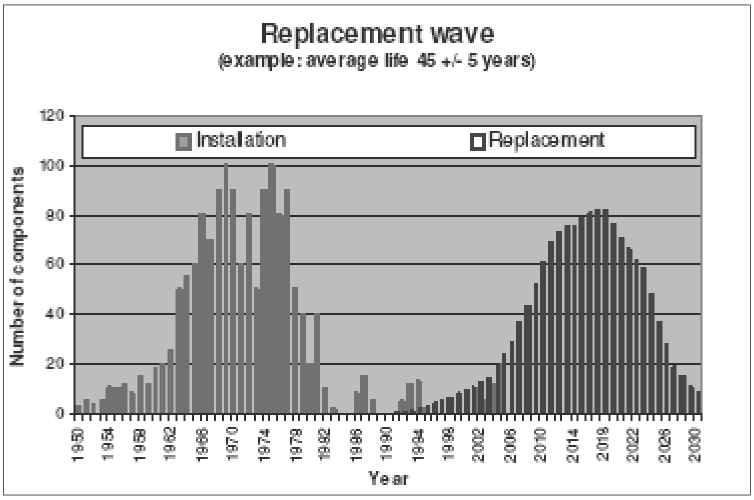


Figure 1 Replacement wave. (Jongepier, 2007)

Essent Netwerk, which is part of the parent company Essent NV, is one of the largest network utility companies in The Netherlands; it is the network operator for about one third of the regulated electricity and gas distribution assets in The Netherlands (Wijnia, 2005a). Besides the regulated activities Essent Netwerk also operates a number of non-regulated activities, such as public lightning, traffic and parking systems and the rental of installations and gas and electricity meters (Essent Netwerk BV, 2007c).

As a network operator, Essent Netwerk will probably face a failure wave of its assets in the near future. Many elements of both its regulated gas and electricity network are becoming aged and are thus in need of replacement in the upcoming period. Essent Netwerk identified this threat and realizes that strategic solutions are necessary. After all, choosing the wrong direction or acting too late might lead to disastrous supply interruptions causing large economic losses for Essent Netwerk. Moreover, as a network operator Essent

Netwerk fulfils an important societal function; many large industries, companies and households are dependent on Essent Netwerk for the delivery of gas and electricity.

As a reaction to the expected replacement wave, Essent Netwerk formulated a long-term optimization report (Wijnia et al. 2005). In this long-term optimization report, Essent Netwerk identified and described the ageing of its gas and electricity assets and the related need of replacement. The report concluded that a failure wave is indeed about to happen in the near future and that replacement cannot be postponed to the moment of failure, but should be undertaken preventively. After the finish of the long-term optimization report, sequential steps are taken. Currently, replacement policies for single groups of electricity and gas assets are being formulated. For every single group of assets it is determined at a central level in the organization how many of these assets should be replaced in which period. This centrally developed planning per asset group is implemented and concretized per region. Finally the replacements are executed according to the formulated replacement policies and worked out plans. Hence, the current approach appears to result in stand-alone policies per single group of assets which are not mutually adjusted to each other (e.g. the proximity of two sub-elements in the network is not taken into account), and which are expected to eventually result in the stand-alone execution of replacements.

According to Essent Netwerk it is this point of the current replacement approach where improvement might be possible, or probably even necessary. The lack of coordination between the executions of the various replacements might have negative effects and might not be the optimal approach to the replacement of their aged assets. In Groningen for instance, recently gas service lines were replaced while later on it turned out that the nearby electricity connections were in bad condition and needed replacement as well (Schimmel, 2007). Because no replacement policy was yet available for these electricity connections and because the current approach was focused on one asset type at a time, no attention was paid to a possibly coordinated way of replacing these asset types. It led to much inconvenience to residents and irritation of the concerned municipality. A very short and preliminary inventory shows a number of possible disadvantages of the stand-alone policies and execution of replacements:

- Inefficient situations in which streets have to be excavated multiple times in a short period for different replacements. Due to the proximity of multiple assets that are in need of replacement, this is probably not economically efficient.
- Deterioration of Essent Netwerk's reputation because of the inconvenience caused by multiple replacement activities at one location and in a relatively short period.
- More digging incidents to Essent Netwerk's and other infrastructures due to more digging activities.

To be short, Essent Netwerk expects that continuing the current approach of uncoordinated replacing might be suboptimal.

1.2 Problem statement

Decision-making on the necessary replacements of aged assets is complex. A constant balancing of costs and performance is required. For this, numerous goals, risks and constraints should be taken into account. The replacement should ideally maximally fulfill all possible goals and meet the constraints of long-term network operation.

The current approach to replacements appears to consist of defining stand-alone replacement policies for single asset types at a central level in the organization. These stand-alone policies are separately implemented and replacements of the many aged assets will consequently be separately executed. Essent Netwerk feels that this approach to tackling replacements might not maximally fulfill the goals and constraints of long-term network operation.

There appear to be 2 knowledge lacunas:

- First, the question of which alternative approaches are available.
- Second, the accompanying question whether these approaches to replacement might better fulfill the goals and constraints of long-term network operation than the current approach.

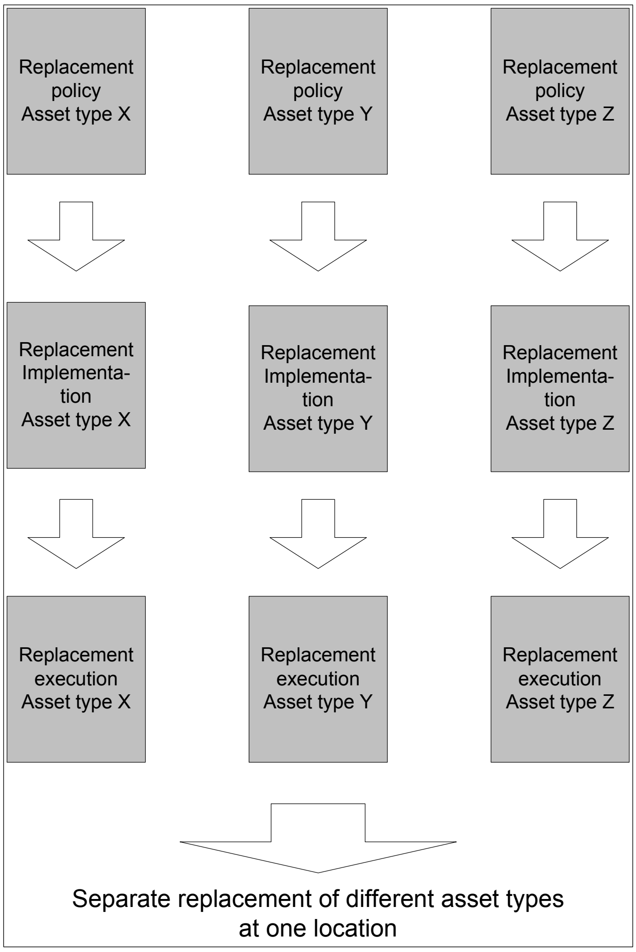


Figure 2 Current approach of Essent Netwerk to the replacement of assets.

From the above, the problem statement of this research can be defined as follows:

The major part of the regulated electricity and gas assets of Essent Netwerk is aged and is in need of replacement in the near future. Essent Netwerk wonders whether its current approach to replacing these aged assets should be improved.

1.3 Research objective and research question

The aim of this research is to recommend Essent Netwerk whether and how to change its course of action with regard to the replacement of its regulated and aged assets.

The research objective of this research can be defined as follows:

To formulate a proposal for the optimal approach to the replacement of the regulated and aged gas and electricity assets of Essent Netwerk such that it maximally fulfills the goals and constraints of long-term network operation.

The central research question to be answered is:

What is the optimal approach for Essent Netwerk to the replacement of its regulated and aged gas and electricity assets such that goals and constraints of long-term network operation are maximally fulfilled?

The final product of the succeeding research is a proposal for this optimal approach, a guideline for applying this optimal approach and organizational recommendations for implementing this approach.

The central question is answered by answering the following sub questions:

1. What does the current approach of Essent Netwerk to the replacement of its regulated and aged assets look like?
2. What are the goals and constraints of long-term network operation for Essent Netwerk and which performance indicators relevant for the approach to the replacement of its aged and regulated assets can be derived from these goals and constraints?
3. What alternative approaches that have potential to improve Essent Netwerk's current approach to the replacements of its regulated and aged assets are available?
4. Which of the alternative approaches (including the current approach) suffices best to the goals and constraints of long-term network operation and hence is the optimal approach?
5. How should Essent Netwerk apply the optimal approach to the replacement of its regulated and aged assets?
6. What are the organizational implications that result from implementing this approach within the organization of Essent Netwerk?

The research is divided into three phases. The first phase is aimed at finding the optimal approach to the replacement of Essent Netwerk's assets and answers sub questions 1-5. The second phase is aimed at identifying the organizational implications that stem from implementing a new approach and answers sub question 6. The third phase gives a reflection and draws conclusions and thereby presents the answer to the main research question.

1.4 Research method

The research approach is presented in figure 3. A research into literature revealed that little has been written about the new issue of large-scale replacement of aged assets and about replacement of assets in general. This research however used the little literature available in discussing and evaluating alternative approaches. Other sources of information for this research were expert interviews and the review of internal documents.

The first research phase aims to find the optimal approach to the replacement of aged assets. The description of the current approach to the replacement of aged assets is based on interviews with Essent Netwerk staff and the review of internal documents. The goals and constraints of long-term network optimization are based on a conducted stakeholder and network analysis and the analysis of the company values of Essent Netwerk. From these goals and constraints the performance indicators relevant for this research are derived. These performance indicators are used for the evaluation of the current and alternative approach. The alternative approaches to the replacement of assets and the selection of the alternative approach to be further investigated is based on literature review and expert interviews.

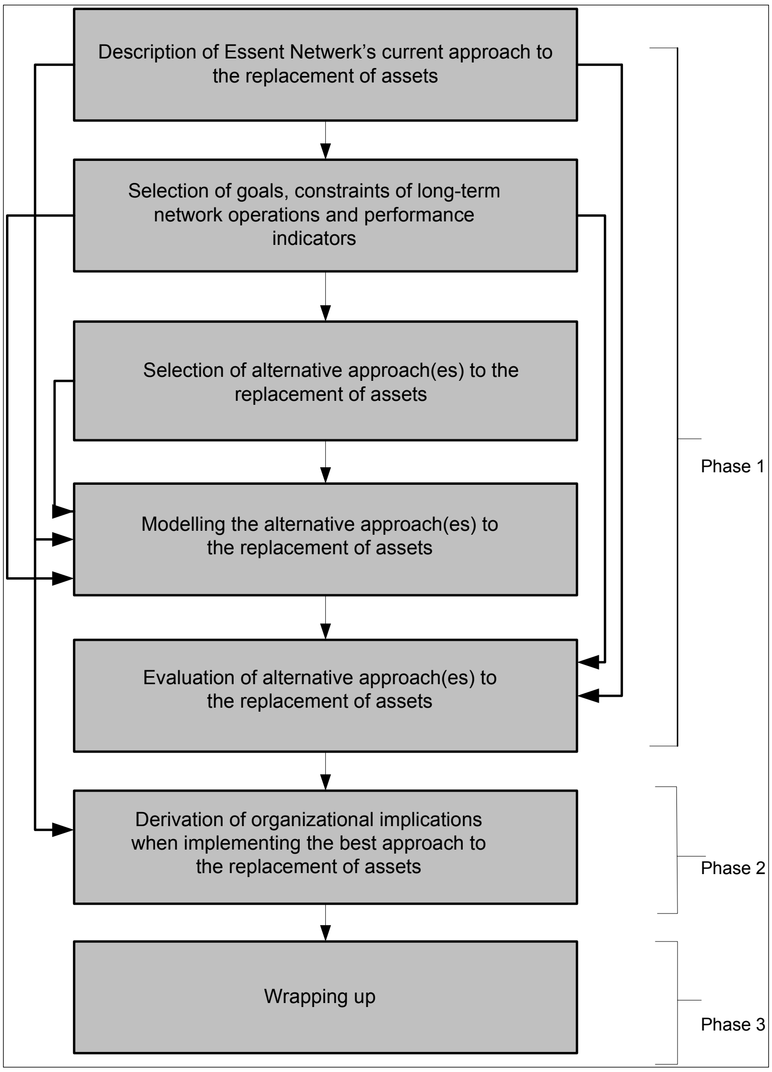


Figure 3 Research approach.

By analyzing how the relevant performance indicators are influenced by the alternative approaches, the external factors are derived. An embedded case study consisting of 5 different cases is used in comparing the alternative approaches. For each case the results of the approaches are determined and compared. Based on these results and an analysis of the results it is depicted which approach is best able to fulfill the goals and constraints. The evaluation of the approaches consists of a quantitative analysis in which a calculation model is constructed that is able to determine the overall value of the monetary expressible performance indicators, based on the influence of the derived external factors. For the model construction and data gathering many internal documents and databases of Essent Netwerk are consulted. The necessary cost compositions are derived from interviews with Essent Netwerk staff responsible for the contact with contractors. The softer performance indicators are qualitatively evaluated. Based on the quantitative and qualitative analyses of the results, decision criteria are developed that can be applied in using the optimal approach.

In the second research phase the organizational implications of implementing the optimal approach of Essent Netwerk to the replacement of aged assets are determined. Findings are based on interviews with Essent Netwerk staff and by applying organizational literature.
The third research phase gives a reflection and conclusions and recommends a course of action for Essent Netwerk.

1.5 Structure of report

The report is structured in three parts, in accordance with the depicted research phases. Preliminary to these parts, first, in chapter 2 a system description is presented. This chapter also discusses the current approach of Essent Netwerk to the replacement of its assets. Moreover, chapter 2 presents a system demarcation.
Part 1 comprises chapters 3 to 6. Chapter 3 is aimed at finding the goals and constraints of long-term network operation and it derives the relevant performance indicators. Chapter 4 discusses available alternative approaches. In chapter 5 the construction of a model to evaluate the approaches is described. Chapter 6 then describes the evaluation of the approaches by describing the five cases, the results of the quantitative and qualitative analyses and the derivation of decision criteria to be applied in the optimal approach.
Part 2 consists of chapter 7 which discusses the organizational implications when implementing the optimal approach.
Finally, part 3 comes up with a reflection on the conducted research and draws conclusions and provides recommendations.

2. System description

2.1 Environment Essent Network

Due to the liberalization of the sector, the Dutch energy market is rapidly changing (Wehman, et. al., 2003). Liberalization created a more complicated sector with more actors, each responsible for another part in the system (De Vries et al., 2004). The complex systems of respectively the gas and the electricity market are depicted in the figure below.

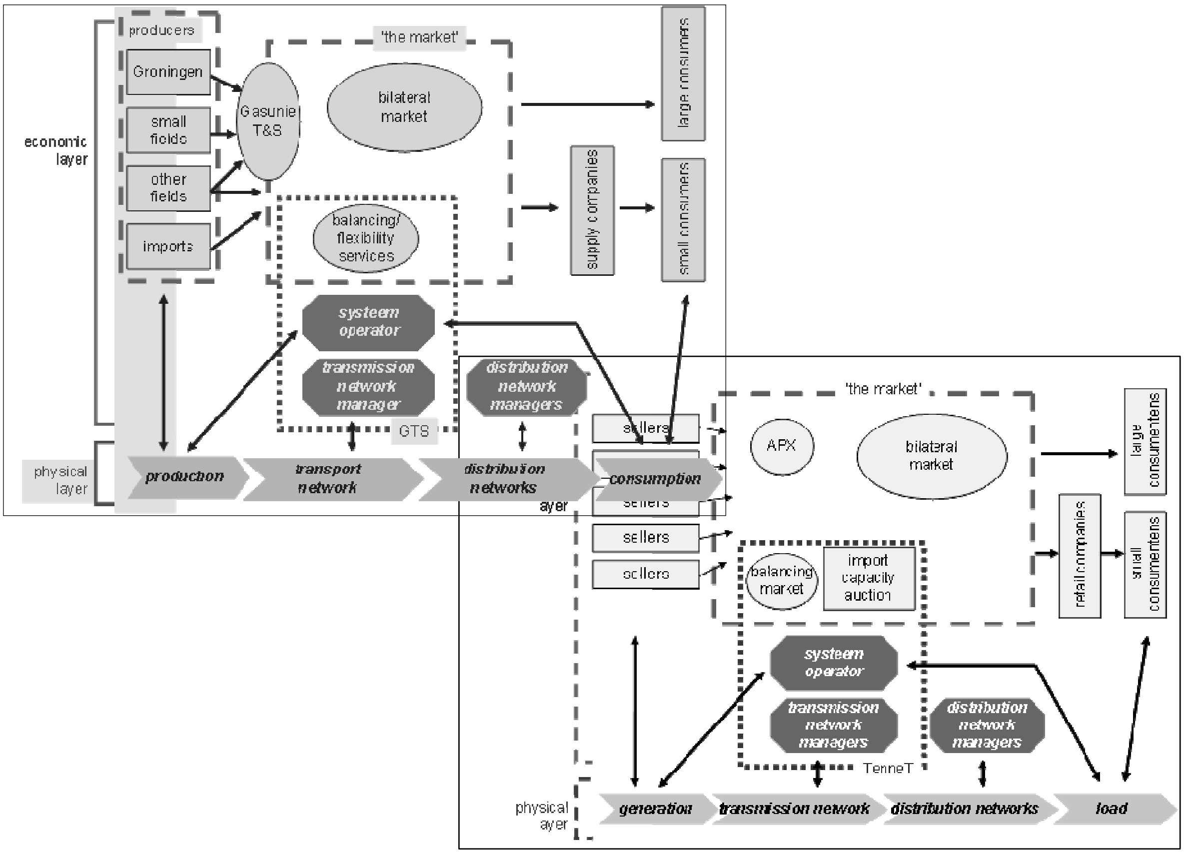


Figure 4 Gas and Electricity system. (De Vries et al., 2004)

With regard to network operation, the Dutch network is operated by two types of operators. The first type is the Transport System Operator (TSO), who is responsible for operating the transmission grid, for maintaining the energy balance and for the import connections with the neighbor countries (Wijnia and Herder, 2004). The TSO for the electricity network is TenneT. Their network currently consists of the ultra high voltage network (380 kV and 220kV) and a part of the high voltage network (Tennet, 2007). The TSO for the gas network is Gas Transport Services.

The second type is the regional distribution companies, of which there are many in The Netherlands (Wijnia and Herder, 2004). Some of these are responsible for just gas *or* electricity; others operate both a part of the electricity and the gas network. The major part of the gas and electricity network is operated by regional distribution operators that operate both. The three largest regional distribution operators are ENECO Netwerk, Essent Netwerk and Continuon; they operate 90% of the distribution network in The Netherlands. (Wijnia and Herder, 2004).

2.2 Essent Netwerk BV

2.2.1 Network operator Essent Netwerk

According to the Electricity Law 1998 and the Gas Law, Essent Netwerk is responsible for the transport of gas and electricity to its consumers and for the maintenance and control of its assets in (parts of) the provinces Friesland, Groningen, Drenthe, Overijssel, Flevoland, Noord-Brabant and Limburg (Essent Netwerk, 2006a).

To fulfill the tasks belonging to the operation of the electricity and gas infrastructure, Essent Netwerk has a comprehensive package of activities. The responsibilities of Essent Netwerk comprise the design, construction, maintenance and control of the regulated infrastructure assets of Essent, the electricity and gas networks. As such, Essent Netwerk holds a monopoly function in the area. However, following the liberalization of the energy industry, Essent Netwerk is legally obliged to provide access to its networks to all potential market parties. The activities of Essent Netwerk are regulated by the regulator DTe.

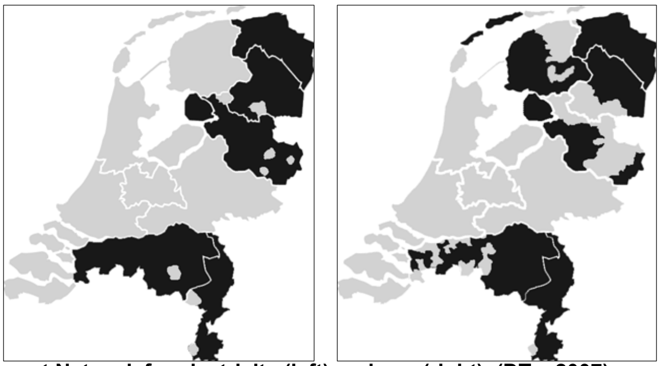


Figure 5 Working areas Essent Netwerk for electricity (left) and gas (right). (DTe, 2007)

2.2.2 Organization structure

Essent Netwerk is a separate business unit of parent company Essent NV. It is legally, organizationally and accounting wise separated from the other, commercial and trade branches of Essent NV. Essent NV was created in 1999 when the former PNEM/Mega Groep and EDON Groep were merged. Essent NV is owned by its shareholders of whom 74% are Dutch provinces and 26% Dutch municipalities. Essent Netwerk is a large organization with a yearly turnover of 1.4 billion euros and about 3,500 employees (Essent Netwerk, 2007a). Its organization structure is shown below.

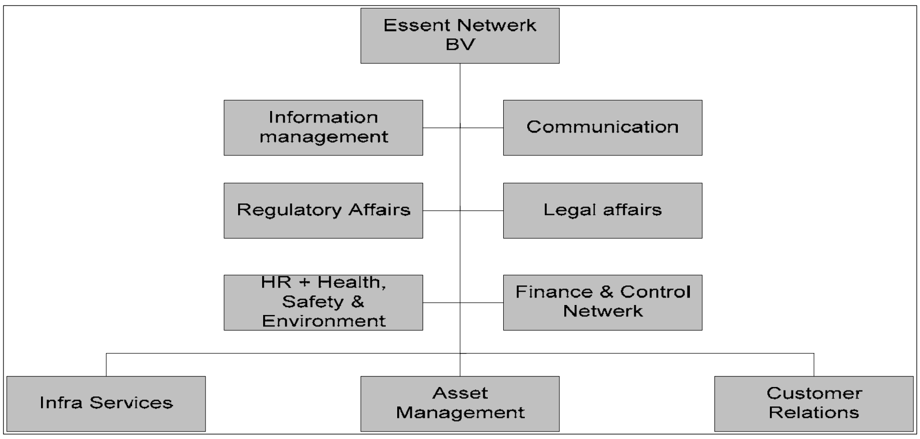


Figure 6 Organization chart Essent Netwerk. (Adapted from Essent Netwerk, 2006b)

As a network operator, Essent Netwerk focuses on finding an optimal way to operate its gas and electricity infrastructure. How this complex task is embedded in the organization can be expressed by Essent Netwerk's

'Asset Management model'. The Asset Management Model defines the roles of the different parts within Essent Netwerk that are directly concerned with the management of the energy network.

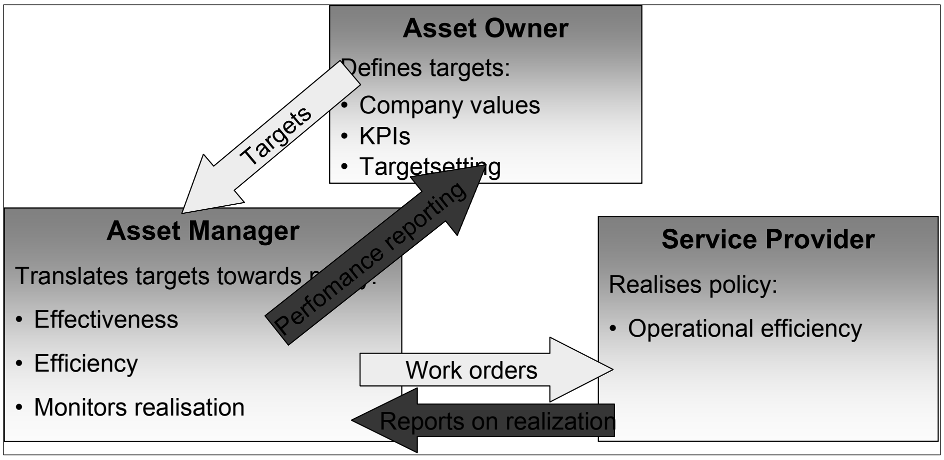


Figure 7 Asset Management model Essent Netwerk. (Slootweg and Clemens, 2006)

The roles can be described as follows:

The Asset Owner: The Board of Essent Netwerk is the Asset owner. It is responsible for setting targets and should provide the necessary (financial) resources. (Slootweg and Clemens, 2006)

The Asset Manager: The Asset Management department is considered to be the asset manager and is responsible for developing the policies to optimally realize the targets set by the asset owner. Furthermore, the Asset Management department guarantees that the Service Provider gets its orders on time and it monitors the progression of the orders (Slootweg and Clemens, 2006). The centrally organized Strategy Development unit and the 5 regionally organized Strategy Realization units of the Asset Management department form the core of this department. The Strategy Development unit defines the policies, while the asset engineers and the program managers of the Strategy Realization units concretize these policies into annual plans for the Service provider.

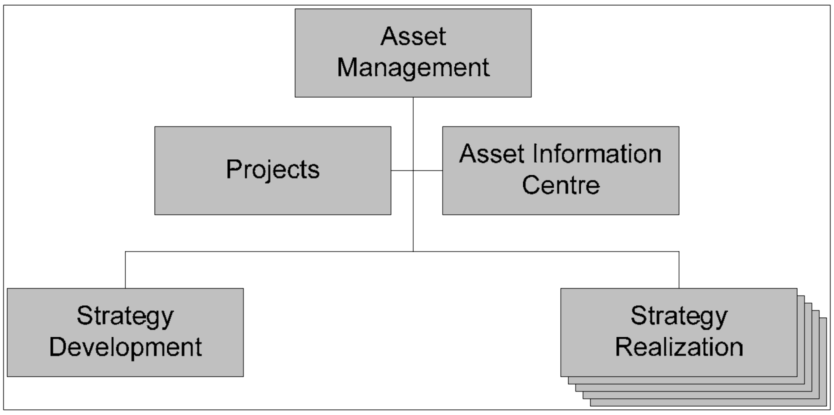


Figure 8 Simplified organization chart of the Asset Management department. (Adapted from Slootweg and Clemens, 2006).

The Service Provider: The Infra Services department is the service provider and is responsible for effectively and efficiently executing the orders developed by the Asset Management department and approved by the board of Essent Netwerk (Slootweg and Clemens, 2006). Infra Services is, like the Strategy Realization unit of Asset Management, decentralized into geographic units and consists of different functional departments, like the 'connection department' and the 'maintenance and failure service department'.

The activities executed on the energy network are divided into different work streams: new standard connections, new custom made connections, reconstructions, failure service, maintenance, replacements and additional work. The first three are customer-driven.

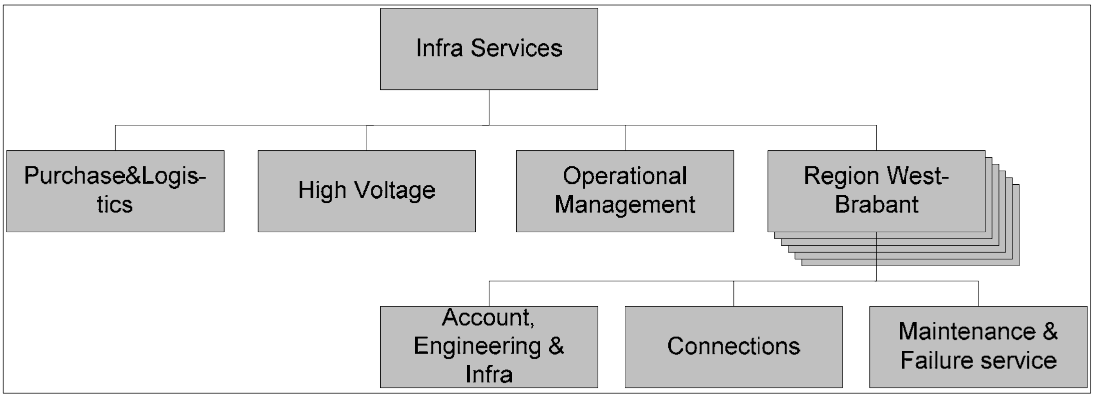


Figure 9 Organization chart of the Infra Services department. (Adapted from Essent Netwerk, 2006e).

The working processes within Essent Netwerk are standardized according to prescribed and detailed procedures. The tasks accompanying these working processes are fulfilled by the many specialists working at the Asset Management and Infra Services departments. Each of these specialists has clear job responsibilities. Since working processes are standardized, main strategies and policies are developed at a central level in the organization and employees have specified tasks, Essent Netwerk can be considered a bureaucracy (Mintzberg, 1983). While the majority of employees at the Asset Management department is high-skilled personnel, the employees of the Infra Services are mainly executing personnel. Therefore, the organization of Essent Netwerk can be considered a mixed form of a professional and machine bureaucracy in which the Asset Management department can best be characterized a professional bureaucracy while the Infra Services department shows many characteristics of a machine bureaucracy (Mintzberg, 1983).

The Asset Management department translates expected work in the electricity and gas networks for the upcoming year into an annual plan for the Infra Services department. The annual plan consists of both specific projects and estimations of the expected customer-driven work and is constructed during the preceding year. As the organization chart in figure 6 shows, the Asset Management department and the Infra Services department are two hierarchically separated departments. However, the processes are such that the Asset Management department somehow steers the Infra Services department. The relation between the Asset Management department and the Infra Services department can be considered a principal-agent relation (Eisenhardt, 1989); the ordering of projects and estimated work is done with service level agreements between the Asset Management department and the Infra Services department in which the Asset Management department pays Infra Services for its activities (Kerst, 2007). It is thus however a principal-agent relation within one and the same organization.
The cooperation between the Asset Management and Infra Services department and within these departments is arranged by many operational agreements, so that the coordination mechanism between and within these departments can be characterized as standardization (Mintzberg, 1983).

2.2.3 The assets of Essent Network

Essent Netwerk operates both gas and electricity infrastructure. The electricity assets currently consist of 3,000 km high voltage (HV) lines (150 and 110 kV), which will be assigned to transport system operator

TenneT from January 2008, 140,000 km medium voltage (MV) (20, 10 and 3kV) and low voltage (LV) (0,4 kV) underground cables and 50,000 transformer stations (Essent Netwerk, 2007c). The gas assets of Essent Netwerk consist of 40,000 km high pressure and low pressure pipelines and 6,900 gas stations. With regard to its electricity infrastructure Essent Netwerk has 2.5 million connections (LV service cables). For gas, Essent Netwerk has 1.8 million connections (gas service lines) (Essent Netwerk BV, 2007c).

These gas and electricity assets are located both underground and above the surface. The underground electricity and gas assets can be categorized into the following asset types:

- Electricity
    - LV service cables
    - LV main cables
    - MV distribution cables
    - MV transport cables
    - MV connection cables
- Gas:
    - Gas service lines
    - Low pressure mainlines
    - High pressure mainlines

The upper ground electricity and gas assets of Essent Netwerk can be categorized as follows:

- Electricity:
    - HV poles and lines
    - Substations
    - Transformers : HV/MV and MV/LV
    - Switchgear: HV, MV, LV
    - Protection equipment
- Gas:
    - District stations
    - Supply stations
    - Transfer stations

Because the gas and electricity networks have evolved throughout the years and have been constructed by different infrastructure owners, there is a large variety of materials and brands for each of the above mentioned asset type groups. In Appendix 2A a subdivision is found of the above asset types in which for instance the different materials used are presented. This division can be even subdivided further, resulting finally in more than 1,000 different asset subtypes.

2.3 Replacement of aged assets; the current approach

2.3.1 Essent Netwerk identified the aged asset problem

In 2005, Essent Netwerk started a research on the ageing of its assets. This long-term optimization research was one of the first steps concerning the replacement of aged assets (Korn, 2007). The research advised Essent Netwerk to replace its assets preventively. It determined optimal replacement ages for the asset population by using extensive failure models and failure data. The optimal replacement age was considered the moment where the costs of preventive replacement equal the (monetary value of) risks of corrective replacement (Wijnia et al., 2006).

Since this long-term optimization research was finished, sequential actions with regard to the replacement of ageing assets are taken. As of 2006, the Asset Management department initiated the creation of replacement policies for some of their asset types. While the long-term optimization research found rough optimal replacement ages and replacement strategies for about 70 asset types, now per asset type and its subtypes a preventive replacement policy should be developed, resulting eventually in all the necessary replacements (Korn, 2007). Currently for two of the above presented asset types a replacement policy is available; Essent Netwerk has developed replacement policies for the majority of their gas service lines and for a specific type of MV installation and currently the first of these asset types are being replaced (see Appendix 2B). By conducting interviews with Essent Netwerk staff and reviewing internal policy documents, an analysis is made of the processes that are followed for these asset types. Based on this analysis the current approach to the replacement of aged assets is characterized.

2.3.2 Current approach

Except for the customer-driven work, all types of work streams, including replacements, are initiated by the Asset Management department and are based on the 'Risk Based Asset Management process' (RBAM-process). This process, which is aimed at mitigating risks, consists of different predetermined steps in which both the Asset Management and the Infra Services department are involved. The RBAM-process has recently been certified by The Institute of Asset Management according to the PAS 55-1 standard (Deursen and Burgman, 2006).

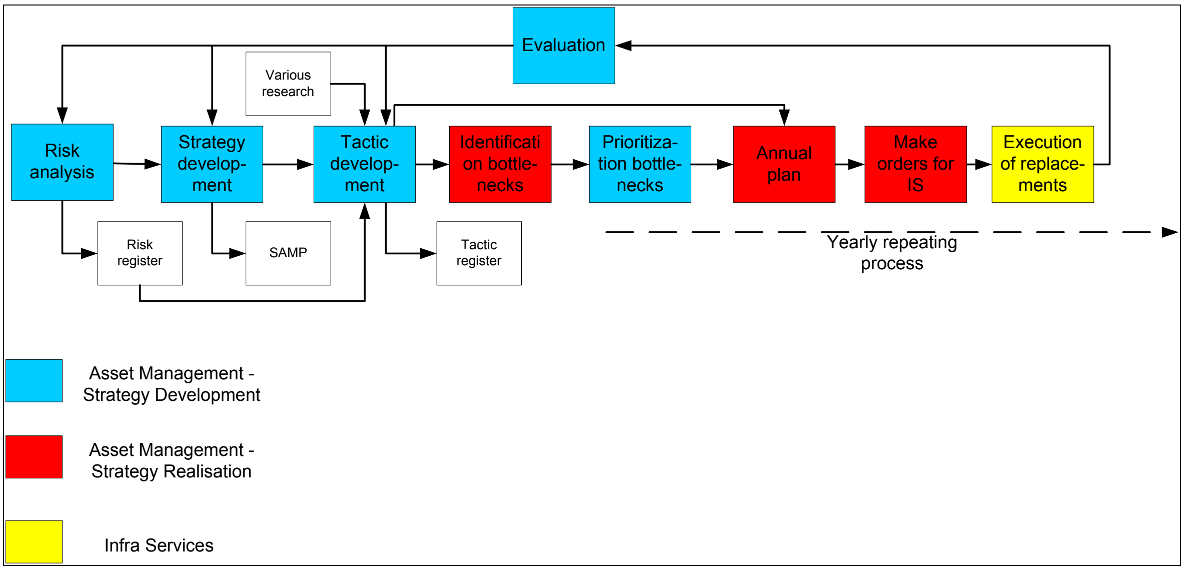


Figure 10 Replacements are initiated by the RBAM-process.

The description below is representative for the current approach of Essent Netwerk to replace its aged assets; it describes the process followed and the departments involved with regard to an aged asset type that needs replacement.

- The process is initiated at the centralized Strategy Development unit of Asset management, with the identification of a risk that an ageing asset type may cause. The Strategy Development unit is concerned with the mitigation of risks that threaten one or more of the company values of Essent Netwerk (Essent Netwerk BV, 2006a). After a provisional estimation, a definitive estimation of the risk level and a decision for risk analysis is made during a risk assessment session within the Strategy Development unit.

- The next step, carried out by the Strategy Development unit as well, is to develop a strategy to mitigate the risk. The strategy prescribes a course of action with regard to the risk. Different strategies might be developed and the strategy that can obtain the highest net present value on the (monetarized) company values is selected (Jager, 2007a).
  A strategy with regard to replacements finds optimal replacement moments for the considered asset type and describes the amount of assets to be replaced and the period available for this action. Developed strategies are processed into the Strategic Asset Management Plan (hereafter: SAMP), which describes the direction of Essent Netwerk for the upcoming 7 years.
- The strategy is then translated by the Strategy Development unit into a tactic describing how the strategy should be executed. It presents methods and tools to find the specific assets that indeed are close to their optimal replacement moment and need replacement. Strategy and tactic making is complex since failure behavior of assets is difficult to predict and depends both on static characteristics such as material type and on environmental characteristics, such as soil type (Wolters, 2004). These different characteristics imply different failure behavior and thereby different optimal replacement moments.
  As said, an asset type can be subdivided into different subtypes; a gas mainline can for instance be divided into subtypes with different pressures and materials. The strategy and tactic made are specifically constructed for one asset type but can be applied to multiple sub types of this asset type, namely those sub types that cause the risk identified in the first step.
- The regional Strategy Realization units of the Asset Management department establish the next step. Via the 'bottleneck assignment' (in Dutch: knelpuntenuitvraag), the Strategy Development unit orders the Strategy Realization units to find a specified amount of those assets that need replacement (the so-called bottlenecks), based on the strategy and tactic. While the replacement strategy gives a purely theoretical approach, the bottleneck finding process aims to find the real physical assets that need to be replaced. Asset engineers search the physical assets in the network (street and house number) that, according to the strategy and tactic, need to be replaced (Berg, 2007).
- The Strategy Development unit then prioritizes the different bottlenecks and orders the Strategy Realization units to concretize them and to process them into final regional annual plans for the upcoming year (Kerst, 2007). Except for the planned replacements an annual plan also comprises the planned projects of other work streams than replacements, such as maintenance activities and reconstructions.
- The Strategy Realization units translate the annual plan, and thus the planned replacements, into service level agreements for the Infra Services department and each Strategy Realization regional unit bundles them into an annual order book for the specific Infra Services regional unit by October (Deursen and Burgman, 2006).
- The Infra Services units execute these orders. They schedule personnel and contractors, request necessary licenses and then streets are excavated by contractors and the aged assets are replaced. The program managers of the Strategy Realization unit monitor and control the progression within the Infra Services department by monthly consultations.
- The last step of the RBAM-process comprises the evaluation in which the risk mitigation, the strategy and the tactic are evaluated and optimized.

The above description confirms the presumption that for one asset type separately a very detailed policy is made and that for this one asset type separately planning is concretized and executed. The process thus considers one asset type at a time, resulting in the separate replacement of asset types at a location where multiple asset types might be located (Jager, 2007b). From the analysis, it can hence be concluded that the current preventive replacement activities are separately optimized per asset type.

Due to the enormous amount of assets to be replaced in a relatively short period more replacements will be executed than both Essent Netwerk and its environment are used to. When indeed executing these replacements separately, multiple returns might be necessary in a relatively short period to execute replacements of the existing asset types. Since streets need to be excavated again for each replacement, this is very likely to be economically inefficient and to cause inconvenience to residents, as the example in the introduction chapter illustrated. Now that the replacement of gas service lines has started, Essent Netwerk is wondering more and more whether for instance the electricity connections located nearby these service lines should also be replaced (Vissia, 2007; Mutsaers, 2007; Korn, 2007).
The lack of the current approach of Essent Netwerk to coordinate between multiple asset types and its potential negative effects is seen in this research as the most important starting point to search for alternative approaches.

It is assumed that a potential improved approach to replacement developed by this research should fit into the current RBAM-process. It is thus not the aim of this research to revise the RBAM-process; although there might be some teething troubles because of the quite recent introduction of this process, the certification indicates that it is considered a correct way of managing assets. Nevertheless, problems currently arising within this process, such as for instance the scarcity of time for the bottleneck-identification step, should be taken into account with implementing a new approach. This research will further elaborate on this in chapter 7.

2.4 System demarcation and demarcation of solution space

2.4.1 Characterization of demarcated system

Essent Netwerk currently feels that its approach to the replacement of aged assets might be improved. The stand-alone approach is likely inefficient, since streets need to be excavated multiple times in a short period of time. This concern and the possibilities for improvements are especially relevant for certain parts of Essent Netwerk's infrastructure. This section demarcates further research to this specific part.

The demarcated system can be characterized as follows:

- Underground asset types; since replacement of underground infrastructure requires digging, it is more vulnerable to the expected drawbacks of the current replacement approach of Essent Netwerk. Digging is costly and the more digging is necessary, the higher the total costs involved and the more inconvenience is caused to residents. For upper ground infrastructure, like the electricity installations, replacements can be mainly executed *within* the station houses. This requires little or no digging and causes little inconvenience to residents (Jager, 2007b).
- Asset types located in densely populated areas; in densely populated areas electricity assets, gas assets and other infrastructure assets, like telecom and water, are (both vertically and horizontally) geographically proximate, since in these areas the utilities were mainly constructed in one trench. According to Guijt (2004), the geographic proximity makes them more susceptible to digging incidents. Moreover, in densely populated areas the inconvenience to residents is larger, since more residents encounter the inconvenience caused.

- Asset types that are nearby other asset types of *Essent Netwerk* at one location; Essent Netwerk only returns for separate replacement at one location when multiple assets of *Essent Netwerk* are present at that location. Thus only in these situations the negative effects of returning for each asset type replacement separately hold.

The above characteristics demarcate the relevant part of Essent Netwerk's infrastructure to the infrastructure elements of Essent Netwerk, that are located underground and that are located in densely populated areas.

2.4.2 Description and quantification of demarcated system

Table 21 in Appendix 2C indicates the asset types that are located underground, in densely populated areas, and that are proximate to other assets of Essent Netwerk. Although a part of both the high pressure pipelines and MV electricity distribution cables also cross densely populated areas, they are outside the scope of this research. The reason is that these asset types are less branched and are therefore not located in all streets. Moreover, these asset types mostly are not located in a same trench with other asset types (Berg, 2007). In the reflection of this research however, the applicability of the results on the high pressure pipelines and MV distribution cables is discussed.

The relevant part of the infrastructure is then demarcated to LV main cables, low pressure gas mainlines, gas service lines and LV service cables that are located in densely populated areas and that are all owned by Essent Netwerk. Since Essent Netwerk operates a larger part of the electricity network than of the gas network, not every gas service line and main line in densely populated areas of *Essent Netwerk* is located in proximity of electricity infrastructure of *Essent Netwerk*. The system is demarcated to that part where Essent Netwerk operates both electricity and gas. By not considering the province of Friesland (where Essent Netwerk only operates the gas network and practically no electricity), it is reasonable to assume that Essent Netwerk approximately operates electricity in all areas where it operates the gas network.

	total	located in densely pop. areas and in proximity of other assets of Essent Netwerk	% of total
LV service cables(#)	2,411,656	425,066	18
LV cables (km)	81,032	7,771	10
LP service lines (#)	1,634,005	425,066	26
LP pipelines (km)	27,589	7,771	28

Table 1 Demarcation of relevant part of the infrastructure of Essent Netwerk. (Based on Essent Netwerk BV, 2007c and CBS, 2007)

Based on the above information the system can be demarcated to the following amounts of gas service lines, gas mainlines, LV service cables and LV main cables. More detailed calculations can be found in Appendix 2C.

Possible improvements in the replacement approach are thus relevant for respectively 18% and 26% of Essent Netwerk's electricity and gas connections and for 10% of all the LV cables and 28% of all the low pressure gas pipelines. The replacement value of the totality of these 4 asset types is around 10.5 billion euro. The replacement value for the demarcated system part is around 1.7 billion Euros (see Appendix 2C). Because of this enormous sum, even small savings can already lead to substantial absolute savings which emphasizes the value of searching for an improved approach.

2.4.3 Demarcation of solution space

In finding an optimal approach to the replacement of aged assets, one could consider a variety of improvement directions. Except for the replacement activity itself one could also consider the characteristics of the new assets that replace the old assets. In that, one could search for those characteristics that anticipate on future events. Taking into account for instance the change in future energy demand and the changing energy sources, one could search for the optimal approach in a way that it uses materials that are best suitable to consider these future changes. However, since these developments are still pretty uncertain, the solution space for the optimal approach in this research is demarcated to how replacement moments are planned and to the way replacements are physically executed. Obviously however, Essent Netwerk should watch such developments closely and should react upon them properly.

PART I: FINDING THE OPTIMAL APPROACH TO THE REPLACEMENT OF AGED ASSETS

3. Goals, constraints and performance indicators

As the research question implies, the optimal approach to the replacement of aged assets should be such that it maximally fulfils the goals and constraints of long-term network operation. The purpose of this chapter is to identify these goals and constraints of long-term network operation and to derive the performance indicators that are relevant for the approach to the replacement of aged assets.

In deciding on investments and estimating risks, Essent Netwerk uses a reference framework based on its five company values (Wijnia, 2007a). These company values can be seen as the goals and constraints Essent Netwerk currently is committed to for its long-term network operation. This research however considers it its scientific duty to verify this framework. Therefore, this research derives the goals and constraints of long-term network operation based on a conducted stakeholder and network analysis, as is the subject of the first section. Thereafter the research compares these goals and constraints to the company values and presents the final goals and constraints of long-term network operation that will be considered in this research. Section 3 presents the performance indicators that can be derived from the final goals and constraints of long-term network and those that are relevant for this research for evaluating alternative approaches.

3.1 Stakeholder and network analysis

According to Enserink et al. (2002), stakeholder and network analyses can be used in order to analyze a possible problem or social issue, but they can also be used for other purposes. In this section a stakeholder and network analysis is used to determine the key stakeholders Essent Netwerk is dependent on and to determine their goals and constraints with regard to its long-term network operation.

Network operation is a crucial factor behind the delivery of energy to customers. In the current days, society becomes increasingly dependent on energy. With the restructuring of the energy market, a higher awareness of greenhouse effects, and a much more social responsible attitude of the public in general, energy companies get more attention than they used to. Like every company, Essent Netwerk is operating in a large playing field and deals with a variety of stakeholders. With a large social function as network operator, there are many actors that are somehow involved with the business of Essent Netwerk.
These actors all have a certain interest in the activities of Essent Netwerk. Shareholders put pressure on return on investment and stock value for instance. Customers demand low tariffs and a good service and they become increasingly powerful in expressing their inconvenience. Regulators determine performance targets, rules and regulations for Essent Netwerk and hand out sanctions when not complying with those rules and regulations. Ministries can put pressure on safety and have the legal authority to formulate and change laws.

With operating its network, Essent Netwerk should take into account the relevant stakeholders. According to Brown and Humphrey (2005; pg. 40) this could be seen as a general goal of Asset Management. They say that: “the objective is to make all infrastructure-related decisions according to a single set of stakeholder-driven criteria”. In addition, since the success of an organization is dependent on satisfying the needs of the key stakeholders (Bryson, 1995), the interests of these key stakeholders with regard to network operation in fact determine what Essent Netwerk should see as its goals and constraints.

The key stakeholders are discussed in this section as well as their individual goals with regard to the long-term network operation of Essent Netwerk. By combining these goals they can be translated into goals and constraints of long-term network operation of Essent Netwerk.

3.1.1 Key stakeholders and their interests with regard to Essent Netwerk

The first step in a stakeholder and network analysis is to identify all stakeholders that are somehow involved with the business of Essent Netwerk. The list of these stakeholders is found in Appendix 3A. The identified stakeholders are analyzed. Based on their substitutability, influential instruments and dependence, the following stakeholders are considered as the key stakeholders for Essent Netwerk:

- Essent NV: Essent NV is the direct shareholder of Essent Netwerk and expects a reasonable profit and is helped with a good reputation of Essent Netwerk.
- Municipalities: With a 26% share in Essent NV, municipalities are indirect shareholders of Essent Netwerk. Besides a reasonable profit share, they desire good energy services for their residents. Furthermore, as local authorities, municipalities allot licenses and set up municipal rules Essent Netwerk should comply with.
- Provinces: With a 74% ownership of Essent NV, provinces are indirect shareholders of Essent Netwerk. As regional authorities, provinces set up rules relevant for Essent Netwerk and they allot licenses, for instance for groundwater withdrawal necessary for large infrastructure construction activities (Essent Netwerk, 2007d)
- Ministry of Economic Affairs; The ministry should guarantee a good working energy market in The Netherlands; with regard to network operation, the ministry prescribes network operators not to misuse their market power towards customers, to provide access for third parties and to provide transparency. The relevant competition law, Electricity law 1998 and the Gas law and the 'grondroerdersregeling' (soil-stirring rule) are supervised by the independent bodies of the ministry:
    - DTe
    - NMa.

Appendix 3B provides a goal analysis for each of these actors and for Essent Netwerk itself as well as a more detailed description of each of the key stakeholders.

3.1.2 Translation into goals and constraints for Essent Netwerk

The key stakeholders have certain interests in the network operation of Essent Netwerk. Since Essent Netwerk depends on its key stakeholders, it should take into account these interests. Based on the analysis above and in Appendix 3B, the interests of the key stakeholder are translated into goals and constraints for Essent Netwerk and they are shown in the table below.

Actor	Interest of stakeholders with regard to network operation of Essent Netwerk	Translation into goals and constraints for Essent Netwerk
Essent NV	Maximal profit from shares in Essent Netwerk Maximal reputation of Essent Netwerk	Minimal costs of network operation Maximal reputation towards public
Municipalities	Maximal reliability of network operation for its residents Maximal safety of network operation for its residents Minimal tariffs for its residents Minimal inconvenience of Essent Netwerk's activities to residents Maximal profit from shares	Maximal reliability of network operation Maximal safety of network operation Minimal costs of network operation Compliance with municipal rules and regulations Maximal reputation towards municipalities

Provinces	Maximal reliability of network operation for its residents Maximal safety of network operation for its residents Minimal tariffs for its residents Minimal inconvenience of Essent Netwerk's activities to its residents Maximal profit from shares	Maximal reliability of network operation Maximal safety of network operation Minimal costs of network operation Compliance with provincial rules and regulations Maximal reputation towards provinces
Ministry of Economic affairs, NMa, DTe	No misuse of power towards customers Transparency Accessibility of network No economic power positions Minimal digging incidents	Compliance with E en G law and net codes Compliance with 'grondroerdersregeling' Compliance with 'Competition law' Maximal reputation towards DTe, NMa and ministry Minimal costs of network operation
Essent Netwerk	Maximal continuity of Essent Netwerk	Minimal costs of network operation

Table 2 Translation of main stakeholder goals into goals and constraint for Essent Netwerk

'Maximal profit' is translated into 'minimal costs', as income is hard to influence because of price-cap regulations in which tariffs are limited to a maximum, (De Vries et al., 2004).

As goals can be seen as the 'should and want' issues, while constraints are the 'shall and musts' (Bahill and Dean, 1999), the rules and regulations set by the stakeholders can be considered the constraints of long-term network operation. Therefore compliance with the rules and regulations presented in the table is seen as a constraint.

3.2 The company values of Essent Network

This section presents an analysis of the company values Essent Netwerk currently uses as its decision-making framework. By comparing the company values with the goals and constraints derived in the previous section it is decided whether Essent Netwerk's decision-making framework can be used in this research.

3.2.1 Company values Essent Network

In its decision-making process Essent Netwerk uses five leading company values (Essent Netwerk B.V., 2006a). These company values are in line with its central stated mission and vision.

The central mission and vision of Essent Netwerk are:

"We are an excellent network operator for our clients, shareholders and employees. "

&

"We are an excellent network operator with a reliable and safe electricity network and gas network. Through good communication, correct invoicing and reliable supply, we fulfill the expectations of the client. We deliver sufficient returns for shareholders. For employees we improve the level of convenience and realize a safe and inspiring working environment."

(Essent Netwerk BV., 2006a; pg.1)

The company values of Essent Netwerk are:

- **Safety:** network operation should be safe; "the safety of own and hired personnel as well as of the public receives special attention" (Essent Netwerk BV., 2006a; pg.3)
- **Quality of supply**: network operation should have a certain reliability of supply and the service of supply is maximized (Essent Netwerk BV., 2005b)

- **Economy**: network operation should be such that the lifecycle costs of assets should be minimized (Essent Netwerk BV., 2005b)
- **Compliancy**: network operation should be such that it is compliant with relevant laws and regulations (Essent Netwerk B.V., 2005b); "the network must always comply with relevant laws and regulation" (Essent Netwerk BV., 2006a; pg.3)
- **Reputation**: network operation should be such that it is executed in a social responsible way (Essent Netwerk BV., 2006d)

These company values are considered the current decision-making framework of Essent Netwerk. As stated in the Asset Management policy statement, the company values are the core of targets the asset owner (the board of Essent Netwerk) set for the asset manager (the Asset Management department) (Essent Netwerk BV., 2006). The Asset Management department should make decisions that contribute to the above company values, as is also stated in the mission of the Asset Management department as:

"The control of the company values of cable and line energy infrastructures"

(Essent Netwerk BV., 2006a; pg.1)

Decisions concerning network operation are consequently made according to their effects on these company values which imply that also the decisions with regard to the replacement of aged assets would be made according to these values.

3.2.2 Comparison of company values with derived goals and constraints

The presented company values were derived from a stakeholder analysis that Essent Netwerk conducted some years ago. The following stakeholders were then depicted as key stakeholders: Shareholders, Municipalities and provinces, DTe, Execution department, Customers, Employees & Workers Council (Cap Gemini Ernst & Young, 2002).
This list of key stakeholders has overlaps with the key stakeholders derived by this research. To see if the stakeholder analysis conducted by Essent Netwerk and the one conducted by this research resulted in comparable goals and constraints, the company values that were derived from the former are compared with the goals and constraints derived in the previous section.

The goals and constraints derived by this research are categorized and as figure 11 shows the company values appear to be quite similar. This implies that the company values of Essent Netwerk still represent the demands of its key stakeholders with regard to its network operation. The similarity provides an important argument to use Essent Netwerk's decision-making framework in this research.

Translating the company values into decomposable goals and constraints results in the following goals:

- Maximal quality of supply of long-term network operation
- Minimal costs of long-term network operation
- Maximal safety of long-term network operation
- Maximal reputation of long-term network operation

And in the following constraint:

- The long-term network operation should be compliant with all relevant rules and regulations

The optimal approach to replacement should consequently be such that it maximally fulfils these goals and constraint. In this way it aims at reaching the overall optimum in an integrated manner.

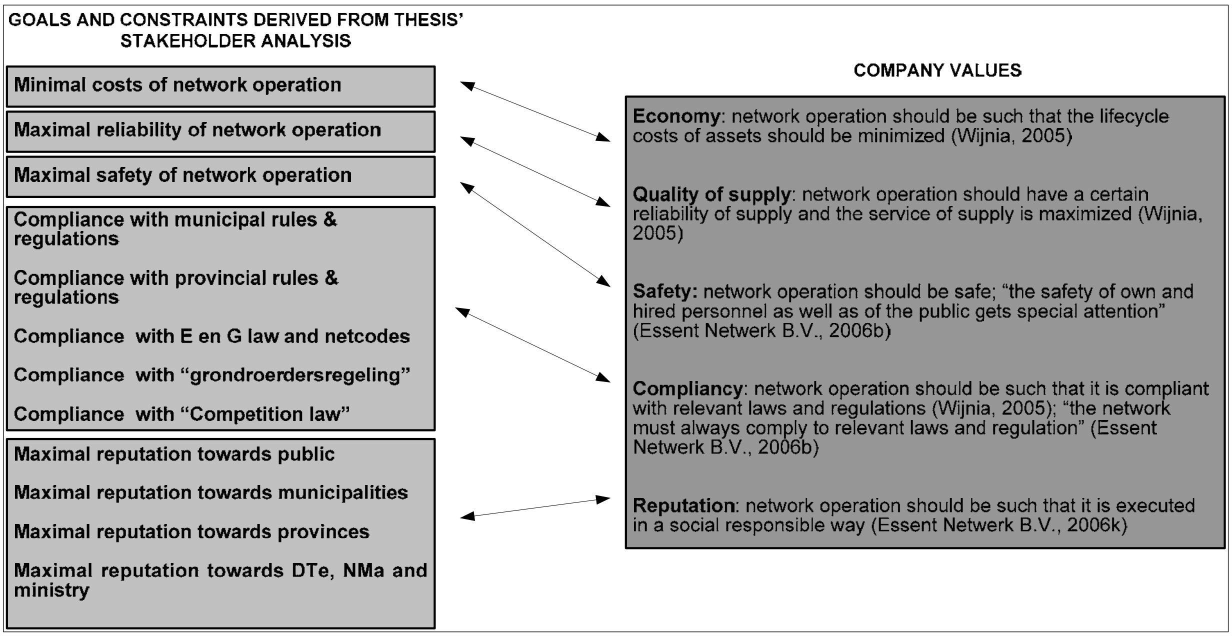


Figure 11 Comparison of goals and constraints derived from thesis' analysis and company values

3.3 Performance indicators

3.3.1 Performance indicators for long-term network operation

To determine how these goals and constraint can be fulfilled, their accompanying performance indicators are derived. These performance indicators are used later on in this research for evaluating the current and selected alternative approaches to the replacement of Essent Netwerk's aged assets.

For each goal and constraint a key success factor is identified and these key success factors are translated into the performance indicators. The performance indicators for each key success factor were determined by reviewing internal documents of Essent Netwerk. Essent Netwerk uses 'balanced score cards' to measure its key success factors and these balanced score cards present performance indicators relevant for the key success factors (Essent Netwerk BV, 2006a). Also the risk tolerability matrix, which is used by the Asset Management department to measure the effects on the company values and to accordingly make decisions concerning network operation, is used to derive performance indicators. The performance indicators are shown in the table.

Goals/Constraints	Overall key success factor	Performance indicators according to Essent Netwerk documents
Maximal safety of long-term network operation	Minimal number and seriousness of incidents of network operation	• Number of Incidents to employees and public (Essent Netwerk BV, 2006a) • Level of incidents to employees and public (Essent Netwerk BV, 2006a) • Gas safety indicator (Essent Netwerk, 2007b)
Maximal quality of supply of long-term network operation	Maximal reliability of supply and service of supply (Wijnia, 2005b)	• Customer minutes lost (minutes) (Essent Netwerk BV, Jager, 2007a) • Yearly interruption duration (minutes) (Essent Netwerk BV, 2007b) • Interruption frequency (#) Essent Netwerk BV, 2007b) • Voltage quality (%) Essent Netwerk BV, 2007b)

Minimal costs of long-term network operation	Minimal costs	• Production costs (= maintenance costs + replacement costs + expansion costs + reconstruction costs + failure costs) • Overhead costs (administration, P&O, customer centre) • Purchase costs (=connection costs Gasunie/TenneT) (Wijnia et al., 2005)
Maximal reputation of long-term network operation	Maximal reputation towards public, municipalities, provinces and DTe	• Inconvenience to public • Transparency of business • Commercial quality • Innovation (Vroom, 2006)
The long-term network operation should be compliant with relevant rules and regulations	Be compliant with all relevant laws and regulations (Essent Netwerk, 2006k)	• Compliance with municipal rules • Compliance with provincial rules • Compliance with DTe, NMa and ministry

Table 3 Performance indicators

3.3.2 Performance indicators for the replacement approach

Not all of the presented performance indicators can be influenced by the approach of Essent Netwerk to the replacement of its assets. As the aim of this research is to find the approach to the replacement of the aged assets that maximally fulfils the goals and constraint of network operation, the performance indicators of these goals and constraint that can be influenced by such a replacement approach are needed. Only the performance indicators that can be influenced by the replacement approach are relevant for this research.

For each goal and constraint it is determined which performance indicators are influenced by the replacement approach and which performance indicators are consequently used in the remainder of this research to evaluate the current and possible alternative approaches:

Performance indicators of the goal 'Maximal quality of supply':

The quality of supply can be measured by different performance indicators, of which the first three in table 3 have to do with interruption of supply. The interruption of supply can be influenced by the replacement approach; during replacement activities digging incidents to infrastructure may cause outages. Interruptions of supply caused during replacement activities are therefore considered in the evaluation of replacement approaches.

Since the optimal replacement moment of an asset type is calculated such that it prescribes to replace assets before failure probability strongly increases, the failure probability of an asset is very low and at a constant level until this optimal replacement moment. As becomes clear later on, only alternative approaches that prescribe to replace assets at or before their optimal replacement moment are considered. Therefore and because of the assumed same constant failure probability until the optimal replacement moment of an asset, no interruptions of supply that are either caused by too late or too early replacement are considered in this research. It is moreover assumed that the approach to the replacement of aged assets does not influence the voltage quality.

The best way to measure the extent of the outages caused *during* replacement activities is:

- Customer minutes lost; the customer minutes lost present the total time customers are interrupted from energy supply. Yearly interruption duration and interruption frequency are also indicators for measuring the quality of supply. However, the yearly interruption duration presents the total interruption time per customer and the frequency the amount of interruptions per year, while with 'customer minutes lost' it is possible to present the total interruption time per replacement activity. Moreover, as becomes clear later on, 'customer minutes lost' can be given a monetary value, which provides the possibility to compare alternatives financially.

Performance indicators of the goal 'Minimal costs':

- Replacement costs. Obviously, the replacement costs are influenced by the approach to the replacement of aged assets. The digging equipment, the amount of ground moved, assembling the new assets and the like all influence the total replacement costs. As becomes clear later on, these replacement costs are composed of different cost components.
- Direct failure costs = digging incident costs: The way the replacements are arranged may influence the amount of failures of assets due to digging incidents. Since no interruptions of supply due to either too late or too early replacement are considered in this research, the failure costs are only determined by failures that are caused by digging incidents. These failures need to be repaired which brings along costs. These can be called the digging incident costs.

Performance indicators of the goal 'Maximal reputation':

- Inconvenience**:** Replacing assets requires excavation of surfaces for a while. This may for instance result in traffic congestions and decreased accessibility leading to inconvenience to the public (Jung and Sinha, 2007). The approach of Essent Netwerk to its replacement can hence influence the inconvenience to residents and thereby its reputation.

Performance indicator of the constraint 'Be compliant with all relevant rules and regulations':

- Compliance with municipal rules: As replacements are a local activity and since this research is demarcated to those asset types located in densely populated areas, which usually comprise living areas and streets in city centers, municipal rules are relevant. Since compliance is considered a constraint for long-term network operation, Essent Netwerk should be compliant with the relevant rules set by these local governments. DTe rules are considered not to be at issue with replacement activities.

Maximal safety:

Safety is obviously a very important issue for Essent Netwerk and a value that should be respected at any time. With regard to replacements, safety incidents might be caused by digging incidents. The probability of a safety incident caused by a digging incident to the electricity infrastructure however is described as nil (Bakker, 2006b). The same holds for safety incidents caused by digging damage to telecom, water, sewage and internet infrastructure. For gas infrastructure, the probability of a digging incident is small, but present. A quick estimation however showed that the multiplication of probability and effect of a safety incident caused by a digging incident is too small to notice any significant changes caused by alternative approaches to replacement. Moreover an interview with the Health Safety and Environment department of Essent Netwerk turned out that no significant changes are expected from adopting another replacement approach with regard to safety (Goedhart, 2007). It is therefore decided not to consider safety effects in this research and therefore no performance indicators for safety are presented here.

3.4 Conclusions

The optimal approach of Essent Netwerk to the replacement of aged assets should be such that it fulfils the goals and constraints of long-term network operation. This chapter was aimed at finding these goals and constraints. It conducted a stakeholder analysis and derived goals and constraints for Essent Netwerk. Thereafter it compared these goals and constraints with the company values Essent Netwerk currently uses in it decision-making. Since they were comparable the company values were used as a basis for the goals and constraints of long-term network operation. The goals and constraint are:

- Minimal costs of long-term network operation
- Maximal quality of supply of long-term network operation
- Maximal safety of long-term network operation
- Maximal reputation of long-term network operation
- The long-term network operation should be compliant with all relevant rules and regulations

The approach to replacement of assets should be such that it maximally fulfils these goals and constraint.

For the goals and constraint the relevant performance indicators with regard to the replacement of aged are derived and these are:

- Replacement costs (€)
- Direct failure costs = digging incident costs (€)
- Customer minutes lost (minutes)
- Compliance with municipal rules
- Inconvenience

The performance indicators are used in evaluating the current and alternative replacement approach(es).

4. Alternative approaches to replacement

This chapter is aimed at finding alternative approaches to the replacement of aged assets and at selecting the most promising alternative approach(es) for further research.

4.1 Possible alternative approaches to the replacement of aged assets

The current approach of Essent Netwerk to the replacement of its aged assets is characterized by optimization per asset type. The replacement moment is determined per asset type separately and based on calculated optimal replacement moments of these asset types. Since Essent Netwerk feels that its approach might be improved, this research searched for alternative approaches to replacing assets. Alternative approaches can be found in the way of determining replacement moments, since the determination of replacement moments is a central issue in the current approach. Alternative approaches can also be found in the way of physically executing replacements, e.g. the replacement techniques, since it is at this point where the possible negative effects of the current approach arise.

The following alternatives are found and are discussed in the remainder of this chapter:
Alternative determination of replacement moments:

- Waiting for replacement till assets fail, by applying corrective replacement
- Planning replacement before assets fail, by applying preventive replacement. This preventive replacement yields multiple options:
    - A stand-alone approach: Preventive replacements per asset type separately
    - A coordinated approach that considers preventive replacement of multiple asset types of Essent Netwerk simultaneously
    - A coordinated approach that considers preventive replacement of multiple assets of both Essent Netwerk and other infrastructure operators simultaneously
- Postponing replacement by using life extension techniques

Alternative replacement techniques:

- Traditional trenching techniques that require excavation of the whole surface
- Trenchless replacement techniques that require minimal excavation

4.2 Quick scan and selection of alternative approaches

4.2.1 Alternative determination of replacement moment

4.2.1.1 Corrective replacement

Since many assets are ageing, network operators are facing the question of how to cope with the enormous set of assets that reach their end of lifetime in the near future. Should they wait until these assets definitely fail or should they take preventive actions? Both with regard to maintenance of assets and replacement of assets a distinction is made between a corrective and a preventive strategy. With regard to maintenance, Birkner (2004) distinguishes for instance corrective maintenance after failure, time-based maintenance, condition-based maintenance and reliability centered maintenance.

For asset *replacement* also a distinction can be made between corrective and preventive replacement. Van Noortwijk (1998; pg.1) describes corrective replacement as "replacement after failure" and preventive

replacement as “replacement before failure”. Corrective replacement thus implies waiting until an asset definitely fails and then replace that asset while preventive replacement means predicting asset failure and choosing the best moment to replace. These strategies can be generally applied to all sorts of infrastructures, but according to Van Noortwijk (1998; pg.2) the first should be chosen when the consequences of failure (“the costs arising from failure”) are small and the latter when these consequences are large. He claims that in structural engineering the consequences are mainly so large that preventive replacement should be applied.
With regard to the Dutch energy distribution network, corrective replacement or maintenance prevailed in the past. According to Jongepier (2007; pg.1) the replacement and maintenance strategy has for quite a long time been “keep off until it fails, repair the part that failed, and only replace if really necessary”. Probably this was not because the consequences of failure were assumed to be ‘small’, but because the assets were relatively young and failures were thus not age-related and therefore less predictable.

Corrective replacement has many drawbacks. Corrective replacement is namely expensive in multiple ways. As Wijnia et al. (2006; pg.2) put it, “corrective maintenance and corrective replacements take more time than the preventive equivalents”. Currently, with the expectation that many assets will fail in a relatively short period, corrective maintenance would result in an enormous unplanned workload which would be too large to tackle. This would very likely result in more outages and higher costs.
Wijnia et al. (2006; pg.4) describe in their research that corrective replacement is indeed more costly then for instance preventive replacement; corrective replacement would occur “at inconvenient times, require service restoration action, temporary measures and so on. Furthermore, “uncontrolled failure has costs in the form of Customer Minutes Lost and safety incidents, which would not occur if the replacement was planned before failure” (Wijnia et al., 2006; pg. 4). With the many assets to be replaced in the near future and the high costs arising from corrective replacement, the alternative of correctively replacing the concerned asset types is not expected to improve the current approach. It is therefore not considered an alternative in this research.

4.1.2.2 Preventive replacement – multiple options

With more assets ageing, preventive replacement appears to become a prevailing strategy. As Burns et al. (1998) for instance shows, the replacement of water supply, sewage disposal, public transport and roads in Australia gets increasingly based on preventive replacement. Preventive replacement implies replacement before failure; failure behavior is predicted and based thereon asset replacement is planned before failure. It appears to be a suitable approach now that many of the assets are ageing and are reaching their moment of definite failure.

In planning these preventive replacements, the replacement moments can be optimized per asset type, resulting in separate replacements, or planning can incorporate replacement moments of multiple asset types simultaneously, resulting in combined replacement.

Stand-alone approach: Optimize preventive replacements per asset type separately

When network operators decide to apply preventive replacement, they should decide how preventive the replacement should be. Per asset type, an economic optimal replacement moment can be determined, using calculation models (Higgins et al., 2002). Failure rates and failure models can be used to find these optimal moments (Wijnia et al., 2006). Based on the optimal replacement moments assets are replaced as close as possible to these moments. This is how Essent Netwerk currently approaches its replacements.

A coordinated approach that considers preventive replacement of multiple asset types of Essent Netwerk simultaneously

According to Ghairabeh et al. (1999), who developed a methodology for an integrated highway management system, managing components that are owned and managed by the same agency in a coordinated way could be beneficial to both consumers as operators. It claims that uncoordinated rehabilitation projects of for instance nearby located pavements, bridges, road signs and intersections can lead to both increased agency costs and user costs (more delays due to travel through work zones) (Ghairabeh et al., 1999). The research shows that combined replacement of multiple highway components can lead to great savings (see figure 12).

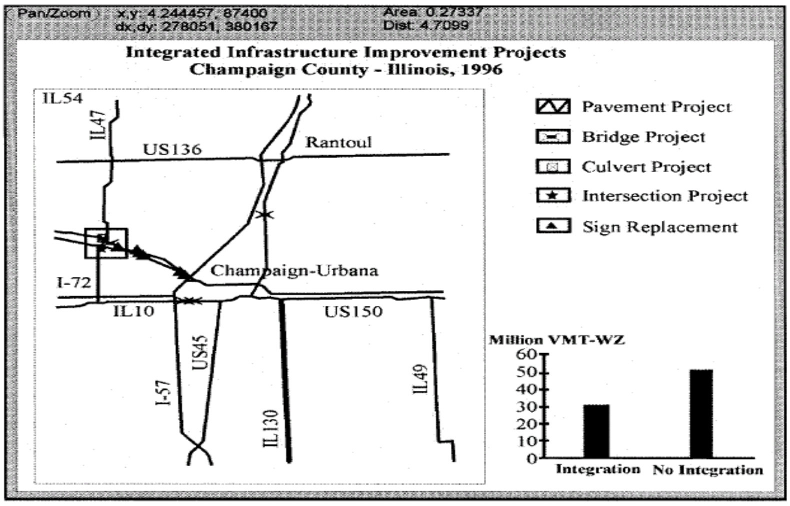


Figure 12 Savings of integrated replacement of multiple highway assets. Measured in time traveled trough working zones (VMT-MZ); this expresses both agency and customer costs. (Ghairabeh et al., 1999).

These findings might also be applicable to the network of Essent Netwerk. In contrast to optimizing replacements per asset type and consequently replacing these assets separately, Essent Netwerk could consider multiple asset types with planning its replacements. As indicated, the asset types relevant for this research are geographically proximate; a coordinated approach could prescribe to replace these asset types simultaneously when this turns out beneficial. When a street is excavated for the replacement of for instance the gas mainline, a more coordinated approach could consequently prescribe to simultaneously install a new electricity cable. This implies that the street is only excavated once instead of twice for the replacement of these asset types. Except from the decreased disturbance of traffic and inconvenience to residents it could also lead to fewer excavation costs.

Combining replacements is not totally new to Essent Netwerk. However, the combined replacements that occurred so far were only initiated *during* the execution of replacements when maintenance staff remarked that a nearby asset type was in real bad condition. The alternative approach described here implies a structural approach in which combined replacement is planned beforehand.

Within Essent Netwerk there appears to be support for this coordinated approach. Since the first replacements of gas service lines started, similar situations as described might occur in the near future, making more and more people within the company wonder whether simultaneously replacing assets might be more efficient. Within Essent Netwerk, it is expected that when nearby asset types need replacement not too long after the other asset type, combining replacement decreases the costs spent on excavation and restoration of streets (Jager, 2007b; Korn, 2007; Mutsaers, 2007). Moreover, decreased inconvenience to residents is seen as another strong motivation for considering combined replacement possibilities (Jager 2007b; Korn, 2007; Mutsaers, 2007).

The coordinated approach of replacements is worth considering, since combining replacements may in certain situations be more efficient, it may lead to fewer costs for replacements and decreased inconvenience as compared to the current approach. Therefore, this approach is considered as a potential alternative in the remainder of this research.

A coordinated approach that considers preventive replacement of multiple assets of both Essent Netwerk and other infrastructure operators simultaneously

Higgins et al. (2002) claims that in an ideal world, utility companies should work closely together to develop long and short term plans for rehabilitation of assets at minimum costs. According to Higgins et al. (2002) replacement of assets should be considered in a more integral way and the research recommends for instance to simultaneously replace sewer systems and roads. The research shows the possibilities for a municipality in Canada to integrate replacements of water, storm sewer and sewer systems and pavements. These assets are geographically proximate and replacing one would affect the other significantly and therefore integration should be considered (Higgins et al., 2002).

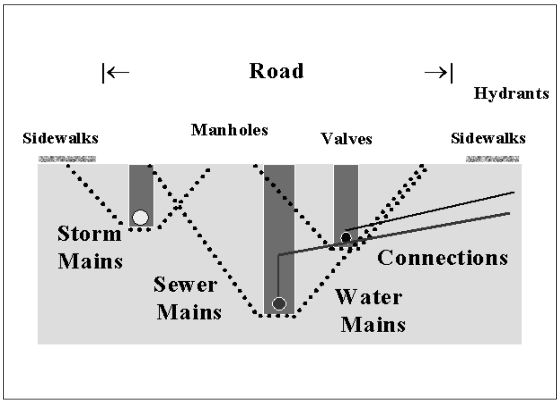


Figure 13 Combined replacement of multiple infrastructures. (Higgins et al., 2002).

With preventively replacing its assets Essent Netwerk could also choose to consider possibilities for combined replacement with other network operators. Currently, in The Netherlands, the *construction* of new cables and pipelines in new housing estates is already predominantly executed in coordination with multiple network operators. Essent Netwerk is for instance incorporated in Synfra, an alliance that works on the combined construction of cables and lines in Noord-Brabant and Limburg (Vissia, 2007). According to Synfra (2007), advantages of this cooperation are reduced costs and decreased inconvenience and the realization of a sustainable underground infrastructure. These advantages could possibly also be gained with the combined *replacement* of multiple infrastructures.

In the Netherlands, some combined projects have already been executed; in 1999, Delft Municipality initiated a soil sanitation project and invited other network operators to simultaneously replace their assets in that street. After this project, they maintained a 5 year period in which no replacement activities of other network operators were allowed; the majority of network operators joined and finally a 40% saving was obtained (Mischgofsky, 2007). Except from these cost savings, the inconvenience to residents was greatly limited to only one instead of multiple periods of trenched streets and inaccessible houses and shops.

Replacing multiple infrastructures simultaneously appears to be interesting because of its reduced costs and inconvenience. However, considered from an organizational perspective, the combined replacement of multiple infrastructures is complex. The municipality considered in the research by Higgins et al. (2002) owned and operated all the considered infrastructures itself, making integration organizationally much easier then when ownership of assets is spread over multiple companies. In The Netherlands, where ownership of these infrastructures is spread over different network operators, combined replacement of multiple infrastructures might result in difficult organizational questions about who should be the initiator of the combination projects, and in complex costs allocations and the need for mutual trust (Mischgofsky, 2007).

Despite this organizational complexity, combining replacements of assets of Essent Netwerk with the assets of other infrastructure operators is seen as an approach that has potential to improve the current approach. However investigating the potential of combining replacements of assets with different infrastructure network operators for Essent Netwerk, demands detailed information of the other network operators' assets. Since this information is not directly available and difficult to discover in the academic setting of this research it is decided not to consider this alternative in this research phase. However, it is assumed that the possible economic advantages of combining replacements within Essent Netwerk also apply for the alternative approach of combining replacement of assets with other infrastructure network operators. The reflection chapter of this research further elaborates on cooperation with external infrastructure operators.

4.2.1.1 Life extension techniques

Network operators could also decide to prolong the life of assets by upgrading or refurbishing assets (life extension techniques) and thereby postpone the replacement of their assets (Jongepier, 2007). Dominelli et al. (2006) describe it as a way for network operators to cope with budget and staff constraints. By using inspection and monitoring techniques the weaker parts of assets can be identified and repaired, resulting in longer asset life times (Dominelli et al., 2006). By using different life extension techniques the lifetime of assets can thus be prolonged. This means that the replacement moments can be postponed and that the difficult replacement issue does not need to be considered now, but can be postponed to a later moment. However, it is a fact that asset life is not everlasting and while life extension might be a solution for the short term, on the long-term the replacement should still be considered. Moreover as the life extension technique on its own does not take away the mentioned drawbacks of the current approach it is not considered an alternative in this research.

4.2.2 Alternative replacement techniques – Trenching or trenchless replacement

To install or replace assets in densely populated areas, Essent Netwerk currently only applies trenching techniques that require excavation of the entire surface (Dijk and Verbeek, 2007). In the Netherlands, these trenching techniques currently appear to prevail with replacing or installing cables or lines. However, a relatively new and fast growing technique that is able to install, rehabilitate or upgrade underground infrastructure without excavating the whole surface does exist. Instead of excavating the whole trace, only an entrance and exit pit is required and the asset is replaced without excavating the entire surface (Lueke and Ariaratnam, 2001).

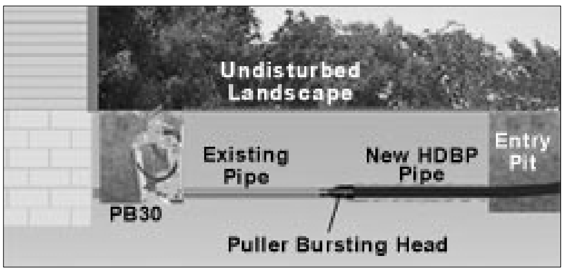


Figure 14 Trenchless replacement technique. (UKSTT, 2007).

A number of these trenchless techniques exist, but for the replacement of pipelines, pipe bursting is the most renowned technique; an expanding device shatters the old pipe while drawing in the new one behind it (UKSTT, 2007). With regard to trenchless replacement of power cables, the wash-over method, where old cables are bored free and pulled and the new cable is installed in the void made by removing the old, prevails (Bayer, 2007).

The main advantage of trenchless replacement methods is that they cause minimal impact on daily life of traffic and citizens, since only little inaccessibility is caused (Jung and Sinha, 2007). Besides this decreased inconvenience to residents, trenchless replacement is also able to decrease the costs for restoration of sidewalks or landscapes in certain situations (Jung and Sinha, 2007).

Besides these advantages trenchless replacement also brings risks (Lueke and Ariaratnam, 2001);

- With pipe bursting for instance, fragments of the old line being burst can remain in the soil and can damage the new pipe.
- The new pipe that is installed can fail when the pull force is too strong and excels the tensile strength of the pipe.
- The ground movements accompanied with trenchless replacement may lead to damage, due to fewer control of the underground. Moreover, when depth is too shallow, also ground movements at the surface may occur.

In addition, trenchless replacement can still remain more expensive than trenching. As Lueke and Ariaratnam (2001) claim, trenchless techniques only become economically advantageous when assets are located at a depth of more then 3 meters, since only then the costs of excavation exceed those of applying the trenchless techniques. With regard to excavation costs, the potential of trenchless replacement is also considered to be higher in situations where the excavation of soil is very expensive, as for instance is the case in countries, unlike The Netherlands, with rock soil, or when assets are located beneath expensive surfaces such as asphalt (Dijk and Verbeek, 2007).

Expert interviews revealed that Essent Netwerk currently applies trenchless techniques, but only in specific situations, namely (Dijk and Verbeek, 2007);

- When assets are located beneath railways, waterways and highways; Governments prohibits closing these important transportation ways. Moreover, in these situations, applying trenchless techniques is cheaper then using trenching techniques.
- For a part of the gas service lines that is located in rural areas. These service lines are long as compared to those situated in densely populated areas. Moreover, due to the fewer houses in rural areas, the concentration of gas service lines is low. For replacing these service lines a simple and relatively cheap trenchless technique can be used, making trenchless replacement in those situations cheaper than trenching. This technique is only suitable for replacing the relatively small gas service lines. However, even for replacing or installing service lines in rural areas, the traditional trenching techniques prevail.

The above implies that trenchless techniques are currently thus not used for the demarcated infrastructure elements.

Trenchless replacement is able to take away the negative effects of excavation. However, expert interviews turned out that with the current state of the art its potential to replace the concerned assets in densely populated areas is currently relatively small. In densely populated areas houses are situated tight to each other, implying that there are many gas service lines or LV service cables connected to a gas mainline or main cable. Replacing for instance the gas mainline with trenchless techniques still demands that a pit needs to be excavated each 2 or 3 meter to connect the gas service lines to the gas mainlines. This consequently still requires much excavation, taking away the possible cost advantages of trenchless replacement (Dijk and Verbeek, 2007). Moreover since these assets are located at a shallow depth and not in extreme soil types such as in foreign countries, at this moment using trenchless techniques for replacing the main net is expected to be more expensive than trenching, even without considering the many necessary pits. The same holds when considering trenchless replacement of the relatively short gas service lines or service cables in densely populated areas.

Currently, applying trenchless techniques to replace assets in densely populated areas is still much more expensive than trenching techniques. Moreover, since still excavation pits are necessary it is not able to decrease inconvenience to residents. Therefore, trenchless replacement is not considered an alternative in the remainder of this project and it is assumed that traditional replacement techniques are used. It is however advisable to watch both the financial and technical developments of the trenchless methods; once their costs fall or possibilities arise to simultaneously and trenchless install the main net and connections, it might become an interesting alternative.

4.3 Conclusions

This chapter looked for alternative approaches with regard to the replacement of the assets of Essent Netwerk. It focused on alternatives that influence the individual replacement moment of assets and the replacement technique and that could thereby improve the current approach.

After scanning the alternative approaches, it is decided to not investigate the alternative of trenchless replacement techniques and that consequently the approaches to be investigated make use of the usual excavation techniques. It is decided to further investigate one approach in more detail; the coordinated approach of preventive replacement of multiple asset types of Essent Netwerk.
This approach implies that during the planning of replacements it is considered whether the replacement of multiple asset types can be combined. In the following chapters this approach is compared to the current approach in which replacement is optimized per asset type. The two approaches are presented in the figure above.

Although outside the demarcated solution space, one could have also considered alternative ways of placing the new assets in the underground in relation to other existing assets, or one could have considered alternative characteristics of the new assets. With regard to the former one could think of for instance cable tunnels, which is a tunnel that captures all present cables and is covered with a capping in the pavement. Cable tunnels enable an easy repair and addition of new cables and protect cables from being damaged by activities on present pipelines or sewage (FDN, 2007). A drawback is that they are much more vulnerable to vandalism and moreover installing these tunnels actually demand cooperation with other infrastructure operators. With regard to alternative characteristics of asset types, one could think of materials that anticipate on a changing energy market, thus for instance pipelines that can cope with higher percentages of hydrogen.

As the solution space was demarcated as in paragraph 2.4.3, in this research the evaluation of alternative approaches is confined to the earlier presented approaches. In the reflection of this research these issues are however further discussed.

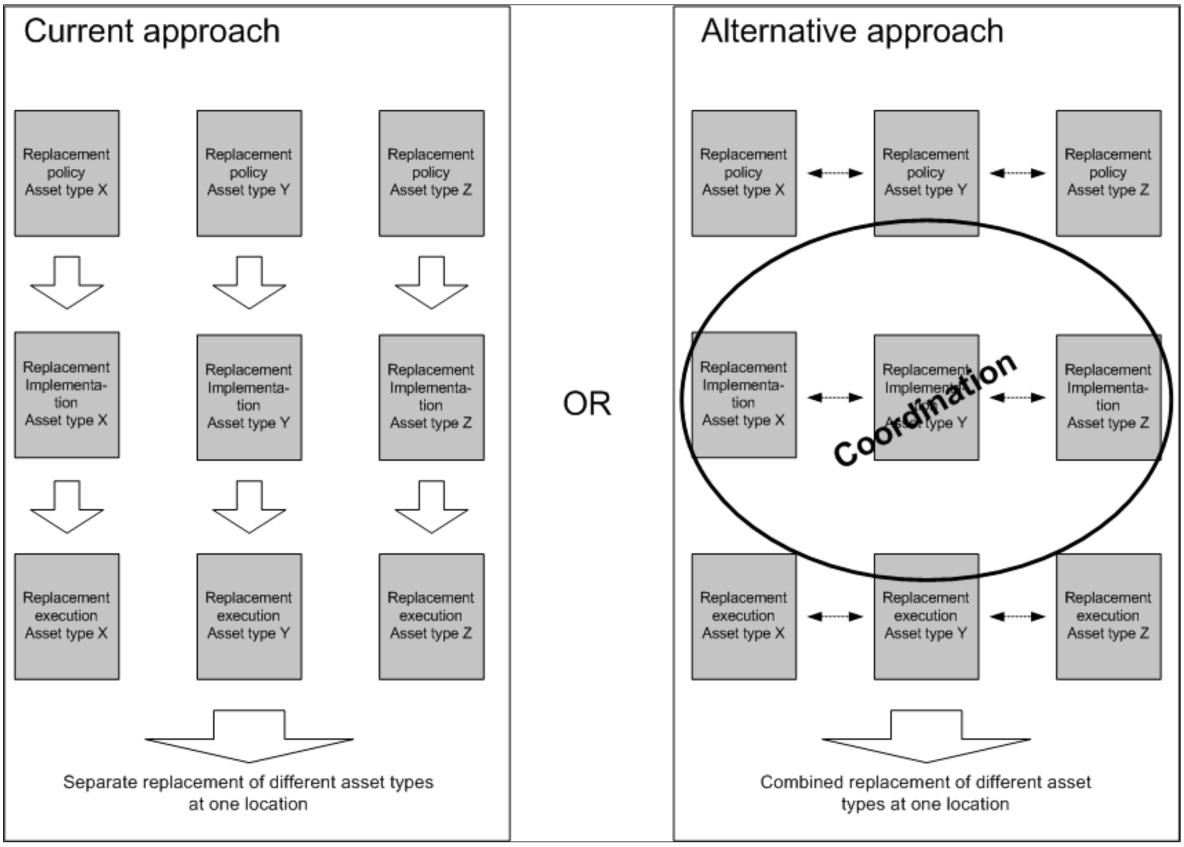


Figure 15 In the remainder of the research the above presented alternatives are discussed.

5. Modeling the current and the alternative approach; combined versus separate replacement

The current approach of Essent Netwerk implies that asset types are replaced separately. With the alternative approach multiple asset types are considered during replacement planning, which may result in combined replacement of these multiple asset types.

To find out whether Essent Netwerk should stay with its current approach or should adopt the alternative one, it first needs to be researched whether combined replacement of the asset types of Essent Netwerk *can* be more beneficial than separate replacement with regard to the goals and constraint of long-term network operation. Can combining replacement indeed lead to lower costs and fewer digging incidents? Or is there a catch somewhere? To be able to find out, the effects of separate and combined replacement on the performance indicators need to be compared. This chapter starts with a conceptualization in which the external factors of replacement that influence the performance indicators, are derived and explained. The second section presents the choices to be faced when considering combined replacement of assets. Section 3 presents the method used to compare the effects of combined and separate replacement. In section 4 the construction and specification of the calculation model used for the quantitative analysis is discussed.

5.1 Conceptualization

The replacement of Essent Netwerk's aged assets is currently optimized, planned and executed per asset type separately. Since it is expected that many of the assets will fail in the near future in a condensed period of time, it is expected that contractors and maintenance staff have to return multiple times in a relatively short period, which is inefficient and results in inconvenience to residents.

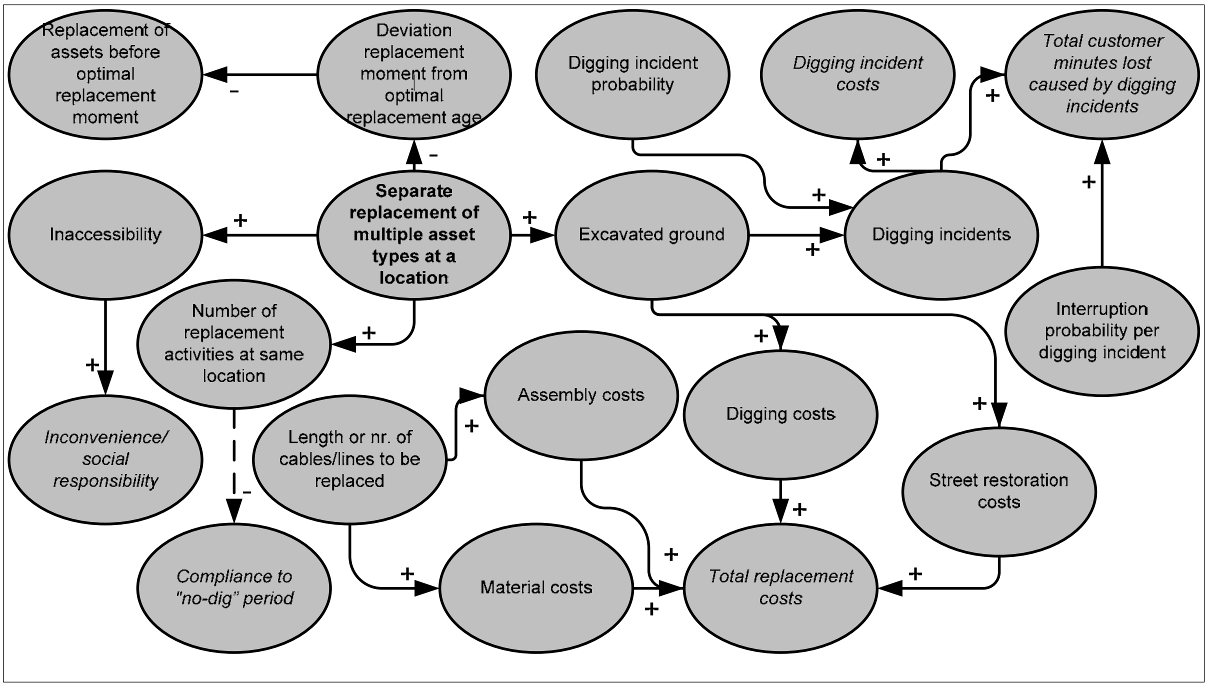


Figure 16 Relation diagram.

To determine whether this indeed is inefficient and brings extra costs and inconvenience as compared to combining replacements, the external factors that influence the performance indicators depicted in chapter 3 are derived, based on expert interviews. The causal diagram in figure 16 shows the effects of separately replacing the existing asset types on the external factors and consequently on the performance indicators depicted in chapter 3.

In the diagram it is assumed that the fewer separate replacements imply the more combined replacements. Consequently, when certain asset types are replaced all separately from one another, the total digging costs and costs for street restoration are higher than when some or all of these assets are replaced together. Moreover, since overall more ground is excavated with separate replacements than when replacements are combined, more digging incidents occurs, resulting in more interruptions and direct damage costs. However, when the replacement of one asset type is combined with the replacement of another asset type, one of these asset types is probably replaced before its determined optimal replacement age. This means that replacement investment that would actually be made later in time, is made now.

The following sub sections and the remainder of this chapter explain the depicted relations in the causal diagram, by discussing the factors that influence each depicted performance indicator. Based on this information, later on, a calculation model can be constructed.

5.1.1 Replacement costs

Replacement of assets requires excavation of the surface. Moreover, it requires new assets to replace the old assets. After replacement, the surface needs to be restored. These actions are mainly executed by contractors hired by Essent Netwerk and they all imply large costs. If replacements are necessary, the Infra Services department contacts the contractors and orders them to execute replacements. Based on interviews with staff members of the Infra Services department responsible for the execution of replacements and arranging the necessary contractors, the components of the replacement costs are determined. These are:

- Digging costs
- Assembly costs
- Material costs
- Street restoration costs (Aarssen, 2007)

The sum of these costs is considered the total replacement costs. With the separate replacements more ground is excavated than with combined replacement. This consequently results into higher costs for digging and for restoring streets.

5.1.2 Digging incident costs

Gas and electricity infrastructure as well as telecom, internet, water and sewage infrastructure are prone to damage. Literature distinguishes different causes of damage to these assets, like corrosion, construction/material mistakes and digging activities (Guijt, 2004; Asseldonk, 2006).

Oort et al. (2007) name investigations claiming that 30 to 50% of all damages to underground cables and lines can be attributed to digging activities. It also mentions an investigation that claims that even 97% of damages to gas lines in The Netherlands are caused by digging activities. More damage by digging activities can be expected in more densely populated areas and when the frequency of activities is higher (Oort et al., 2007). According to Guijt (2004), pipelines with a cover depth of less than 1 meter or those built in densely populated areas are more prone to digging incidents.

During replacement activities there is always a probability that damage is caused to other cables and lines present. This leads to damage that Essent Netwerk needs to remunerate. With the separate replacements more ground is excavated than when combining these replacements; this increases the total amount of digging incidents.

The digging incident costs are assumed to be determined by a certain fixed probability of a digging incident occurring per amount of ground that is excavated and by a fixed amount of damage costs per digging incident.

5.1.3 Customer minutes lost

Digging incidents might also result into so-called 'consequence damage', like interruptions of supply (Pauwels and Wieleman, 2004). Pauwels and Wieleman (2004) assume that the effects of interruptions by digging incidents for telecom and water are minimal. Essent Netwerk assumes that interruptions of gas supply are nil because of the strong branching and meshing of the gas network (Bakker, 2006b). Consequently, only the interruption effects on electricity infrastructure are relevant. Assuming that a replacement of a certain asset type could only result into damage to *other* asset types, only the replacement activities of Essent Netwerk concerning solely the gas infrastructure might result in interruptions. The total customer minutes lost depend on the probability that an outage is caused when a digging incident occurs and on the accompanied customer minutes lost.

5.1.4 Compliance with municipal rules

Municipalities set constraints for the construction and maintenance of energy infrastructure. They allot licenses for replacement activities and can force Essent Netwerk to execute replacements in a certain prescribed way. This research does not elaborate on the entire set of rules set by local governments, since they differ too greatly per municipality. There is however one constraint that seems to become increasingly important. According to Sebregts (2007) local municipalities become stricter with regard to underground activities as they try to minimize these activities. Municipalities set constraints on the number of digging activities during a certain period (Sebregts, 2007). They want network operators to combine their work as much as possible and can refuse to allot licenses if they do not (Versteeg, 2007). Especially the larger municipalities develop more and more policies to reduce the activities in the underground (Vissia, 2007).

Sometimes it is the municipality itself that execute digging activities at a location and invite network operators to execute their necessary activities simultaneously and again if they do not, they won't allot licenses if their next activities would be in a short time. Since combining replacements with other network operators (such as municipalities) is not discussed in this research phase however, this situation is not considered.

The strictness of the so-called 'no-dig period' varies per municipality, but mostly a period of 5-10 years is used. As municipalities however seem to get more involved in underground activities, they perhaps tighten their rules in the future and come up with larger 'no-dig periods', making the 'no-dig periods' an increasingly important factor (Poorts, 2007). When replacements of aged asset types are executed separately, this might imply that this 'no-dig period' is violated as the dotted line in figure 16 shows.

5.1.5 Inconvenience

Replacing infrastructure is almost inherently accompanied with inconvenience to residents. Each time a street is excavated, houses and shops become hardly accessible. The more excavations take place in a short period, the more inconvenience is experienced by residents. According to Jung and Sinha (2007) excavations can lead to different forms of inconvenience to the public: traffic congestion, passing delays, interruption of local business, interruption of other existing utilities and an increased chance on road accidents. The inconvenience of excavations necessary for replacements may negatively influence the reputation of Essent Netwerk from both customer's and municipalities' view.

Since municipalities seem to increasingly interfere with network operators' activities in the underground and since they have the authority to set new rules and constraints, Essent Netwerk has a certain interest in keeping municipalities content. Moreover, since it is seen as a goal of long-term network operation to maximize reputation, Essent Netwerk should try to minimize inconvenience as much as possible. The inconvenience caused by replacements is a soft factor and difficult to measure. It is expected however that when combining replacements prevents returning multiple times in a relatively short period, residents experience less inconvenience of the replacements.

5.2 Combined replacement options

The scope of this research is demarcated to the gas service lines, low voltage electricity service cables, gas mainlines and low voltage main cables of Essent Netwerk. Multiple possible combinations exist when considering combined replacement of these asset types.

Currently, especially the gas assets of Essent Netwerk are nearing their replacement moments. When Essent Netwerk is confronted with aged gas service lines its current approach would only focus on these gas service lines; the alternative approach however would for instance consider taking along the replacement of the electricity service cables at that same location. It might also consider possibilities of taking along the replacement of the gas mainline in that street or even to trench the whole street and to replace all the present gas and electricity infrastructure at once.

To find out whether and when the combining replacement of multiple asset types might be a better option than separately replace assets, the most relevant combination options are considered in this research. Considering the four asset types demarcated for this research and the fact that the gas assets need replacement first, the following combined replacement options appear most relevant to investigate (Berg 2007):

1. Combined replacement of gas service lines and electricity service cables
2. Combined replacement of gas mainlines and electricity main cables
3. Combined replacement of gas service lines and gas mainlines
4. Combined replacement of all four asset types

To determine the potential of combined replacement each of the above combined replacements is compared to separately replacing these asset types, such as presented in figure 17.

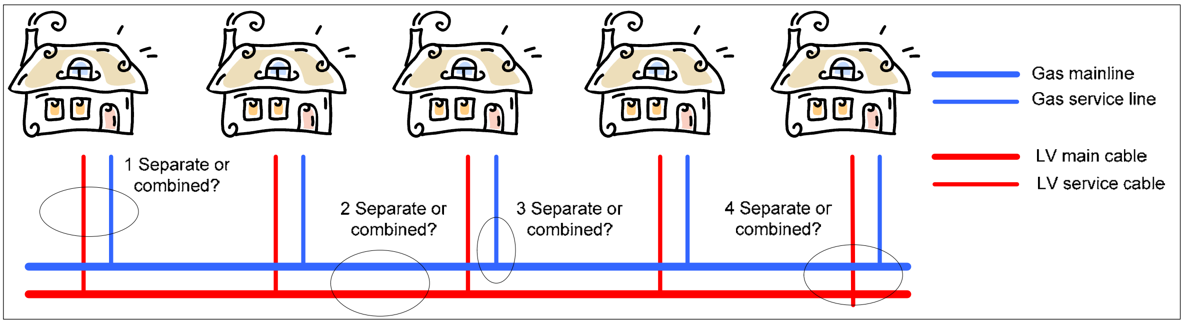


Figure 17 Combination options to be evaluated with the calculation model.

For instance, *combined* replacement of gas service lines and electricity service cables is thus compared with *separate* replacement of gas service lines and electricity service cables in a street.

In reality, even more combinations might exist, such as combined replacement of the LV main cable and the LV service cables. However, to research the potential of combined replacements, only the above presented combination options are evaluated.

It is assumed that combined replacement takes place at the optimal replacement moment of the asset type that needs replacement first. Since, as said, the gas assets of Essent Netwerk generally need replacement earlier than the electricity assets, the combination options are considered such that the gas asset initiates the combined replacement, meaning that either an aged gas service line or an ages gas mainline initiates combined replacement. With regard to the combination option of gas service lines and the gas mainline, either the former or the latter can initiate combined replacement.

5.3 Method

To calculate if for the combined replacement options combined or separate replacement is better; the overall value of combined and separate replacement on the performance indicators should be determined and compared. This section presents the method that is used.

To compare the overall effects of combined and separate replacement on the performance indicators, five cases are selected. Each case comprises a street and for each street the replacement of asset types is considered according to the above presented four combination options. To determine the effects of combined and separate replacement a part of the effects is quantitatively evaluated and another part qualitatively.

5.3.1 Quantitative or qualitative analysis

Decision-making on network operation should be such that it maximally fulfils all goals and constraints of long-term network operation. However, the goals and constraints might be conflicting. In its decision-making Essent Netwerk expresses the effects of available alternatives on the company values (e.g. the goals and constraints) in monetary equivalents and chooses the alternative with the highest overall monetary value (e.g. the lowest total costs) (Jager, 2007a). This approach consequently assumes equal importance of all company values and provides to make balanced choices when goals conflict.
This research adopts a quite similar approach to that of Essent Netwerk; It expresses the presented indicators 'replacement costs', 'digging incidents' and 'customer minutes lost' in costs and thereby assumes that either combined or separate replacement is the best option considered from the cost and reliability goal when it results in the lowest overall costs.

Essent Netwerk also expresses the effects on its company values 'Compliancy' and 'Reputation' in costs, by using frequency and effect categories for these values and by having a resembling cost category for each effect category (Jager, 2007a). However, this research chooses to not express 'compliance with municipal rules' and 'inconvenience' in costs, but qualitatively discusses the effects of combined and separate replacement on these indicators. With regard to inconvenience, the reason is that there is too little experience on the inconvenience effects of separately replacing assets within a short time, because of the newness of the replacement issue. Since therefore it is hard to come up with reasonable cost effects for the inconvenience caused per replacement activity in a street, this research chooses to qualitatively consider this reputation indicator. For compliance, the reason is that it is considered a constraint and the compliance for

such individual replacement activities is easy to see; Essent Netwerk either is compliant with the 'no-dig period' with its separate replacements or it is not.
When during the development of decision criteria it turns out that effects on the inconvenience indicator prescribe another direction than the effects on the monetary expressed indicators (e.g. when they conflict), a reasonable decision should be made.

5.3.2 Quantitative analysis method

To calculate whether combined replacement is a better option than separate replacement based on the overall effects on the monetary expressed performance indicators, the cost advantage of combined replacement is determined by comparing the total costs of the combined and the separate replacement alternative:

Combination advantage =

Total Costs $COMBI_{XY}$ – (Total Costs of SEP_X and SEP_Y)

In which:

X =	the asset type that initiates the combined replacement, thus the asset type that needs replacement earliest
Y =	the asset type that needs replacement later in time and that with combined replacement is replaced before its optimal replacement moment
Total Costs $COMBI_{XY}$ =	total costs of combined replacement of asset type X and asset type Y
Total Costs of SEP_X and SEP_Y =	total costs of separate replacement of X and separate replacement of Y

Combined replacement is considered a better option than separate replacement when the combination advantage turns out positive. The formula is now explained in more detail.

<u>Total Costs $COMBI_{XY}$</u>

Total Costs $COMBI_{XY}$ =

Replacement costs $COMBI_{XY}$ + Costs CML $COMBI_{XY}$ + Digging incident costs $COMBI_{XY}$

- **Replacement costs $COMBI_{XY}$ =** Total replacement costs of combined replacement of asset type X and asset type Y. The replacement costs are the total sum of:
  - Digging costs = (Digging costs per m. or # asset type X in case of combined replacement * m. or # asset type X) + (Digging costs per m. or # asset type Y in case of combined replacement * m. or # asset type Y)
  - Assembly costs = (Assembly costs per m. or # asset type X in case of combined replacement * m. or # asset type X) + (Assembly costs per m. or # asset type Y in case of combined replacement * m. or # asset type Y)
  - Street restoration costs = (Street restoration costs per m. or # asset type X in case of combined replacement * m. or # asset type X) + (Street restoration costs per m. or # asset type Y in case of combined replacement * m. or # asset type Y)

    - Material costs = (Material costs asset type X m. or # asset * m. or # asset) + (Material costs asset type Y per m. or # asset * m. or # asset)
- **Costs CML COMBI$_{XY}$ =** Total costs of customer minutes lost of combined replacement of asset type X and asset type Y. These are determined by:
    - Probability of interruptions per digging incident * probability of digging incident per m. of ground excavated * length of ground excavated * costs per customer minute lost
- **Digging incident costs COMBI$_{XY}$ =** Total costs digging incident costs combined replacement of asset type X and asset type Y. These are determined by:
    - Probability of digging incidents per m. of ground excavated* length of ground excavated * damage costs per digging incident

The replacement costs contractors charge can be charged per meter of asset or per piece. Therefore either the length of an asset or the number of assets should be used in the above formulas (thus either m. or #). The digging and street restoration costs were said to be determined by the amount of ground excavated. Since the digging and street restoration costs are charged per m. or # of asset, in the formulas this amount of ground excavated is assumed to be similar to the length of a certain asset.

<u>Total Costs of SEPx and Costs SEPy – including the time value of money</u>

To determine the total costs of separate replacement, it should be taken into account that the investment in the replacement of X and the replacement of Y takes place at two separate moments in time; namely each at its own optimal replacement age. The optimal replacement age presents the economically optimal moment for replacement of assets. When asset types are replaced separately it is assumed that they are replaced at their optimal replacement age. Most of the asset types have different optimal replacement ages. As it is assumed that combined replacement is initiated by the asset types that needs replacement first and takes place at his optimal replacement moment, it implies that when asset type X and asset type Y are replaced together one of these asset types is replaced before its optimal replacement age. Imagine now that the optimal replacement age of asset type X is such that it needs replacement in 2007 and that the optimal replacement age of asset type Y is such that it needs replacement in 2013. With combined replacement there is one investment, in 2007. With separate replacement there are two investments, one in 2007 and one in 2013, as shown in figure 18.

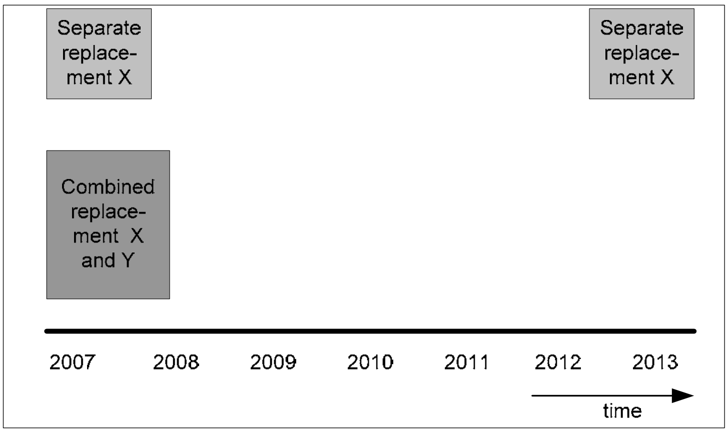


Figure 18 One combined replacement in 2007 or two separate replacements in 2007 and 2013.

To find out whether it is cheaper to combine the replacement of these asset types in 2007 or to execute the replacement of asset type X in 2007 and of asset type Y in 2013, the costs of combined replacement of X and

Y in 2007 should be compared with the total costs of separate replacement of asset type X in 2007 and asset type Y in 2013.

Total Costs SEPx and Costs SEPy – Present Value

With separate replacement, the two investments do not take place in the same year but the investment of the replacement of asset type Y is later. Simply summing up the costs of separate replacement of X and the costs of separate replacement of Y and compare these costs with the costs of combined replacement of X and Y is consequently not possible, since money in 2007 does not have the same value in 2013. Therefore, the value of the investment that would actually be done in 2013 needs to be calculated for 2007; this is called the present value or discounted value of the investment in 2007. Thus:

$$\textbf{Total costs } SEP_X \textbf{ and } SEP_y = \textbf{Costs } SEP_x \textbf{ at tx + Present value at tx of Costs } SEP_y$$

And:

$$\textbf{Present value at tx of Costs } SEP_y = (\textbf{Costs } SEP_Y)/\ (1+r)^{\wedge(tx - ty)}$$

In which:

r = the real interest percentage

tx = optimal replacement moment of asset type X

ty = optimal replacement moment of asset type Y

This method is based on the method to calculate the present value of an amount: $PV = A/(1+r)^n$, in which *A* is the amount to be discounted over *n* years with a discount rate of *r* (Boer et al., 2001). It thus provides a way to calculate the present value of costs to be made in the future. By assuming a certain discount rate the present costs of a future investment can be calculated when it is known when that investment actually takes place. It thus provides a way to calculate the present total costs of a separate replacement done now and a separate replacement that is done in the future. This present value is then compared to the costs of the combined replacement that takes place now. The interest rate used is mostly the weighted average cost of capital corrected for inflation. The interest rate used in this research is 4.5% according to the interest rate Essent Netwerk uses in her calculations.

Since with combined replacement there is one investment at one moment in time for X and Y and with separate replacement there is one investment now for X and one later for Y, the amount spent with combined replacement on the part for Y gets relatively higher when the difference between the moment of combined replacement and that of the actual separate replacement of Y becomes larger. The above implies that the total present value of the separate replacement investment decreases when the difference in optimal replacement moments increase and that thus separate replacement remains a relatively cheaper option when optimal replacement moments diverge too much.

The optimal replacement moment is determined by:

Optimal replacement moment asset type X = construction year asset type X + optimal replacement age asset type X

The Costs SEP_x and Cost SEP_y are calculated in a similar way as the Total Costs COMBIXY, but then respectively only for X or Y (See Appendix 5B).

5.4 Construction of calculation model

The formulas presented in paragraph 5.3 are translated into an Excel calculation model. The model calculates the combination advantage by comparing the costs of separate replacement of asset types and the costs of combined replacement of these asset types. This section presents the specification of the external factors which influence the obtainable combination advantage and it discusses assumptions made. These external factors can be seen as the input parameters of the calculation model.

5.4.1 Specification of input parameters

5.4.1.2 Constant parameters

The values of the below presented parameters are identical in all cases.

Digging incident probability and damage costs per digging incident

More digging activities lead to more digging incidents as became clear in 5.1. These might both be incidents to own infrastructure and to infrastructure of other network operators.

Since Essent Netwerk has no detailed information on damage to other infrastructures, both literature was consulted and an expert interview was conducted to find the probability of a digging incident.

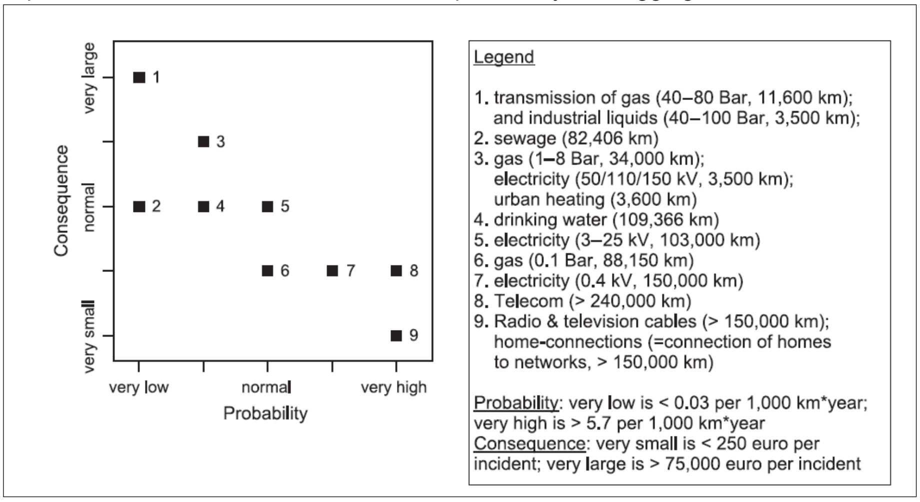


Figure 19 Digging incident probability and digging incident effects. (Oort et al., 2007).

Most of the relevant literature only gives data on the absolute number of digging incidents that occurs per year or only provides probabilities that one single asset type is hit. A research report by Pauwels and Wieleman (2004) presents qualitative information on digging incidents for all types of utilities. It assumes certain probabilities of a digging incident occurring per km. of cable or line for different asset type.

Moreover it assumes average amounts of damage costs per asset type. According to an expert interview, this information probably gives the best estimation possible (Oort, 2007b). Therefore it is decided to calculate the probability of a digging incident based on the information from the research by Pauwels and Wieleman. Based on this information the following probabilities and damage costs are calculated:

	Service cables/lines	Main cables/lines
Average probability of digging incident (per km. of ground excavated)	**0.37**	**0.04**
Average costs per incident (Euros)	**92.46**	**630.35**

Table 4 Probability of a digging incident per km. excavation and average damage costs per digging incident. (Based on Pauwels and Wieleman (2004) and Oort, (2007b)).

These probabilities are used in the remainder of this research to calculate the total digging incident cost; they are considered constant factors. The detailed calculations are presented in Appendix 5B.

Interruption probability per digging incident to electricity infrastructure, Customer minutes lost per interruption and Costs per customer minute lost

A digging incident to a LV main or service cable always leads to an outage, which makes the interruption probability 1 (Bakker, 2006b). Each digging incident to either a LV main or service cable results in an outage of 10 households with an average duration of 130 minutes, which makes the total customer minutes lost per digging incident 1,300 (Bakker, 2006b). It should be noted that the effect of an interruption is relatively small here; for a MV transportation cable, an interruption leads to 180,000 customer minutes lost. A second note is that only outages occurring during digging activities are considered. In reality a digging incident might not lead to an outage directly, but only after some weeks or months. Its effects are then larger since streets that were obviously already restored need to be excavated again. The customer minutes lost per outage and the costs per customer minute lost are considered constant factors in this research:

- Outage probability per digging incident = 1 (Bakker, 2006b)
- Customer minute lost per outage (minutes/outage) = 1,300 customer minutes lost (Bakker, 2006b)
- Costs per customer minute lost (costs/cml) = € 0.50 per cml (Bakker, 2006b)

5.4.1.2 Variable parameters

The values of the following parameters are situation-dependent (e.g. they depend on street characteristics, asset types, combination option, etc.), and below a description follows of how they are derived.

Digging costs/ assembly costs per meter or piece of asset (costs/m or costs/#)

The digging and assembly costs of replacing assets are taken as one in the calculation model, since contractors mainly calculate these costs in clustered price packages (Essent Netwerk B.V., 2006c). The digging/assembly costs consist of multiple cost components. The composition of the digging/assembly costs differs per asset type and per combination option (Aarssen, 2007). They are derived based on interviews with Essent Netwerk staff and on the contractors' tariff manual, valid in the provinces of Brabant and Limburg (Essent Netwerk B.V., 2006c). Tariffs in other provinces might differ from these, but differences are slight (Siegersma, 2007). The tariffs from the tariff manual are tariffs charged for individual operations. However, since no information was available on prices charged for project work, since these are separately boarded out per project, and since the individual tariffs are assumed to give a tolerably view according to Siegersma (2007), these tariffs are used in this research. The cost composition is presented in Appendix 5C.

Street restoration costs per meter or piece of asset (costs//m or costs/#):

The street restoration costs consist of two components:

- Street restoration costs charged by contractors: After closing the trenches, contractors need to recover the streets. The costs charged by the contractor differ per pavement type.
- Remuneration costs charged by municipalities: Besides the costs that are charged by contractors, municipalities also charge remuneration costs when contractors execute digging activities. These costs are composed of degeneration costs, costs for street restoration, maintenance costs and monitoring costs (VNG, 2004). The remuneration costs charged by municipalities are dependent on amongst others pavement type and soil type (VNG, 2004).

For this research, contractor costs are obtained from the tariff manual and the remuneration costs municipalities charge are obtained from the 'paving restoration document' that give total remuneration costs per pavement type. Two types of pavement are considered; normal bricks and paving stones and decorated pavement. The precise cost composition of the remuneration costs charged by municipalities depends on the agreements between contractors and municipalities. For this research some fixed amounts were assumed. More detailed information and assumptions on the street restoration costs are found in Appendix 5C.

Material costs per meter or piece of asset (costs/m or costs/#):

The material costs relevant for this research are derived from the SAP database, with help of interviews with Essent Netwerk staff. The material costs charged differ per asset type. For gas service lines the material costs are charged per service line and some different cost categories exist dependent on the length of the gas service line.

The digging/assembly and material costs thus differ per asset type; e.g. the cost for digging a trench and assembling for a gas service line are different from that of an electricity cable. Moreover, the material costs for a gas service line and electricity cable are different. As said, within an asset type different sub types exist; the one sub type can differ from the other in the material used. However, since the current policy of Essent Netwerk is that new assets of a certain asset type are all made of the same material (e.g. all new service lines are all made of 'pvc') the digging/assembly and material costs for a certain asset type are all depicted for one specific type of material (e.g. for the material costs of the new gas service lines the material costs for 'pvc' is used).

The assets of a certain asset type can also vary somewhat in their diameter and the charged digging/assembly and material costs actually also depend somehow on this diameter. However, these differences are slight. In the cases that are considered in the next chapter, the assets of a certain asset type constantly have the same diameter in all cases. Therefore only one type of diameter is assumed in this research. This makes that the digging/assembly costs (per m. or #) only differ per asset type and combination option and that the material costs only differ per asset type.

Moreover, in this research it is assumed that on the short term the above costs are not subject to market developments and that consequently these costs are stable over the coming years.

The length of ground excavated (m) / the length of assets (m)

The length of ground excavated determines the total digging incidents costs and costs for customer minutes lost. The length of ground excavated is assumed to equal the length of the asset type to be replaced. Thus the length of a trench excavated for the replacement of a gas service line equals the length of the gas service line. For combined replacement of assets located in one trench, the ground excavated obviously equals the length of only one of the assets.

For determining the digging/assembly and street restoration costs also the length of assets is taken. This is reasonable since contractors charge digging/assembly costs and street restoration costs per meter of asset type.

The lengths of asset types are derived from the Geoversum database, a database that comprises information on the location and characteristics of the infrastructure of Essent Netwerk.

The number of assets (#)

Material costs and digging/assembly costs for gas service lines are charged per number of gas service lines. The digging/assembly costs for the LV service cables are charged as well per LV service cable. Therefore the number of gas service lines and LV service cables is needed. Moreover the number of gas service lines and LV service cables are necessary to calculate the remuneration costs that municipalities charge.

Construction year

The construction year of asset types is needed to determine the optimal replacement moment. The construction year is derived from the Geoversum database. Not all data on construction years of asset types is available, since registration of asset type information has not always been complete in the past. For instance, the construction year of LV main cables is not available in most situations. Therefore it is assumed that the construction year of the LV main cable is similar to that of the LV service cable, which is reasonable since they were mostly constructed at the same moment.

Optimal replacement age

The optimal replacement age is considered the economically optimal age of an asset to replace it, considering the costs of preventive replacement and the risks of not replacing an asset at that age. Chapter 2 described that replacement strategies and tactics determine optimal replacement ages of asset types and sub types. It also explains that currently these strategies and tactics are only available for the gas service lines. However, to be able to make calculations the optimal replacement age is needed. After all, those optimal replacement ages show when an asset type needs to be replaced.

The long-term optimization report roughly determined optimal replacement ages for asset types and subtypes. These optimal replacement ages are used in the calculation model for the assets to be replaced. Since these are roughly determined optimal replacement ages, they could diverge from the real optimal replacement ages; for the many different existing asset sub types the size of the asset, the material used or other specific characteristics like the soil type may all implicate different best moments to replace. For electricity cables for instance the long-term optimization report distinguishes two types, 'gplk' and 'alkudi' and assumes 94 as the optimal replacement age for 'gplk' cables. Since many electricity cables that were constructed in the 1960s and 1970s are 'gplk' cables and are thus considered in the cases, they all have an optimal replacement age of 94, while in reality within the 'gplk' cables differences exist which make some of them need replacement earlier or later. Moreover, the long-term optimal replacement research does not distinguish between different gas service line subtypes and thus only provides one optimal replacement age for gas service lines, while in reality perhaps these ages might diverge for different sub types.
Despite the differences that in reality might exist in the replacement moments of the many different subtypes, the optimal replacement ages determined by the long-term optimization research give a reasonable approximation (Wijnia, 2007). The optimal replacement ages are presented in Appendix 5B.

Per combination option and its separate antithesis above factors will be specified for each case. Together they form the input parameters for the calculation model. An example of a set of input parameters for one of the cases is presented in Appendix 5D.

5.4.2 Assumptions in calculation model

The following additional assumptions are made in constructing the model:

- The costs for street restoration in case of combined replacement of assets located in a same trench are based on the costs for restoration of the widest trench in case of single replacement of one of these assets.
- When the connections and the main net are replaced simultaneously conversion costs for converting the connections to the mains are only charged once.
- With combined replacement of connected asset types (connections and the main net) as considered in choices 3 and 4, it is assumed that in total 25% less ground needs to be

excavated than with separate replacement and that consequently also 25% less pavement needs restoration. This implies that with calculating digging/assembly, street restoration, digging incident and customer minutes lost cost, a 25% reduction of costs is applied. With regard to the combined replacement of all asset types together also less ground is excavated and a smaller part of pavement needs restoration than when all asset types are separately replaced. Here it is assumed that the same amount of ground is excavated as with combined replacement of gas service lines and gas mainline.

- The model considers the first necessary replacement of an asset type; it does not consider the lifecycle and investments of following replacements of that asset type in the future. Because of the relatively large lifetimes of assets, incorporating these future replacements would have only marginal effects on the outcomes.
- Combined replacement takes place at the optimal replacement moment of the asset type that needs replacement first.
- Separate replacement of an asset type takes place at the optimal replacement moment of that asset type.

5.5 Conclusions

This chapter presented the factors that influence the performance indicators and it showed how to calculate the overall value of the monetary expressible performance indicators. Moreover, it discussed the influence on the qualitatively expressed performance indicators.

The discussion on the influence of the various factors on the performance indicators implies that combined replacement results into lower total digging/assembly costs, lower total street restoration costs, lower digging incident costs and lower costs for customer minutes lost. Moreover, from the description of the influence of the difference in optimal replacement moments in 5.3 it is expected that when these moments diverge too much, the benefits might be lost and separate replacement remains the cheapest option. With the constructed calculation model that is able to calculate the overall combination advantages, this is investigated in the next chapter.

6. Evaluating the current and alternative approach: combined versus separate replacement

This chapter aims to show whether combined replacement can result into lower overall costs than separate replacement and, if it can be a more favorable option based on the compliance constraint and reputation effects. Moreover, it aims to show *when* combined replacement is more favorable.

Section 1 first presents the cases for which combined and separate replacement are evaluated and it shows the combination advantages obtained for these cases. Section 2 presents an analysis of the results of the cases; it shows why results vary and how input parameters influence the obtained combination advantages. Based on these findings, section 3 comes up with the quantitative decision criteria that prescribe when to combine replacements. Section 4 reflects these decision criteria on the total asset population of the concerned asset types and based thereon discusses the potential of combined replacement in practice. Section 5 presents the qualitative evaluation in which it is discussed if combined replacement can lead to better results with regard to 'compliance with municipal rules' and 'inconvenience' effects and it derives the qualitative decision criteria. The last section presents the conclusions; it concludes on the need to adopt the new approach, it shows a decision guideline that is derived from the decision criteria and it discusses the value of the constructed calculation model.

6.1 Combined or separate replacement: 5 cases

For the mentioned combination options, the choice for combined or separate replacement is evaluated for 5 cases. Each case comprises a street in the Western part of the province of Noord-Brabant. The selection of these cases aims to obtain cases that are all somehow different from each other, e.g. the set of input parameters was different for each case. By selecting cases with different characteristics and by the external validation by varying the input parameters, the findings are assumed to be representative for a broader range of cases (Yin, 1994).

This section describes each case and it presents the calculated combination advantage for each combination option in each case. Thereafter, in 6.2, the values of the input parameters are varied for each case as to see what the influence is of these input parameters on the obtainable combination advantage.

6.1.1 Cases

The considered streets, the asset types that are located in the streets and further characteristics of the streets, are derived from the Geoversum database. The cases are presented below and the following additional assumptions hold for all of them:

- The gas service lines gas and LV service cables are located in the same trench.
- The gas mainlines and the LV main cables are located in the same trench.
- The length of service cables and service lines are based on the real situation, but an average is considered for both the cables as the lines when in reality a difference exists.
- All assets of one asset type are constructed in the same year and of the same material; in reality some variety might exist in some situations (e.g. it might be that one of the gas service lines in a street is constructed of different material than the others since it had already been replaced before due to whatever reason) but homogeneity is assumed for the cases.
- Combined replacement of gas service lines and gas mainline can be done uninterrupted and in a short time, so that no extra unavailability of service is caused.

- The paving in cases 1, 2, 4 and 5 consist of normal bricks and paving stones. The paving in case 3 is assumed to be decorated.

6.1.1.1 Case 1: Esdoornstraat, Bergen op Zoom

The Esdoornstraat is a street located in a densely populated residential area in Bergen op Zoom, just out of the city centre. The energy infrastructure is old and all constructed in 1953. The gas and electricity infrastructure is located on both sides of the street. Since the asset types are all located in the same year and since the asset types diverge much in optimal replacement ages, the optimal replacement moments of the asset types diverge much as well; especially between the gas service line and the electricity service cable.

name	Esdoornstraat			
city	Bergen op Zoom			
asset type to be replaced	serviceline gas (GS)	servicecable LV (ES)	mainline gas (GM)	maincable LV (EM)
nr. of connections	48	48		
length of connections	2	2		
length of mainnet			400	400
sub type	steel	gplk	crude iron	gplk
yr. construction	1953	1953	1953	1953
opt. repl. age	56	94	67	94
opt. repl. year	2009	2047	2020	2047
pavement type	normal bricks and paving stones			

Table 5 Input characteristics Case 1.

Figure 20 Data for the Esdoornstraat retrieved from Geoversum.

6.1.1.2 Case 2: Ratelaarstraat, Bergen op Zoom

The infrastructure in the Ratelaarstraat has, unlike the previous case not all been constructed in the same year; this makes the optimal replacement moments of the asset types and the differences in optimal replacement moments diverge from those in the first case. The gas service lines are namely already replaced before, in 1979. Furthermore, the length of the connections and of the main net differs from that in the first case.

name	Ratelaarstraat			
city	Bergen op Zoom			
asset type to be replaced	serviceline gas (GS)	servicecable LV (ES)	mainline gas (GM)	maincable LV (EM)
nr. of connections	30	30		
length of connections	3	3		
length of mainnet			320	320
sub type	PE	gplk	crude iron	gplk
yr. construction	1979	1954	1954	1954
opt. repl. age	56	94	67	94
opt. repl. year	2035	2048	2021	2048
pavement type	normal bricks and paving stones			

Table 6 Input characteristics case 2.

6.1.1.3 Case 3: Fictive street with decoration pavement, Breda

Case 3 is a street with decorated pavement, situated in Breda. Decorated pavement is more expensive than normal pavement; the restoration costs charged by contractors and the remuneration costs charged by the municipality are therefore higher as compared to the other cases. The gas and electricity infrastructure is constructed respectively in 1960 and 1970. The electricity cables are aluminum cables, a material used for cables since around 1970. Their optimal replacement age is much shorter than of the electricity cables in the previous cases and therefore the difference in optimal replacement moments of the gas and electricity asset types is smaller.

name city	Fictive street Breda			
asset type to be replaced	serviceline gas (GS)	servicecable LV (ES)	mainline gas (GM)	maincable LV (EM)
nr. of connections	40	40		
length of connections	3	3		
length of mainnet			320	320
sub type	steel	alkudi	steel	alkudi
yr. construction	1960	1970	1960	1970
opt. repl. age	56	51	50	51
opt. repl. year	2016	2021	2010	2021
type of pavement	decoration bricks and paving stones			

Table 7 Input characteristics case 3.

6.1.1.4 Case 4: Dr. Ensinkstraat, Halsteren

Typical for the Dr. Ensinkstraat are its steel gas mainlines. Steel gas mainlines have a relatively short lifetime and therefore their optimal replacement age is shorter then of the other types of mainlines. Another characteristic of this street is that the service lines and cables are longer than those in the previous cases.

name city	Dr. Ensinkstraat Halsteren			
asset type to be replaced	serviceline gas (GS)	servicecable LV (ES)	mainline gas (GM)	maincable LV (EM)
nr. of connections	35	35		
length of connections	5	5		
length of mainnet			300	300
sub type	steel	gplk	steel	gplk
yr. construction	1967	1961	1967	1961
opt. repl. age	56	94	50	94
opt. repl. year	2023	2055	2017	2055
type of pavement	normal bricks and paving stones			

Table 8 Input characteristics case 4.

6.1.1.5 Case 5: J. Israelstraat, Roosendaal

Oppositely to the previous cases there is one gas mainline and one LV main cable located in the middle of this street, e.g. the net is single-sided instead of double-sided. This also implies that the gas service lines and the LV service cables are longer and that there are more connections per meter of main line or cable.

name city	J. Israelstraat Roosendaal			
asset type to be replaced	serviceline gas (GS)	servicecable LV (ES)	mainline gas (GM)	maincable LV (EM)
nr. of connections	39	39		
length of connections	7,5	7,5		
length of mainnet			205	205
sub type	steel	gplk	crude iron	gplk
yr. construction	1959	1959	1959	1959
opt. repl. age	56	94	67	94
opt. repl. year	2015	2053	2026	2053
type of pavement	normal bricks and paving stones			

Table 9 Input characteristics case 5.

In the presentation and discussion of the obtained results of the cases, the asset types and combination options are referred to as follows:

GS = gas service line

ES = LV service cable

GM = gas mainline

EM = LV main cable

Combination options are referred to as **GS-GM, GS-ES**, etc.

6.1.2 Quantitative results of cases

As table 10 shows, the obtained combination advantages differ throughout the cases. For some combination options the combination advantage turns out positive, implying that combined replacement is a cheaper option there, while for others separate replacement appears to remain the cheapest option.

Case 1				
	GS-GM	**GS-GE**	**GM-EM**	**all**
Separate	38.498	26.565	32.029	46.301
Combined	37.625	37.084	32.726	54.151
Comb. Advantage(%)	*2.3*	*-39.6*	*-2.2*	*-17.0*
Case 2				
	GS-GM	**GS-GE**	**GM-EM**	**all**
Separate	27.887	22.522	24.866	37.027
Combined	27.269	23.968	25.074	38.392
Comb. Advantage(%)	*2.2*	*-6.4*	*-0.8*	*-3.7*
Case 3				
	GS-GM	**GS-GE**	**GM-EM**	**all**
Separate	44.287	38.162	39.419	72.404
Combined	38.750	34.103	33.960	52.518
Comb. Advantage(%)	*12.5*	*10.6*	*13.9*	*27.5*
Case 4				
	GS-GM	**GS-ES**	**GM-EM**	**all**
Separate	33.854	23.380	22.191	40.145
Combined	29.811	29.808	24.562	42.248
Comb. Advantage(%)	*11.9*	*-27.5*	*-10.7*	*-5.2*
Case 5				
	GS-GM	**GS-ES**	**GM-EM**	**all**
Separate	32.558	27.745	18.173	38.943
Combined	29.306	35.784	19.217	42.181
Comb. Advantage(%)	*10.0*	*-29.0*	*-5.7*	*-8.3*

Table 10 Combination advantages, expressed in percentages. The minus sign indicates that combined replacement is more expensive than separate replacement.

It was expected that combined replacement results in decreased total digging/assembly costs, street restoration costs, digging incidents and customer minutes lost as compared to separate replacement, but that the advancement of the replacement of one of the asset types might take away these savings. The reduction in digging/assembly costs, street restoration costs and digging incidents and customer minutes lost that can be obtained by combining replacements differ per combination option; for some, savings can for instance mainly be obtained by the reduced costs for excavation while with others savings are obtained by the fewer required conversions.

A breakdown and analysis of the savings that can be obtained by combining replacements is presented in appendix 6A for each case and combination option. The appendix shows that the obtainable savings in digging/assembly and street restoration costs are substantial with combined replacement. It also shows that

digging incidents costs and costs of customer minutes lost are indeed lower with combined replacement, but that since their small contribution to the total costs, their relative effects are nil.
The real savings, e.g. the real combination advantage of a combination option is also affected by how many years an asset type is replaced before its optimal replacement moment. When it is replaced too early because the optimal replacement moments of the asset types diverge too much, the savings in digging costs and street restoration costs are lost and separate replacement will turn out cheaper. The next section further elaborates on this and on the effects of other input parameters.

6.2 Analysis of results and effects of parameter variation

This section discusses the potential of combined replacement based on the results of the 5 cases. The combination advantages differ per case and per combination option. As said, the optimal replacement moments of the asset types considered in the combination options influence the combination advantage. However, the values of other input parameters also influence the obtainable combination advantage. This section presents the results of an analysis of the effects of input parameter variation on the combination advantage. A detailed analysis is found in Appendix 6B, while the results are discussed in this section. The effects of variation of the following input parameters are discussed:

- Construction year
- Optimal replacement age of assets (this one and the above together determine the optimal replacement moment)
- Pavement type and the accompanying street restoration costs per meter
- Length of connections
- Length of main net, which is divided in two categories; the length when the net is located on one both sides of the street (double-sided) or when it is located in the middle of the street (single-sided)

Since it supposed that the material costs and the digging/assembly costs are fixed per asset type or combination option and since it is assumed that they are not subject to market developments, the influence of varying the values of these factors is not considered.

6.2.1 Influence of diverging optimal replacement moments on combination advantage

The optimal replacement moment, which depends on the construction year and on the optimal replacement age of an asset type, is the moment at which an asset type needs replacement. For the cases in which for a certain combination option the optimal replacement moments of asset types are close (e.g. when the asset types need replacement closely after each other), the combination advantages tend to be more positive. The relation between the difference in optimal replacement moments of the gas service lines and the gas mainline and the combination advantage for this combination option in case 1 is shown in figure 21.

In this case the gas service lines need replacement first and the blue line shows the costs of combined replacement of the gas service lines and the gas mainline at the optimal replacement moment of the gas service lines. The pink line presents, for all feasible differences in optimal replacement moments of the gas service line and mainline, the present value of the costs of the two separate replacements at the optimal replacement moment of the gas service line.
The graph shows that for this case the break-even point lies at approximately 12 years; when the optimal replacement moment of the gas mainline is within the maximum of 12 years after that of the gas service line,

it is cheaper to combine the replacements now, instead of replacing the gas mainline 12 years later. The relation between the difference in optimal replacement moments and combination advantage is strong.

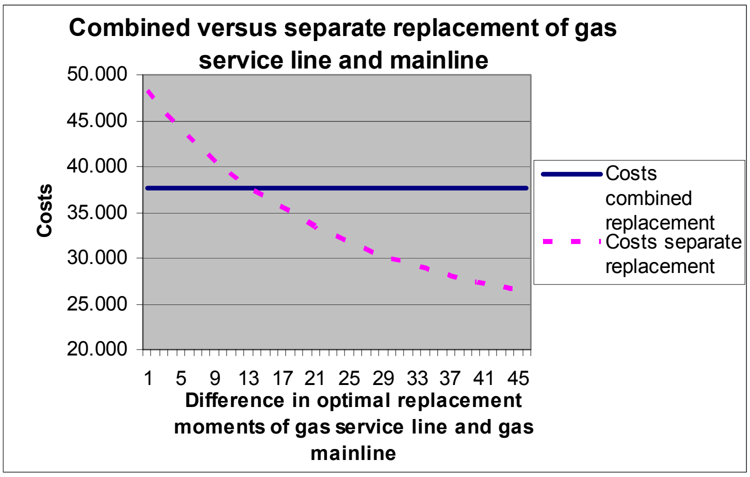


Figure 21 Combination advantage as dependent on the difference in optimal replacement moments

By considering the combination advantages for every combination option and for all feasible differences in optimal replacement moments, the break-even points are derived for all cases and concerned combination options. Results are shown in the table below.

	Break-even points at which combined replacement gets cheaper
case 1	
GS-GM	12
GS-ES	7
GM-EM	24
case 2	
GS-GM	15
GS-ES	9
GM-EM	26
case 3	
GS-GM	20
GS-ES	11
GM-EM	34
case 4	
GS-GM	13
GS-ES	11
GM-EM	24
case 5	
GS-GM	21
GS-ES	13
GM-EM	21

Table 11 Break-even points: when the difference in optimal replacement moments equals or is lower than this point, combined replacement is cheaper than separate replacement.

With regard to the combination option of all 4 asset types such a break-even point is not derived because countless combinations of differences in optimal replacements between the four asset types exist at which combined replacement of the four together is cheaper than separate replacement. This chapter elaborates on this later.

As table 11 shows, the maximal differences in optimal replacement moments at which combined replacement is cheaper than separate replacement varies per combination option and case. This implies the influence of other input parameters. Why for instance can optimal replacement moments for the combination option of gas service lines and the gas mainline diverge so much more in case 5 than in case 1? The remainder of this paragraph presents the influence of the other named input parameters on the obtainable combination advantage and the break-even points. Based on this information later on decision criteria are derived.

6.2.2 Influence of street-restoration costs on combination advantage

Case 3 has decorated pavement and therefore the street restoration costs charged by the contractor and municipality are higher than in the other cases. The combination advantage in case 3 is higher than in the other cases. One of the explanations is that the optimal replacement moments are much closer in case 3 than in the other cases. However, as table 11 shows, the optimal replacement moments can also diverge more than in the other cases for combined replacement to be cheaper. The reason is that the pavement type and the accompanied street restoration costs charged by contractors and municipalities influence the combination advantage and the break-even points.

The impact of the pavement type on the combination advantage and the break-even points is investigated by increasing the street restoration costs for those cases that have normal paving. When the pavement type in cases 1, 2, 4 and 5 is changed to decorated pavement, the combination advantages change. The effects of increased street restoration costs are shown in the tables below. Appendix 6B-1 shows a more detailed analysis.

Case 1				
	GS-GM	**GS-GE**	**GM-EM**	**All**
comb. advantage normal paving	2.3	-39.6	-2.2	-17.0
comb. advantage decorated paving	0.1	-35.6	4.7	-11.9
Case 2				
	GS-GM	**GS-GE**	**GM-EM**	**All**
comb. advantage normal paving	2.2	-6.4	-0.8	-3.7
comb. advantage decorated paving	5.9	-2.1	5.8	5.9
Case 4				
	GS-GM	**GS-GE**	**GM-EM**	**All**
comb. advantage normal paving	11.9	-27.5	-10.7	-5.2
comb. advantage decorated paving	13.5	-20.7	-3.6	-3.0
Case 5				
	GS-GM	**GS-GE**	**GM-EM**	**All**
comb. advantage normal paving	10.0	-29.0	-5.7	-8.3
comb. advantage decorated paving	9.6	-20.7	-1.5	-1.4

Table 12 Combination advantages with normal and decorated pavement

As table 12 shows, with increased street restoration costs, combined replacement gets more advantageous (or less disadvantageous) in the majority of combination options and cases. Put differently, the optimal replacement moments of the asset types can diverge more for combined replacement to be cheaper, as shown in table 13. The reason is that with combined replacement less excavation is necessary than with the total of separate replacements. Hence, when street restoration costs make up a large part of the total replacement costs, because of an expensive pavement type, the savings from combined replacement are therefore high as well.

The effects on the combination advantage for the ‘gas service line – gas mainline’ combination option in cases 1 and 5, where the gas service line needs replacement earlier than the gas mainline, however diverge from the effects on the other cases and combination options. The combination advantage of this combination option in case 1 and 5 namely *is lower* with decorated pavement than with normal pavement. The reason is that the total costs of street restoration of the trench made for the gas mainline are relatively high as compared to the street restoration costs of the trench made for the gas service lines, since more excavation is necessary for replacing the gas mainline than for replacing the gas service lines. Because in case 1 and 5 the gas service lines need replacement earlier than the mainline, the costs for separate replacement of the gas mainline need to be discounted to its present value. Since the costs for the gas mainline are relatively high as compared to the gas service line and since the street restoration costs make up a large part of the total costs, discounting the costs of the gas mainline has a large effect. Therefore with increased street restoration costs, the increase in the total discounted costs for separate replacement of the gas mainline is smaller than the increase in the total costs for separate replacement, implying that combined replacement gets relatively more expensive than separate replacement. This can consequently lead to a decrease in combination advantage.

	case 1	case 1 + decorated paving
GS-GM	12	11
GS-ES	7	9
GM-EM	24	32
	case 2	**case 2 + decorated paving**
GS-GM	15	20
GS-ES	9	11
GM-EM	26	34
	case 4	**case 4 + decorated paving**
GS-GM	13	15
GS-ES	11	14
GM-EM	24	32
	case 5	**case 5 + decorated paving**
GS-GM	21	20
GS-ES	13	18
GM-EM	21	28

Table 13 Change in break-even points with decorated paving

To conclude, combined replacement gets relatively cheaper when street restoration costs per meter are high and consequently optimal replacement moment can diverge more. However, when it concerns combined replacement of the gas mainline and service lines, initiated by the gas service line that needs replacement first, increased street restoration costs can lead to a decrease in combination advantage.

6.2.3 Influence of length of service line and service cable

The length of the gas service lines and service cables vary, dependent on where the mainline or cable is located in the street or whether the gas service lines and service cables for example go through front gardens. In case 1 the gas service lines and service cables are short, just 2 meters, while in case 5, they were 7.5 meters.

When connections are longer more digging is necessary and more paving needs to be restored, resulting in higher digging/assembly costs and higher street restoration costs. Moreover, the total material costs get higher. The analysis in Appendix 6B-1 showed that with longer connections the obtainable combination advantage for the ‘gas service lines - LV service cables’ increases.
The connection length also influences the combination advantage for the ‘gas service lines – gas mainline’ combination option. Whether it increases or decreases the combination advantage depends for this combination on which of the two asset types needs replacement first.

For case 1, the change in combination advantage for the two relevant combination options is shown when the connections are longer. Effects for the other cases are shown in the Appendix.

Case 1		
	GS-GM	**GS-GE**
comb. advantage short connections	2.3	-39.6
comb. advantage long connections	5.5	-29.0

Table 14 Combination advantage in case 1 with short and long connections.

The effect of the connection length on the break-even points is shown in table 15 for the relevant cases and combination options. As the table shows, the break-even points for combined replacement of the gas service lines and LV service cables indeed get higher in every case.

	case 1	case 1 long connections
GS-GM	12	14
GS-ES	7	13
	case 2	**case 2 long connections**
GS-GM	15	13
GS-ES	9	13
	case 3	**case 3 long connections**
GS-GM	20	13
GS-ES	11	18
	case 4	**case 4 long connections**
GS-GM	13	12
GS-ES	11	13

Table 15 Change in break-even points when gas service lines and LV service cables are long.

In case 1 the break-even point for ‘gas service lines – gas mainline’ combination option gets higher as compared to the normal situation, while in the other cases, this break-even point gets lower. This hence has to do with whether either the gas mainline or gas service line initiates the combined replacement and the unequal ratio of the separate replacement costs of these assets.

6.2.4 Influence of length of main net; double-sided or single-sided

The main net in a street is either located at both sides of a street or it is located in the middle (see figure22).

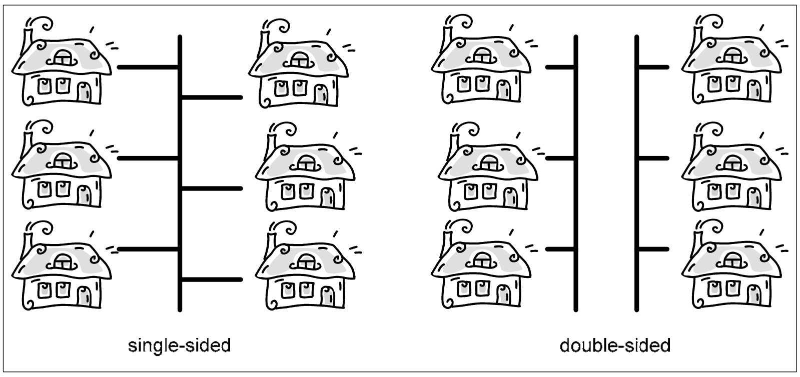


Figure 22 A single-sided and double-sided main net

In cases 1 to 4 the main net is double-sided, while in case 5 it is single-sided and located in the middle of the street. With a single-sided net the length of the mains is shorter than with a double-sided net. Analysis turned out that the configuration of the main net influences the combination advantages of the combination options 'gas service lines – gas mainlines' and 'gas mainlines – LV main cables'. When changing the configuration of the main net in case 1 from double-sided to single-sided results in changed combination advantages for these combination options, as is shown below.

Case 1		
	GS-GM	GS-GE
comb. advantage double-sided main net	2.3	-2.2
comb. advantage single sided main net	9.5	-7.8

Table 16 Combination advantage in case 1 and case 1 with single positioned mainline.

With regard to the 'gas service line – gas mainline' combination option the ratio of the separate replacement costs of the gas service line and separate replacement costs of the gas mainline changes; with a single-sided net the costs of the gas service line get relatively higher as compared to the cost for the gas mainline. Therefore, in cases where the gas service lines need replacement first (as in case 1 and 5), the combination advantage increases with a single-sided net.
Obviously, for combined replacement of the gas service line and mainline, the combination advantage and thus the break-even point decreases with a single-sided net; after all, then less digging is necessary and thus fewer savings can be obtained with combined replacement as compared to separate replacement.

Summarizing, when the gas service lines need replacement first and the gas mainline is relatively short due to the fact that it is singly positioned instead of double, combined replacement gets relatively cheaper (e.g. optimal replacement moments can diverge more). Moreover, as a double-sided net is longer, combined replacement of the gas mainline and LV main cable is more advantageous when the net is double-sided, since the saving that stem from the reduced excavations with combined replacement is larger. The influence of the length of the main net on the break-even points for all cases and combination options is found in Appendix 6B-1.

6.3 Conclusions of quantitative analysis – deriving decision criteria

The cases showed different results; combined replacement can be highly advantageous as compared to separate replacement for some options in some cases, while in others it is absolutely not. A combination option in one of the cases even led to an advantage of almost 30%, while in another case a disadvantage of 30% was obtained.

The analysis showed that the question whether combined replacement is cheaper than separate replacement mainly depends on the advancement of a certain replacement caused by the difference in optimal replacement moments, the pavement type, the connection length and the configuration of the main net.

In addition, the conducted analysis also showed that the obtainable combination advantage and the influence of input parameters vary per combination option. For the combination option of the gas service line and gas mainline it also depends on which of the two initiates the combined replacement, while this distinction is not made for the combination options that concern a gas and electricity asset, since this research only considered cases where the gas assets need replacement first. It was found that for each combination option and case a break-even point can be derived; this is a maximal difference in replacement moments of asset types at which combined replacement of these asset types always is cheaper than separate replacement. Analysis showed that in certain circumstances optimal replacement moments can diverge even more than these break-even points. This for instance holds for certain combination options when the street restoration costs are high due to expensive paving as decorated paving, as was for instance the case in case 3. Or for instance when the connections are long and it concerns combined replacement of gas service lines and LV service cables or gas service lines and gas mainlines and gas service need replacement first, as was the case in case 5.

Based on the 5 researched cases and the input parameter variation, break-even points can be determined at which combined *always* is cheaper (see Appendix 6B-2). These can be used as quantitative decision criteria. Because of the limited dataset, it is chosen to derive decision criteria such that they form a *secure lower limit*. This is done by first considering for each combination option the conditions under which combined replacement is least favorable and then choosing the smallest break-even point found throughout the different cases. Thereafter, for each combination option the parameter value is changed each time to a value that would be more favorable for that combination option and then again the smallest found break-even point throughout the cases is taken. Since the below decision criteria are considered secure lower limits they can be very generally applied; they are expected to be valid in all situations somehow similar to the tested situations and under the assumptions mentioned, which thus comprises:

- The demarcated system part such as indicated in chapter 2.
- Streets with paving that is either normal or decorated or of a price category in between.
- Streets with row houses or streets with a limited space between houses; which is already somehow guaranteed by the demarcation to infrastructure elements in densely populated areas.
- Streets with gas service lines and LV service cables with a maximum length of 16 m.; which is already somehow guaranteed by the demarcation to infrastructure elements in densely populated areas.
- Situations where one of the gas assets initiates possibilities for combined replacement.

The quantitative decision criteria are:

- **Combination option GS-ES (Gas service line – LV service cable):**
    - Always combine replacement of gas service line and LV service cable when LV service cable needs replacement within 7 years after the gas service line.
    - When street restoration costs are high, always combine replacement when LV service cable needs replacement within 9 years after gas service line.
    - When connections are long (=>7.5 m.) always combine replacement when LV service cable needs replacement within 13 years after gas service line.
    - When both connections are long and street restoration costs are high, always combine replacement when LV service cable needs replacement within 18 years after gas service line.
- **Combination option GM-EM (Gas mainline – LV main cable):**
    - Always combine replacement of gas mainline and LV main cable when LV main cable needs replacement within 19 years after gas mainline.
    - When the net is double-sided combined replacement gets more advantageous; always combine replacement then when LV main cable needs replacement within 24 years after gas mainline.

- Combined replacement of gas mainline and LV main cable gets more advantageous when street restoration cost charged per meter are high; in this case always combine replacement when LV main cable needs replacement within 25 years after gas mainline.
- When the net is double-sided and the street restoration costs are high, always combine replacement when LV main cable needs replacement within 32 years after gas mainline.

- **Combination option GS-GM (Gas service line – Gas mainline):**
  - Always combine replacement when optimal replacement moments of the gas service line and gas mainline diverge 9 years or less.
  - **When the gas service lines initiates combined replacement:**
    - Longer gas service lines (=> 7.5m) make the potential for combined replacement higher: always combine replacement then when gas mainline needs replacement within 12 years after gas service line.
    - A single configuration of the main net makes the potential for combined replacement higher: when the net is single-sided always combine replacement when gas mainline needs replacement within 14 years in case of decorated paving and 16 years in case of normal paving after gas service line
    - When both the configuration of the main net is single-sided and the gas service lines are long the always combine replacement when gas mainline needs replacement within 20 years or 21 years after gas service line respectively for decorated and normal paving.
  - **When the gas mainline initiates combined replacement:**
    - High street restoration costs due to decorated paving make that optimal replacement moments can diverge a little bit more; in this case always combine replacement when gas service line needs replacement within 10 years after gas mainline.
    - When the main net is double-sided, always combine replacement when gas service line needs replacement within 12 years after gas mainline.
    - When the net is double-sided and street restoration costs are high, always combine replacements when gas service line needs replacement moments within 13 years after gas mainline.
    - When the net is double-sided, the street restoration costs are high and the connections are short (<7.5 m.) always combine replacement when gas service line needs replacement within 15 years after gas mainline.
- **All asset types:**
  - Combined replacement of all asset types together is always cheaper than separate replacement when the mutual differences in optimal replacement moments are within the above presented limits and the accompanied conditions hold.

The criteria show that replacement should be combined when asset type X needs replacement within x years after asset type Y. This means that the difference in optimal replacement moments of asset type X and Y is x years, in which that of Y is later than of X. For the gas service line – gas mainline option, the 9 year difference coincidently holds either when the gas mainline or the gas service line initiates combined replacement.

6.4 Reflection of conclusions on total asset population

The above section showed that combined replacement can be cheaper than separate replacement. In addition, it showed how much the optimal replacement moments of asset types can diverge for combined replacement of those asset types to be *always* cheaper (the break-even points). To look a little further than the cases, this section shows whether in reality it is likely that for the considered combination options the differences in optimal replacement moments are within these break-even points.

It does so based on information of the total asset population derived from databases used for the long-term optimization research. Based on calculated current average ages of the total asset population of each asset type and their optimal replacement ages, the average optimal replacement moments are determined (see Appendix 6C).

Combination options	Avg. differences in optimal replacement moments
GS-GM = Gas service line – Gas mainline; always combine replacement if difference is <= 9	
Gas service line- Gas mainline 100 mbar PE	11
Gas service line- Gas mainline 100 mbar AC	*6*
Gas service line- Gas mainline 100 mbar crude iron	*7*
Gas service line- Gas mainline 100 mbar Steel	11
Gas service line- Gas mainline 100 mbar PVC	55
Gas service line- Gas mainline 30 mbar PE	11
Gas service line- Gas mainline 30 mbar AC	11
Gas service line- Gas mainline 30 mbar crude iron	*6*
Gas service line- Gas mainline 30 mbar Steel	11
Gas service line- Gas mainline 30 mbar PVC	55
GS-ES = Gas service line – LV service cable, always combine replacement if difference is <= 7	
Gas service line – LV service cable GPLK	15
Gas service line – LV service cable alkudi	*4*
GM-ES= Gas mainline – LV main cable, always combine replacement if difference is <= 19	
Gas mainline 100 mbar PE – LV main cable GPLK	*6*
Gas mainline 100mbar AC – LV main cable GPLK	23
Gas mainline 100 mbar crude iron– LV main cable GPLK	*10*
Gas mainline 100 mbar steel – LV main cable GPLK	28
Gas mainline 100 mbar PVC – LV main cable GPLK	38
Gas mainline 30 mbar PE – LV main cable GPLK	*6*
Gas mainline 30 mbar AC – LV main cable GPLK	*6*
Gas mainline 30 mbar crude iron – LV main cable GPLK	23
Gas mainline 30 mbar steel – LV main cable GPLK	28
Gas mainline 30 mbar PVC – LV main cable GPLK	38
Gas mainline 100 mbar PE – LV main cable Alkudi	*7*
Gas mainline 100mbar AC – LV main cable Alkudi	*10*
Gas mainline 100 mbar crude iron– LV main cable Alkudi	*3*
Gas mainline 100 mbar steel – LV main cable Alkudi	*15*
Gas mainline 100 mbar PVC – LV main cable Alkudi	21
Gas mainline 30 mbar PE – LV main cable Alkudi	*7*
Gas mainline 30 mbar AC – LV main cable Alkudi	*7*
Gas mainline 30 mbar crude iron – LV main cable Alkudi	*10*
Gas mainline 30 mbar steel – LV main cable Alkudi	*15*
Gas mainline 30 mbar PVC – LV main cable Alkudi	51

Table 17 Average differences in replacement moments of total asset population for the three combination options. Combination options are shown per asset sub type.

Based on these average replacement moments the *average differences in replacement moments* for each combination option are derived. In table 17 they are shown and presented together with the smallest break-even points found for that combination option (e.g. the lower limit at which combined replacement always becomes cheaper than separate replacement). As the table shows there are combination options for which the average difference in optimal replacement moments is within the theoretically determined break-even points, especially of gas mainlines and LV main cables. Would specific conditions as described in the decision criteria hold, even for more of the presented combination options in table 17, combined replacement can be cheaper.
Based on the comparison of the theoretically determined break-even points and the average differences in optimal replacement moments of the total asset population, it is expected that in reality combination options exist for which combined replacement in fact is cheaper than separate replacement and that there is thus potential for the combined replacement of assets.

It needs to be emphasized that it is about *average* ages and *average* differences in replacement moments here. The age distribution of assets can differ per asset type which means that the average ages can be such that optimal replacement moments differ too much, but that head or tail of the age distribution of two asset types diverges little such that optimal replacement moments differ only a little there. Consequently, for asset types where the average difference in optimal replacement moments are outside the theoretical limits it could still be that for a part of the population optimal replacement moments diverge little and combined replacement would still be cheaper there. The other way around, for the asset types where average differences in optimal replacement are small it could still be that optimal replacement moments of a part of the asset populations diverge too much for combined replacement.

Based on the above information and the estimated replacement value of the asset population as mentioned in paragraph 2.4, the total saving is estimated that can be obtained when indeed combining the replacement of asset types when this turns out cheaper than separate replacement. The savings are estimated for the above presented combination options for which the average differences in optimal replacement moments of the asset types are within the break-even points; after all, the coordinated approach would imply to combine these replacements. It is estimated that a saving of at least approximately 100 million Euros on the total replacement spending of the demarcated system part can be obtained when the coordinated approach would be adopted (see Appendix 6D). With a total replacement value of the demarcated system part (e.g. the total replacement spending when the totality of considered asset types are separately replaced) of 1.7 billion euros this can be seen as a substantial saving. The saving can in fact be even more since under specific conditions break-even points are higher, implying that even other of the above presented combination options can turn out beneficial in reality.

6.5 Compliance with municipal rules and Inconvenience

Based on the analysis of effects on the quantitatively expressed performance indicators, combined replacement can be a better option than separate replacement under specific conditions, and based on a reflection on the total asset population it showed that these conditions can be met in reality. This section presents the evaluation of combined and separate replacement based on the qualitative performance indicators 'compliance with municipal rules' and 'inconvenience'.

6.5.1 Compliance with municipal rules

Essent Netwerk should comply with the 'no-dig period' whenever municipalities use this rule. In cases 1, 2 and 5 the differences in optimal replacement moments were all outside the 'no-dig period' of 5-10 years; in these situations separate replacement will not violate the 'no-dig period'. In case 4 however, the difference in optimal replacement moments for the gas mainline and gas service lines was 6 years and in case 3 it was 5 years; separate replacement of these combination options would violate the no-dig period. Considered from the compliance constraint, in those situations the replacements should be combined.

Considering the differences in optimal replacement moments and the obtained combination advantages, separately replace the asset types in the considered cases when this turns out cheaper would not violate the 'no-dig period'. Since combined replacement always gets a cheaper option when optimal replacement moments diverge 9, 7 or 19 years as determined in paragraph 6.3, the economic consideration will in many situations already guarantee that the 'no-dig period' is not violated.

As compliance is seen as a constraint, Essent Netwerk should however still combine replacements when separate replacement turns out cheaper but implies that the next separate replacement activity is executed within the prescribed no-dig period. Violation of this municipal rule can result in costly and timely affairs with municipalities to obtain required licenses for replacement activities (Versteeg, 2007). Except from additional costs and time it would possibly also deteriorate the relation with municipalities and might perhaps result in tightening of rules.

6.5.2. Inconvenience

In the considered cases separate replacement would in certain situations absolutely lead to much more inconvenience as compared to combined replacement. When in case 3 the gas mainline and the main cable are separately replaced, the surface is first excavated for the replacement of the gas mainline, resulting in reduced inaccessibility of houses and the like and then 5 years later the same happens, but then for the replacement of the main cable. Combining replacements in such situations is expected to decrease the inconvenience to residents.
Excavating streets only once instead of twice or more during a relatively short period results in less inconvenience; residents only encounter the negative accompanying effects of excavating, such as inaccessibility, passing delays and temporary interruption of business, once instead of twice. Moreover, it only demands customers to be at home once instead of multiple times in a short period (Schimmel, 2007 and Visscher, 2007). The decreased inconvenience is expected to be beneficial for the image of Essent Netwerk, both to the residents and to municipalities and to the public in general (Schimmel, 2007). Asking municipalities for licenses only once and excavating streets only once shows municipalities that Essent Netwerk is working in an efficient way and interrupting both surface and underground as little as possible, something municipalities are increasingly keen on.

The decreased inconvenience resulting from combining replacement is an additional reason to combine replacements. From reputation perspective, it can be said that combining replacements is generally always better than separate replacement; it results in fewer overall inconvenience and it shows an efficient way of working. For this reason, it is assumed that when combined replacement is the best option based on cost considerations, the reputation consideration would always support this option.

When separate replacement turns out cheaper however, reputation considerations can still depict combined replacement as a better option. Since inconvenience is a fuzzy factor it is difficult to formulate a straight forward decision criterion here. This research however assumes that in those situations where from the cost consideration separate replacement would be better, replacements should still be combined when the inconvenience caused by the separate replacements is disproportionately high.

It is expected that this holds in situations where inconvenience effects as mentioned by Jung and Sinha (2007) are relatively large; traffic congestion is for instance larger in through streets and the interruption of business is larger in shopping streets. In these situations replacements have a lot more impact; replacing assets separately in a short time and thereby causing inconvenience twice is here expected to deteriorate the reputation more than would it concern a normal street. In addition it would also lead to much more ado in the local media.

Hence, replacements should always be combined in through streets and shopping streets when separate replacement implies that the next replacement takes place within a relatively short time. There is little information to determine how long this ‘relatively short time’ should be, but the maximum period the municipalities use with their no-dig period, 10 years, seems a reasonable estimation. Experiences in the future however should show whether this period might be adjusted.

The ‘inconvenience decision criteria’ implies a conflict between the goal to minimize costs and the goal to maximize reputation in these situations, since when separate replacement turns out cheaper, the replacement is still combined when it concerns a shopping or through street and the next separate replacement would take place within 10 years. However, as the quantitative decision criteria show, the loss is limited since in many situations combined replacement is already cheaper when the next separate replacement would be within 10 years.

6.5.3 Qualitative decision criteria

Considered from the compliance and inconvenience factors, combined replacement is thus in certain situations a better option then separate replacement. Based on the qualitative analysis the following qualitative decision criteria can be derived:

- If separate replacement of asset types violates the ‘no-dig period’ of municipalities, replacements should always be combined.
- If separate replacement is expected to cause disproportionately much inconvenience replacements should always be combined; this is assumed to be the case when it concerns a shopping street or through street and the next separate replacement would be within 10 years.

6.6 Conclusions

This chapter aimed to show whether and when combined replacement can be better a better option than separate replacement, considered from the goals and constraint of long-term network operation. The quantitative analysis of the five cases showed that in certain situations combined replacement is cheaper than separate replacement and that certain factors can increase the obtainable combination advantage. It was estimated that Essent Netwerk could save at least over 100 million Euros on their replacement spending when adopting the new approach. Moreover, the qualitative analysis showed that combined replacement is in certain situations the only option considered from the compliance constraint and actually leads to less inconvenience in all situations.

The analysis of case results showed that different factors influence if and when combined replacement is a better option than separate replacement. It showed that the difference in optimal replacement moments of asset types is an important factor in making the choice for combined or separate replacement; when optimal replacement moments diverge little, combined replacement has more potential to become a cheaper option than separate replacement. High costs for street restoration, when expensive decorated bricks are used, can in certain situations enlarge the potential for combined replacement for specific combination options. The length of connections and the configuration of the main net also appeared to be of influence on the obtainable combinations advantage. Based on the results of the cases, the analysis of parameter variation and the qualitative analysis, decision criteria were derived that form the secure lower limits of when to combine replacements.

This section discusses the need for Essent Netwerk to adopt the new approach and, based on the decision criteria presented above, it presents a decision guideline showing how the new approach could be utilized.

6.6.1 A new approach to the replacement of Essent Netwerk's aged assets

Essent Netwerk's current approach towards replacement considers one asset type at a time: by optimizing per asset type separately its assets are probably replaced as close as possible to their own optimal replacement moment, but cost and reputation benefits of combining replacements, possibly resulting eventually in a more favorable option are not considered. Moreover, the violation of municipal rules where separate replacement could lead to is not considered.

Since combined replacement *can* result in substantial cost savings, is compliant with municipal rules in situations where separate replacement is not and since it results into less inconvenience, combined replacement is in certain situations better able to fulfill the goals and constraint of long-term network operation than separate replacement.

According to this research, Essent Netwerk should let go its purely elementary view and should take a systems view in which the totality of existing asset types is considered. As such, the alternative approach which is said to consider the multiple asset types in replacement decision-making and is thereby considering the possibility to combine replacements can be seen as the optimal available approach. After all, with considering the possibility to combine the replacement of one asset type with the replacement of another asset type, constantly the optimal deliberation with regard to the goals and constraint of long-term network operation is made, which consequently leads to a better fulfillment of these goals and constraint.

6.6.2 Decision guideline

With planning and executing its replacements, Essent Netwerk should aim at fulfilling the goals and meeting the constraint of long-term network operation. To apply the new approach such that it indeed leads to maximal fulfillment of goals and constraint of long-term network operation, continually a correct choice between combined and separate replacement should be made. Since combining replacement can be advantageous, but since the obtainable advantage depends on the specific situation, a choice should be made per situation based on the advantages of combined replacement (that results from the minimization of replacement activities at a certain location) and the disadvantages (that result from the deviation from the optimal replacement age) compared to separate replacement. To make this choice correctly, Essent Netwerk can use the decision criteria derived in this chapter.

To simplify decision-making Essent Netwerk can also use the decision-guidelines presented on the next pages. These decision guidelines summarize the decision criteria and put some of them together to facilitate easy decision-making. As already depicted in chapter 5, the gas infrastructure is in general in worse condition then the electricity infrastructure and therefore is assumed to initiate possible combined replacement. Therefore the decision guidelines are made based on the assumption that either the gas service lines or the gas main lines need replacement first and thus initiate combined replacement. For each of these starting assumptions a guideline is produced and shown on the next pages. Essent Netwerk can use this decision guideline in which the previously determined decision criteria are translated in simple rules of thumb for its decision-making.

In making the decision guideline the following assumptions are made:

- Connections are long (=>7.5 meter) when the connection goes through a front yard.
- To limit the number of decision steps, certain decision criteria are summarized in 1 step:
    - For the 'gas service line – gas mainline' combination option (with gas service line initiating the combined replacement) it was found that when the main net is single positioned, the optimal replacement moments can diverge either 14 of 16 years (dependent on pavement type); in the guideline the average of 15 years is taken.
    - For the 'gas service line – gas mainline' combination option (with gas service line initiating the combined replacement) it was found that when the main net is single positioned and the gas service lines are long, the optimal replacement moments can diverge either 20 of 21 years (dependent on pavement type); in the guideline 20 years is taken.
    - For the 'gas service line – gas mainline' combination option (with gas mainline initiating the combined replacement) it was found that when the street restoration costs are high or the main net is double-sided, the optimal replacement moments can diverge either 10 or 12 years; in the guideline the average of 11 years is taken.
    - Combined replacement of gas mainline and LV main cable gets more advantageous when street restoration cost charged per meter are high or the main net is double positioned; in the decision guideline this is presented as one step wherein the break-even point is set at 24 when either the street restoration costs are high or the main is double-positioned.

Considering combined replacement possibilities, using these decision guidelines can result in the decision to separately replace the asset type or to combine it with the replacement of another asset type. It can however also result in the decision to simultaneously replace 3 asset types (e.g. the gas service line, gas mainline and LV main cable together) or to replace all 4 asset types together. As it was determined that the replacement of all 4 asset types should be combined when the mutual differences in optimal replacement moments and other characteristics of the combination option equal the conditions set for the combined replacement of two asset types, the possibilities for combined replacement of 3 asset types can be considered in a similar way.

6.6.3 Calculation model

Essent Netwerk can use the presented decision guidelines to make the decision for either combined or separate replacement in a certain situation. It can however also decide to use the constructed calculation model to determine for each situation the obtainable combination advantage and thereafter use the qualitative decision criteria to finalize its decision; in this case the cost consideration steps of the decision guideline can be replaced by using the calculation model.

Essent Netwerk can also decide to use the calculation model to verify and fine-tune the quantitative decision criteria and guideline after some combined replacements have been executed and the real obtained combination advantages of these combined replacements are known. The instructions for using the calculation model are found in Appendix 6E and the calculation model is attached with this research.

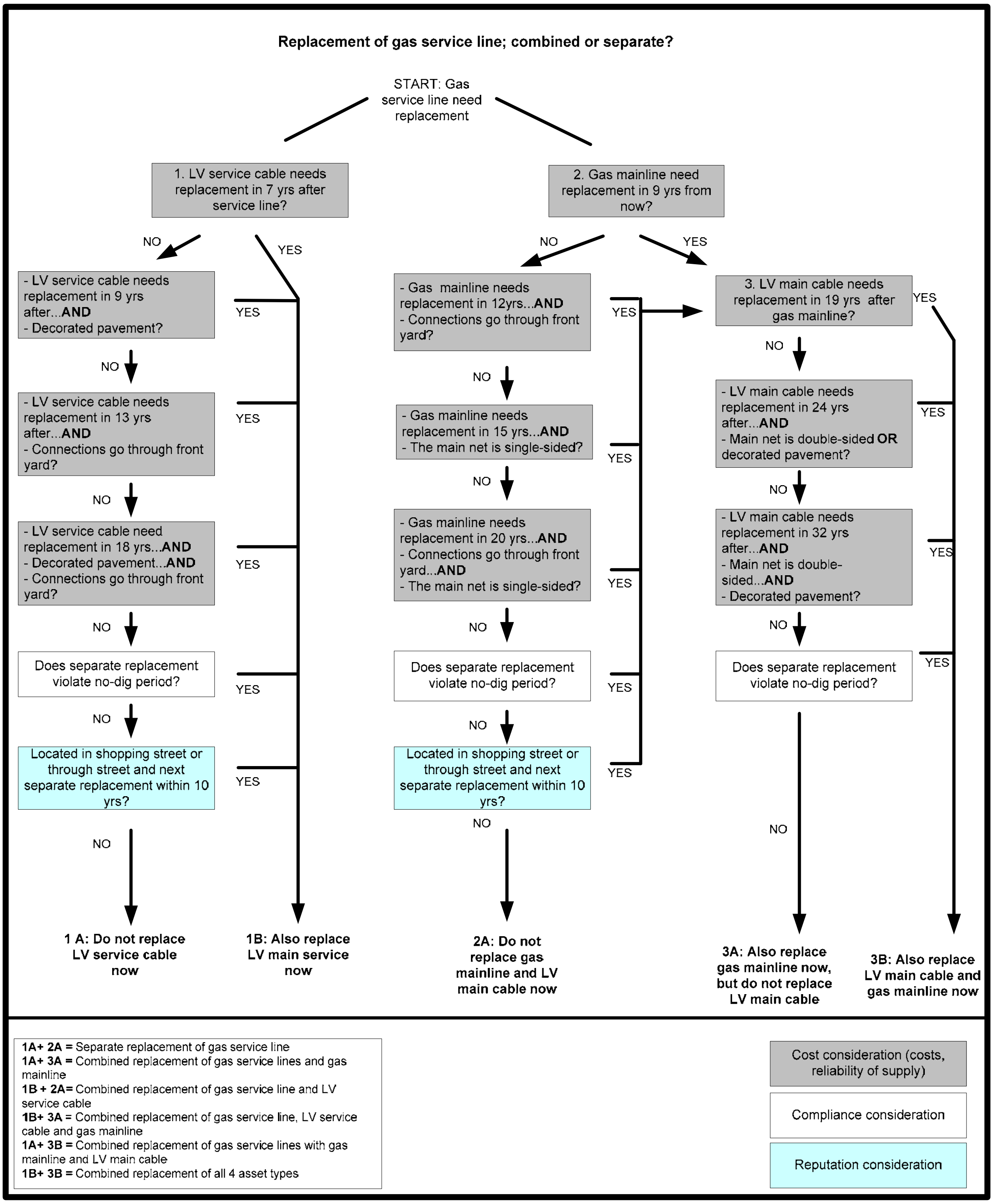
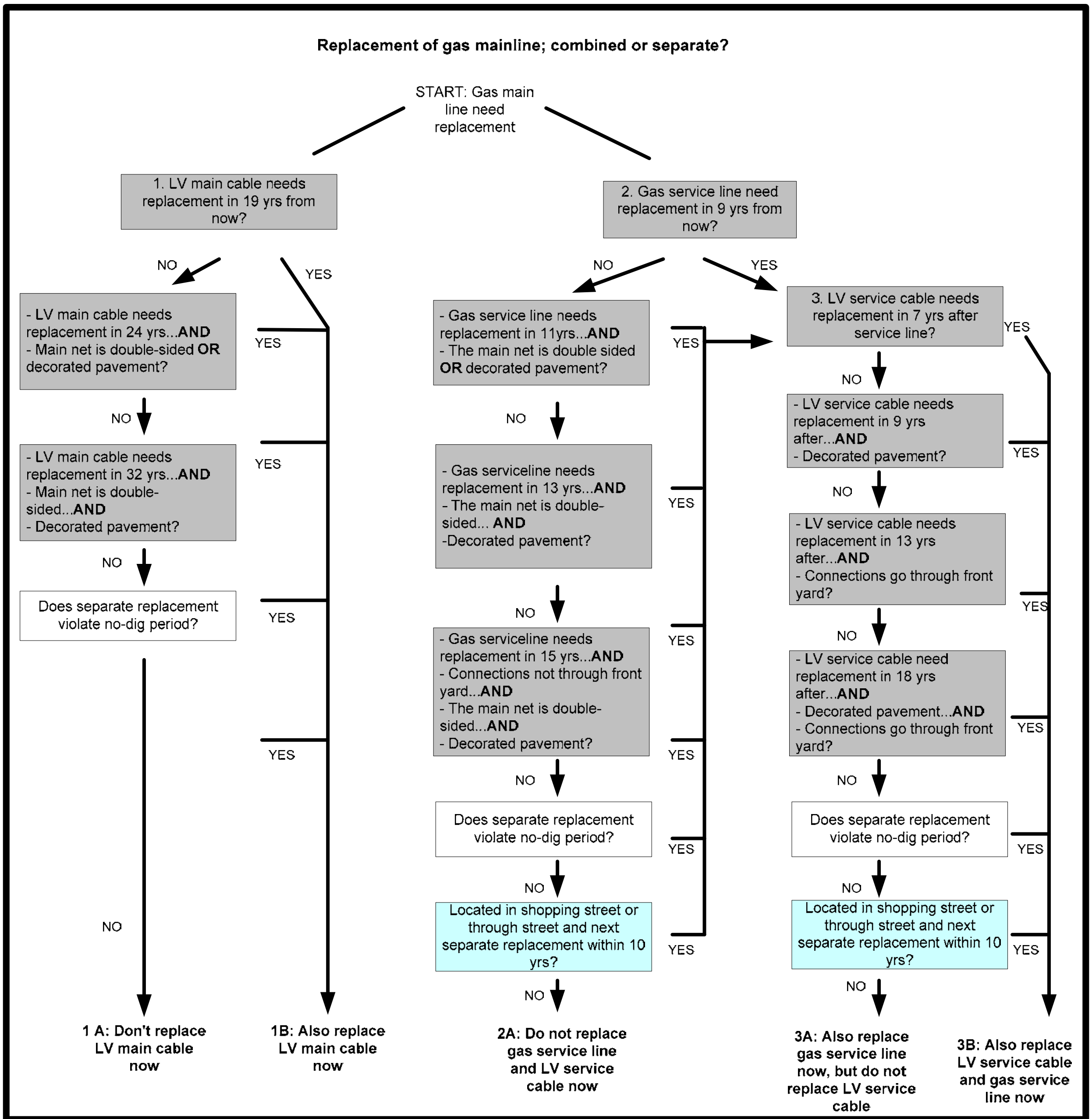


Figure 23 Decision guideline for the replacement of gas service lines.



1A+ 2A = Separate replacement of gas mainline
1A+ 3A = Combined replacement of gas mainline and gas service line
1B+ 2A = Combined replacement of gas main line and LV main cable
1A+ 3B = Combined replacement of gas mainline with gas service line and LV service cable
1B+ 3A = Combined replacement of gas mainline, LV maincable and gas service line
1B+ 3B = Combined replacement of all 4 asset types

Cost consideration (costs, reliability of supply)

Compliance consideration

Reputation consideration

Figure 24 Decision guideline for the replacement of gas mainlines.

PART II: ORGANIZATIONAL IMPLICATIONS FOR ESSENT NETWERK

7. Organizational implications

Research part I concluded that combined replacement of multiple asset types of Essent Netwerk certainly has potential, and that the best approach to the replacement of assets is a coordinated approach that considers the decision for either combined or separate replacement in replacement planning.
By falling back on the described organization structure in Chapter 2, this chapter presents the organizational implications when implementing the new approach. It shows the changes implied by the new approach and it shows possible bottlenecks that may arise. First, it presents where in the process the decision for either combined or separate replacement should be made. Section 2 presents how this decision should be made. The next section presents the implications for the Asset Management department, while section 4 discusses the wider organizational implications.

7.1 Incorporation in current processes

In chapter 2, the current approach of Essent Netwerk to the replacement of its aged assets was presented. It showed that a specified process is followed per asset type separately. The new recommended approach to the replacement of assets also takes into account the other existing asset types. Therefore, at a certain moment in time, the total set of existing asset types should be considered and thereafter the decision should be made whether only one asset type or multiple asset types are replaced. The first question then arising is *when* and *where* this decision should be made. As was indicated in chapter 2 the aim of this research was not to totally revise the RBAM-process, but to see if improvements can be made in the way replacements are considered during this process. This implies that the decision for combined or separate replacement should be somehow incorporated in the RBAM-process.

To make a decision for combined or separate replacement, one should at least know which other asset types exist nearby the asset type that needs replacement, and one should know at least some of their characteristics, like the materials used. This information is not available at the central levels of the organization but is available at the geographically decentralized Strategy Realization units. Interviews with Essent Netwerk staff showed that the most obvious place to consider whether the replacement of an asset type should be combined with replacement of another is therefore during the bottleneck-identification step at the regional Strategy Realization units (Bakker, 2007; Schimmel, 2007; Pol, 2007). It is namely at this point in the process that the situation specific information is available and collected by the asset engineers.

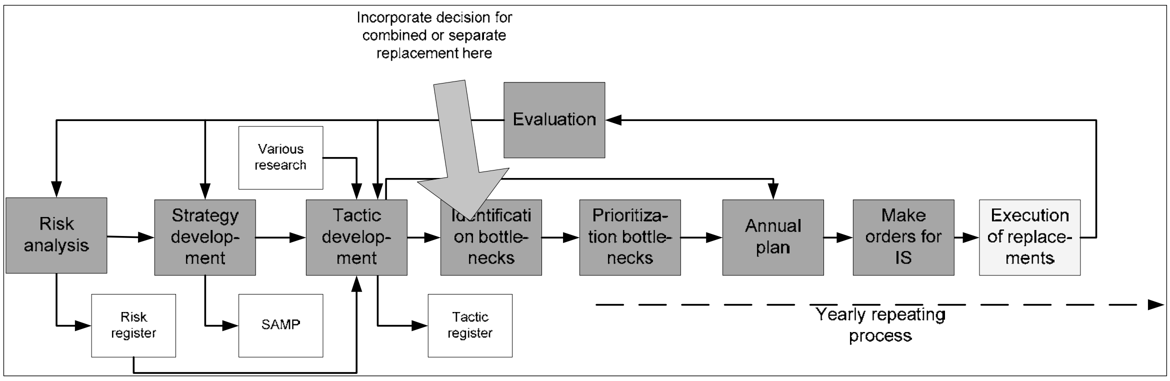


Figure 25 Incorporation of combined-separate decision-making in current process

The decision for combined or separate replacement should be seen as an additional action during the so-called bottleneck-identification step. With regard to the replacement activities, the bottleneck-identification

step would then consist of two parts. The first part is similar to the current approach and comprises the identification by the asset engineers of the bottlenecks, e.g. the physical assets that, according to the replacement strategy and tactic, need replacement. The second step comprises the identification of asset types that are located nearby the above mentioned assets and that, based on the decision criteria, need to be replaced simultaneously. For the purpose of the second step, the asset engineers search for the nearby asset types and their characteristics (material, construction year) in a database, in a similar way as they do for the bottlenecks. Thereafter, they use the decision criteria to decide whether these asset types need to be replaced simultaneously with the identified bottlenecks. On the list of bottlenecks that the Strategy Realization units deliver to the Strategy Development unit prior to the prioritization, these units then also mention the combined replacement possibilities.
It is expected that the extra time asset engineers need to execute the additional action is relatively limited and that the additional action can be relatively smoothly adopted by the asset engineers (Mutsaers, 2007).

7.2 Making the decision for combined or separate replacement; absence of replacement policies

For making a deliberate choice to either separately replace for instance the gas service lines or to simultaneously replace other existing asset types as well, the Strategy Realization units need information on these other existing asset types. They need to know the characteristics of the asset types and they need to know when these asset types need replacement. After all, making the decision to combine replacements or not depends amongst others on the replacement moment of the asset types.

Determination of the optimal replacement moments is normally based on the strategies and tactics developed by the Strategy Development units. Ideally, there should be strategies and tactics available for all asset types (Wehman, 2007). However, with regard to the asset types considered in this research, -the gas service lines, the LV service cables, the gas mainlines and the LV main cables-, only for the gas service lines such a replacement strategy and tactic is currently available. Consequently, at this moment only for the gas service lines the exact optimal replacement moments can be determined. Although for the gas mainline a replacement policy is currently under construction, at this moment for the mainlines and electricity cables only the roughly determined optimal replacement ages such as calculated in the long-term optimization research are available.

The question then arising is whether to wait until replacement strategies and tactics for the other asset types are finished as well and only then implement the new approach or to still implement it now. From the interviews it turned out that waiting until replacement policies (replacement strategy and tactic) are finished means waiting long. Making replacement policies is time consuming and it is not expected that all policies are finished within a short time (Bakker, 2007, Wijnia, 2007). Since a part of the gas service lines already need replacement now and in the very short future, it would be a pity not to take advantage of considering possible combined replacements till all replacement policies are finished.

Thus, despite the absence of certain replacement policies, the decision to combine replacements or not should still be considered during the bottleneck-identification step. This implies that the asset engineers should be somehow able to find out when the asset types for which currently no replacement policy exists, need replacement and to thereafter determine whether combined replacement is beneficial. For this purpose, it is advisable to set up some basic criteria to determine the replacement moments of these asset type. Such criteria can for instance be based on material type, soil type, interruption information from the 'Nestor' interruption database, experiences on the condition of asset types from the Infra Services units and the roughly determined optimal replacement moments from the long-term optimization report (Bakker, 2007). The criteria should, like the strategies and tactics, be set up by the central Strategy Development unit.

Hence, the decision to combine replacement or not is then based on both the decision criteria developed in this research and some additional criteria that help asset engineers determine the replacement moments of the asset types for which currently no replacement policy exists; together they form the new procedures accompanied with the new replacement approach. In the mean time, replacement policies for the other asset types should be finished by the Strategy Development unit and once they are completed, they can substitute the additional criteria.

A risk of using additional criteria for determining the replacement moments of asset types in stead of strategies and tactics is that confusion might be caused within the organization about the still recently introduced RBAM-process. Interviews namely turned out that currently the RBAM-process that was introduced in 2005 is not yet totally embedded in the entire organization and that therefore the RBAM-process is not yet always followed up correctly (Korn, 2007). Basing the decision to take along the replacement of one of the asset types on a set of criteria instead of on a strategy and tactic hence diverges from the RBAM-process and will therefore probably not help the observance of the RBAM-process. Therefore, when introducing the new approach to the employees it should be emphasized that using the additional criteria instead of a replacement strategy and tactic is a 'temporary solution'. Attention should also be paid to a 'reintroduction' of again totally following up the RBAM-process as originally intended, once the other replacement strategies and tactics are finished.

7.3 Implications for Asset Management

The new approach necessitates implications for the Asset Management department. This paragraph first describes the implications for the five regional Strategy Realization units. It thereafter discusses the implication for the relation between these five units and the central Strategy Development unit. The third section elaborates on the ease of adopting and accepting the new approach by the Strategy Realization units and the last section shows the main implication for the Strategy development unit.

7.3.1 Strategy Realization implications

7.3.1.1 Increased workload

With implementing the new approach more work is assigned to the asset engineers at the Strategy Realization units; except for finding the bottlenecks, they should now also search for possibilities to combine replacements. Currently time for the bottleneck-identification step already appears to be short; the asset engineers encounter problems in identifying the total amount of bottlenecks that the Strategy Development unit orders them to find (Berg, 2007). When this happens, a certain amount of bottlenecks to be identified is postponed to next year. Although it is expected that the extra time required for the additional step during the bottleneck-identification step is limited, the new approach will nevertheless increase the workload for asset engineers. Essent Netwerk should therefore consider how this extra work stemming from the new approach can be fitted in, in the currently already time consuming step.

At this moment a project is started in which the possibility to transfer more standard decisions from the Strategy Realization units to the Infra Services department is investigated (Mutsaers, 2007). When indeed more standard decisions are shifted towards the Infra Services department, more time is freed for the Strategy Realization units and possibly this opportunity might be seized to fit in the extra work.

7.3.1.2 Increased cooperation

Besides the increased amount of work, searching for combined replacement possibilities at the Strategy Realization units also implies that the asset engineers need to cooperate more closely. After all, when they for instance investigate possible combination options for the gas service lines and the electricity cables, it implies that the asset engineers specialized in gas infrastructure need to cooperate with the asset engineers specialized in electricity infrastructure. More direct communication is thus necessary within the Strategy Realization units and more time is necessary to enable this communication. Although the employees might need to get used to this intensified cooperation, according to an interview with the manager of one of the Strategy Realization units, it is expected that this cooperation proceeds smoothly, since the units are relatively small and people are working at the same location (Mutsaers, 2007).

7.3.1.3 Compatible presentations of bottlenecks

Asset engineers have to search the specific assets that need replacement in the upcoming year (e.g. the bottlenecks). Currently different methods to search and visualize bottlenecks are used; some asset engineers present their information with help of Excel, while others use geographic pictures (Mutsaers, 2007). Such methods are not compatible and will hamper the search of combination possibilities. An implication for the work of asset engineers within the Strategy Realization units therefore is that they collect and present the data of asset types to be replaced in a similar way (Mutsaers, 2007).

7.3.2 Strategy Realization – Strategy Development implications

7.3.2.1 Division of responsibilities

By making the decision for combined or separate replacement at the regional levels of Strategy Realization, the pith of the important choice with regard to possible combined replacements will be at these levels. One could question whether you should burden these regional departments with such an important decision in an organization where decision authority is mainly centralized. However, as the RBAM-process prescribes, the bottleneck-identification step is followed by a prioritizing step conducted by the central Strategy Development unit. Moreover, already before this prioritizing takes place, the identified bottlenecks which thus provide a look ahead on next year activities, are discussed within the Management Team of the Asset Management department in which both the Strategy Development unit and the central level of Strategy Realization are represented (Pol, 2007). This guarantees that also with the new approach the division of responsibilities remains appropriate.

7.3.2.2 Framework of Strategy Development for Strategy Realization units

The new approach implies that the complexity of work at the Strategy Realization units with regard to the replacement activities is increased. In an organization where the information and decision flow is mainly top-down and regulated, procedures should be standardized and clear (Mintzberg, 1983). Incorporating the decision to combine replacements or not within the Strategy Realization units therefore demands that the procedures made by the central Strategy Development unit for making this decision are clear (Bakker, 2007).
Even with the current approach, the Strategy Realization units namely sometimes claim that there is too little clarity of policies made by the Strategy Development unit; centrally made policies are sometimes not explicit and practical enough to be worked out (Essent Netwerk, 2006e). A result of this might be that the identification of assets that need replacement is postponed and that finally replacements are delayed, since asset engineers wait with working out policies until they understand what to do.

On the other hand, as is characteristic for professionals working in a bureaucracy, asset engineers might make their own interpretations which diverge from the real intentions of the policy. For example, in one of the Strategy Realization regions of Essent Netwerk, recently the asset engineers did not exactly follow up the replacement policy as intended; they decided their selves that the electricity cables located nearby needed replacement as well and they made their own rules of thumb which they used to decide on replacements. The decisions that should be made at a central level in the organization were thereby thus switched to the decentralized region, which was not in accordance with the standardized working processes. Such occurrences might lead to conflicts between Strategy Development and the Strategy realization units, which again might result in delays and thereby in a postponement of replacements.

Moreover, as there are 5 different Strategy Realization regions which in fact are separate from one another, each region may interpret or understand a policy made by the Strategy Development unit differently. Since according to Wehman (2007) the historically grown differences between these regional units still result in a somehow different way of working, possible divergence in interpretation and understanding of procedures might be increased even more. Although obviously the final results of worked out policies may differ from each other, because of for instance differences in the asset characteristics per region, different soil type or different municipal policies, a different way of working might imply that a policy is not worked out as intended, finally causing unintended results.

Hence, indistinctness of the new procedures made by the Strategy Development unit might cause confusion at the Strategy Realization units possibly resulting in delayed replacements, or it might result in unintended and very free interpretations of policies probably resulting in conflicts between the Strategy Realization and Strategy Development unit and thereby eventually also in delayed replacements. The differences between the five Strategy Realization units might complicate this situation even more.

As the new approach is expected to bring extra complexity of the work of the Strategy Realization units, possibly even more misconceptions of policies and procedures and differences between regions might arise. This implies that the Strategy Development unit should create the procedures that are accompanied with the new approach Strategy Development unit such that they are interpreted and understood correctly by the Strategy Realization units. Therefore the Strategy development unit should pay attention to the clearness and explicitness of these procedures. Moreover, by a collective introduction of the new approach and the accompanying new procedures with all regions and asset engineers together, one could stimulate a similar way of working throughout the different regions. By such a collective introduction also possibilities arise to collectively improve procedures based on sounds coming from all regions, which will further support a similar way of working and correct interpretation of procedures.

As depicted in chapter 2, the bottlenecks that are to be identified by the Strategy Realization units are described in the ‘bottleneck-assignment’, made by the Strategy Development unit in cooperation with the central level of the Strategy Realization units. An additional implication for the communication between the Strategy Development unit and the Strategy Realization units is that this bottleneck-assignment should now also mention the need to consider possibilities for combined replacements during the bottleneck finding process (Bakker, 2007).

7.3.3 Ease of adoption and acceptance of new approach by Strategy Realization

The implementation of the new approach within Essent Netwerk thus somehow changes the work of the asset engineers of the Strategy Realization units. As Essent Netwerk is considered a bureaucracy and bureaucracies are not to keen on adapting to changes, one might expect some difficulties within the Strategy

Realization units when implementing the new approach (Mintzberg, 1983). Moreover, as it was shown that currently the RBAM-process is not yet totally embedded, one might expect that the asset engineers need time to get used to the new approach and that thus embedding the new approach now could take much time as well. However, as already became clear throughout the previous sections, the change of work for the asset engineers caused by the new approach is limited, also because the new approach only comprises the replacement activities and for the other activities so far nothing changes. Moreover, since at the Strategy Realization unit the work is done by relatively high skilled people who more easily adapt to changes, it is expected that, except for some starting-up time, the implied changes of the new approach are relatively smoothly embedded within these units.

The new approach implies more work, more cooperation and a more complicated task for asset engineers. It is expected that the Strategy Realization units relatively easily accept the increased cooperation and complexity of tasks. During the execution of this research it was found that both the managers of the Strategy Realization units and the asset engineers themselves were interested and positive about possibilities to combine replacements. Many of them already faced situations in which they wondered whether combined replacement could be possibly a better option. Since the Strategy Realization units are convinced of the need of replacement and the upcoming replacement wave, they will likely be positive about ways to improve efficiency of these replacements. However, although the expected positive attitude of these units, they can show resistance when it implies an increased workload due to the additional time needed. Therefore, as said, attention should be paid to freeing time for the additional work.
For a smooth acceptance of the new approach by the Strategy Realization units, it is moreover important to prevent that these units feel that they are forced to adopt the new approach. Therefore, especially in the initial stage, the Strategy Development unit should watch carefully if the asset engineers work smoothly and as intended with the new procedures and they should listen to criticisms and suggested improvements from these assets engineers and should translate these sounds into improvements of the procedures. In addition, as is the last step in the RBAM-process, a good evaluation by the Strategy Development unit should take place.

7.3.4 Strategy Development implications

The main implication for the Strategy Development unit is that they set up clear procedures for making the choice for combined or separate replacement of asset types at the Strategy Realization units. These procedures should consist of a decision framework showing when to combine replacements, based on the decision criteria developed in this research and additional criteria that enable asset engineers to determine the replacement moments of the asset types for which no replacement policy exists. It is important that the Strategy Development starts quickly with setting up these procedures and that they thereafter take care of a good introduction of the new approach. In addition they should see to it that the Strategy Realization units adopt the approach smoothly, adjust procedures if necessary and they should take care of a good evaluation.

7.4 Wider organizational implications

Except for the implications for the Asset Management department, the new approach also has implications for the Infra Services department and its relation with the Asset Management department. The first section describes the implications for the Infra Services units. In the second section the implications for the relation between the Infra Services units and the Asset Management department is discussed. Thereafter a solution to possibly arising bottlenecks is presented. The fourth section discusses the ease of adoption and acceptance of the new approach by Infra Services. The last section presents some additional implications.

7.4.1 Infra Services implications

Within the Infra Services' regional units, work is divided into functional departments. The department concerned with the gas and electricity connections (department 'Aansluitingen') is another department than the one concerned with the main net (department 'AE&I'). Moreover, people concerned with the electricity infrastructure are others than those concerned with the gas infrastructure. With the new approach orders from Asset Management to Infra Services can prescribe to execute *combined* replacements. Preparation of combined replacement activities consequently demands involvement of more departments and people concerned with the different infrastructures. While, as discussed earlier, the required cooperation between asset engineers at the Strategy Realization units remains within the same unit, here cooperation between the different functional departments might be necessary, which obviously demands more coordination (Schimmel, 2007). Although currently cooperation exists between these departments every now and then and although this appears to work smoothly, the expected increase in combined replacements resulting from the new approach might demand adjustments in the relation between these units (Knol, 2007).

The Infra Services units outsource the majority of its executing activities to contractors and each Infra Services unit has agreements with multiple contractors. Many of these contractors are specialized either on gas connections or on electricity connections. In addition, contractors concerned with the main net are usually others then those that do the connections. The Infra Services units indicated that it is desirable to work with only one contractor at a time (Vissia, 2007; Slegers, 2007) and therefore combining replacement of multiple asset types requires the use of multi-disciplinary contractors. Infra Services should thus at least schedule their contractors such that the mono-disciplinary contractors do the solo work and the available multidisciplinary contractors are arranged for the combined replacements. It is however questionable whether currently the Infra Services units contracted enough multi-disciplinary contractors (Vissia, 2007). An implication therefore is to search for other, multi-disciplinary contractors.

7.4.2 Implications for Infra Services – Asset Management

As is always the case with principal-agent relations, a risk for the principal, which in this case is the Asset Management department, is whether the agent (Infra Services) performs as intended (Tijhaar, 2007). During interviews throughout the organization it turned out that, as is somehow historically grown, the focus of the Infra Services department currently predominantly is on the customer-driven work (Kerst, 2007). When confronted with unexpected additional work or scarcity of available personnel, the Infra Services units give right of way to the customer-driven work, implying that the Infra Services units or even functional departments within sometimes choose to postpone internally ordered work (e.g. orders initiated by the Asset Management department) (Kerst, 2007). As moreover it appears that currently the need of replacement of the aged assets is not yet totally embedded throughout the Infra Services units, it is likely that these units, when giving right of way to the customer-driven work, postpone the ordered replacement activities and that these activities thus get behind. As postponing replacements might in the end lead to even more workload because of the unpredicted failure of assets (Wijnia et al., 2005), this might on the longer term result in problematic situations. Moreover, the fact that the decisions to postpone internally driven orders are made at a decentralized level does not fit the structure of a machine bureaucracy Essent Netwerk is and results in an uncontrollable processes (Vossen, 2007).

Because of the expected replacement wave, the Infra Services department is confronted with an increasing amount of replacement activities in the future. Since with *combined replacement* some replacements are advanced (e.g. replaced before their optimal replacement moment), the amount of replacements to be executed by the Infra Services units in the *near* future is increased even further. Thus, the expected replacement wave and implementation of the new approach demand that the Infra Services units start to recognize the importance of replacements, thereby executing the replacement activities ordered by Asset Management and thus not postponing replacements any more to a later stadium. How this might be dealt with is discussed later on.

As a principal, the Asset Management department is able to control the agent (Infra Services) by monitoring and controlling the work done (Tijhaar, 2007). The program managers of the Strategy Realization units monitor and control the progress of the internally driven work by monthly consultations with the Infra Services units. According to Vossen (2007), who researched the cooperation between Asset Management and Infra Services, the monitoring process currently does not always give a clear insight in the progress, since the departments really involved in executing the work are not directly involved in these consultations.
Controlling the progress also remains a difficult task since in fact the Asset Management and Infra Structure department are two hierarchical separated departments, implying that Asset Management cannot directly steer Infra Services, but that the control is done in mutual concession (Vossen, 2007; Mintzberg, 1983). Moreover, as there currently appears to be no formal agreements on the prioritization of projects and because the timely delivery of projects is not used as a measure, delay of internally driven work, such as replacements, is difficult to control and prevent (Vossen, 2007).
Since the new approach and the accompanying combined replacements demands the involvement of multiple departments within the Infra Services units, it should be taken into account that with the new approach, monitoring and controlling the progress of replacement activities becomes even more difficult.

Another implication interesting for the cooperation between the Infra Services department and the Asset Management department concerns the order delivery from Asset Management to Infra Services. Currently the final annual plan with service level agreements are ordered to Infra Services in the last quartile; since especially in the beginning the preparation of combining replacements might demand more coordination and might take more time, a timely delivery of the orders concerning combined replacements or at least an estimation of combined replacements is necessary (Visscher and Knol, 2007).

7.4.3 Possible solution: a new department

A solution to the above presented bottlenecks that might arise when implementing the new approach might be to set up a new functional department especially concerned with the replacement of infrastructure, as suggested during an interview with the staff members of one of the Infra Services units (Knol, Schimmel and Visscher, 2007). Such a department is then responsible for the replacement of the aged connections and the main net of both the gas and electricity infrastructure. Such a replacement department enables an easier cooperation between specialists of different disciplines. Moreover, it likely facilitates an easier monitoring and controlling by the Asset Management department, since only one department needs to be monitored and controlled. An extra advantage of setting up a separate replacement department within the Infra Services units is that it helps increasing the focus of these units on the replacement activities.
Such a replacement department should comprise employees that have reasonable experience with replacements of both the ‘Connection’ department and the department ‘AE&I’ of the Infra Services units, and both specialists on gas and specialists on electricity infrastructure.

With setting up such a separate replacement department, it should however be taken into account that it implies that all other departments get relatively isolated from the replacement issue.

7.4.4 Ease of adoption and acceptance of new approach by Infra Services

As showed, the new approach implies substantial changes for the Infra Services units; much more cooperation is necessary, they should schedule multi-disciplinary contractors and plan combined replacements and possibly even a new department is set up. Such changes might possibly lead to resistance of the Infra Services units, as at least, especially with setting up a new department, their focus should be changed to be more on replacement activities. Because Asset Management cannot directly steer Infra Services it is very important that this resistance is minimized and that the Infra Services units somehow feel an incentive to focus on replacements and to adapt to the changes stemming from the new approach. and thereby to guarantee that the (combined) replacements are executed in time.

Creating such an incentive and convincing Infra Services of the need to adopt the new approach is a challenging task. In fact they should at first still be convinced of the need of replacement in general; they should be showed that the preventive replacement of aged asset is necessary and that postponing replacements might in the end result in more workload for Infra Services, due to the unpredicted failures that result from postponing replacements. Second, they should feel incentives to adopt the new approach and to indeed carry out the combined replacements. The potential cost savings that can be obtained by the new approach on its own likely is not an incentive for the Infra Services department to adopt the new approach. However, as it is the employees of the Infra Services units that really have contact with the customers, they might feel the decreased inconvenience to customers as an incentive to combine replacements. Moreover, as personnel capacity is an ever increasingly important issue for the Infra Services units (Vissia, 2007), they might see the improved efficiency in the use of personnel when combining replacements as an incentive to adopt the new approach.

Except for possible resistance at the Infra Services units, embedding the approach within these units in general might take some time and effort, as was also the case with the implementation of the RBAM-process. Essent Netwerk should therefore pay attention to the acceptance and the ease of adoption of the new approach by Infra Services. They should guarantee a good introduction to the Infra Services units about the underlying thoughts and the implications of the new approach. Moreover, especially with the preparation and execution of the first combined replacements at Infra Services, an intensified communication and support from the Asset Management might be necessary. Additionally, despite the more efficient use of personnel, with the new approach, when currently the internally driven orders are mainly postponed because of personnel shortages, the new approach probably cannot solve the entire personnel shortage. Therefore, it is advisable that even with the new approach Essent Netwerk should attract more personnel for the Infra Services units.

7.4.5 Additional implications

Another wider organizational implication stems from the practical execution of combined replacements. When executing combined replacements of the gas service lines with the gas mainlines the contractors can be confronted with customers that are not at home during the replacement activity. Since access to customers' homes is required to convert the new gas service lines to the mainline it delays the replacement, since the trench for that specific gas service line and for the relevant part of the gas mainline needs to remain open until this customer returns home. This might eventually lead to more inconvenience. However, this could be overcome by timely and accurately informing customers on the replacement activities that are to take place and the need to be at home. For this, the Communication department of Essent Netwerk should be involved.

7.5 Conclusions

This chapter showed that the new approach implies that the decision to either combine replacements or not should be somewhere incorporated in Essent Netwerk's current processes. It was concluded that the best place to incorporate this decision is at the bottleneck-identification step carried out by the Strategy Realization units of the Asset Management department. To make the decision to combine replacements or not, the decision criteria used in this research can be used. Some additional criteria need to be constructed by the Strategy Development unit for the asset types of which currently no replacement policies exist, to enable that asset engineers can determine when these asset types need replacement. These and the decision criteria developed criteria developed in this research are seen as the new procedures accompanying the new replacement approach. The Strategy Development unit should make sure that these procedures are clear and unambiguous and that they are used in a similar way throughout the 5 Strategy Realization units. In general it is expected that the new procedure is relatively easily adopted and accepted by the Strategy Realization units. The Strategy Development unit should however verify in the initial stage whether asset engineers can work with new procedures and it should possibly adjust them based on criticism or suggested improvements of the asset engineers. Moreover, time should be freed for the additional work.
With regard to the Infra Services department internal cooperation should be intensified as well. Moreover, the Infra Services department should acknowledge the importance of the replacement activities. As in the new approach multiple people and departments of the Infra Services units are involved in replacement activities, the monitoring and controlling process of Infra Services by Asset Management which is currently already complex, might be complicated even further. A possible solution mentioned for the above bottlenecks might be to set up a new functional department within the Infra Services units concerned with replacement of infrastructure. At least enough attention should be paid to the adoption and acceptance of the new approach by the Infra Service units. In addition, the need for the Infra Services department may arise to contract new multidisciplinary contractors that can both replace electricity and gas connections and main nets. Moreover, when combining replacements the Communication department of Essent Netwerk should be involved to inform customers and thereby prevent delays of the execution of replacements.

PART III: WRAP UP

8. Reflection

8.1 Personnel capacity

This research focused on finding the optimal replacement approach considered from the goals and constraint of long-term network operation. The availability of personnel was not considered so far.

Since the Dutch network companies employed most of their personnel during the 1970s and on average this personnel retires after 40 years, it is expected that the network companies will face a large outflow of personnel in the upcoming decade (Wijnia et al., 2006). This also applies to Essent Netwerk. In addition, as technical skilled people become scarce, Essent Netwerk expects a difficult recruitment of new personnel.

Figure 26 Age profile of network companies' employees. The current average age of employees is depicted by the dark bar. (Wijnia et al., 2006).

The ageing assets and the accompanied extra work due to necessary replacements, makes this issue even more challenging (Lave et al., 2007). Right before the replacement wave as described in the introduction of this research is expected to start the workforce will thus be halved. With a shortage of personnel some replacement activities might inevitably be postponed to a later moment, just because there are not enough people to do the work. This might result in a vicious circle as shown below, finally resulting in even more failures and consequently more workload.

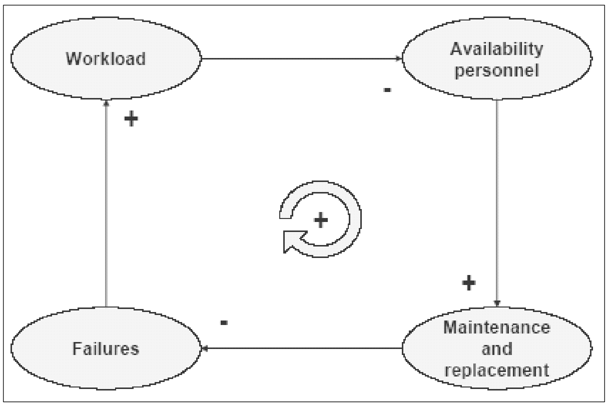


Figure 27 The problem of personnel shortage. (Wijnia et al., 2006)

According to Wijnia et al. (2006) the personnel shortage in combination with the increasing workload should be tackled by higher recruitment rates, flexible personnel resources, speeding up preventive replacements and efficiency improvements. Speeding up of preventive replacements thereby implies to replace assets earlier than their optimal replacement moment. By doing so, the replacement wave is somehow flattened and personnel currently still available can be used to execute the replacements.

The recommendation of speeding up replacements to overcome personnel shortages supports the need to adopt the new approach to the replacement of aged assets as developed by this research. After all, with combining replacements one of the asset types is replaced substantially before its optimal replacement moment. This implies that with combining replacements a substantial amount of the replacements of aged assets is advanced, which flattens the expected replacement wave and enables to make use of the currently still available personnel. In addition, combining replacements is in itself also a way to tackle personnel shortages, since with combined replacement fewer replacement activities are necessary and thereby the personnel capacity is more efficiently used. The expected run out of personnel is consequently an additional reason to adopt a coordinated approach and to combine replacement where possible.

8.2 Cooperation with other network operators

Chapter 4 discussed the alternative approach of coordinating the preventive replacements with replacements of other infrastructure network operators It was decided not to evaluate this alternative approach in this research. Nevertheless, it is expected that the obtainable benefits of combining replacements within Essent Netwerk are also obtainable when combining replacements with other infrastructure network operators.

Present infrastructure	Owner/operator	Depth (cm) (Pauwels and Wieleman, 2004)	Average life span infrastructure (Zundert, 2005)
Telecommunication	Especially KPN; Due to third-part access also accessible for third parties	30-60	Glass fiber cables: 25- 50 yr Copper cables: 75-100 yr Coax cables: 30- 40 yr
CAI (radio/TV/internet)	Cable operators (major part operated by Casema en UPC)	30-60	25-50 yr
Sewage	Municipalities	110	60-100 yr
Water supply	Water supply companies (12 in The Netherlands)	100	50-100 yr
City heating	Energy network operators	80-100	-
Industrial transport pipelines	Transport pipeline companies	120	-
Street-lightning	Energy network operators/municipalities/	60-80	-
Pavement	Municipalities	0	Open: 20-30 yr. Closed: 30-40 yr
Electricity	Energy network operators	60-80	40-100 yr
Gas	Energy network operators	90	40-100 yr.
Government networks for traffic management	Ministry of V&W	-	-

Table 18 Cooperation with other network operators

In table 18 the existing infrastructures in the Dutch underground and thus the infrastructures to possibly combine replacements with are presented; it shows the infrastructure operators they are operated by, and it shows some characteristics of these infrastructures.

The cost benefits that can be obtained with combining replacements with other infrastructure operators can be even higher since now not only the assets of Essent Netwerk but also those of telecom operators or water companies are replaced simultaneously, resulting consequently in lower total costs for each operator.
Also from reputation perspective combining replacements with other infrastructure operators is expected to be beneficial; residents are not confronted with replacement of telecom cables the one year, new paving the next year and replacement of electricity and gas infrastructure another year after. Moreover, when combining replacements with other infrastructure operators, possibilities such as the use of cable tunnels arise. After all, in these situations the multiple operators can decide to install their asset types in such tunnels, resulting in. At least, with combining replacements a better disposition of how these assets are located in relation to each other can be achieved, minimizing future digging incidents and difficulties with digging activities.

Currently in many regions the different infrastructure network operators cooperate successfully with regard to the construction of new infrastructures in new housing estates. However with regard to the replacement of infrastructure such cooperation does not yet exist, likely due to bottlenecks that still appear to exist with such cooperation. This research pinpoints the following bottlenecks with regard to cooperation with other network operators for *replacing* infrastructure:

- Since the average life spans of existing infrastructures are different, replacement moments might diverge too much to let combined replacement be of interest for all infrastructure operators. At least, finding those moments to replace infrastructures simultaneously such that it satisfies each infrastructure operator and the public is expected to be difficult.
- As became clear from a forum discussion held with multiple infrastructure operators the willingness to cooperate exists (Essent Netwerk B.V., 2006 November). However, such cooperation brings complex organizational questions. An interesting and difficult question is for instance who should take the lead in these coordinated replacements; should that be the municipalities that are both infrastructure operator and local authority or is their double role a reason not to?
- Another difficulty is that combined replacement of multiple infrastructures requires mutual insight in replacement plans of infrastructure operators for a longer term such that replacement moments can be adjusted. As the forum discussion showed currently these plans are not available with the infrastructure operators (Essent Netwerk B.V., 2006 November).

Hence, this research presumes that cooperation with other infrastructure operators certainly can result in substantial advantages, but that before first above presented bottlenecks should somehow be overcome.

8.3 Applicability of findings outside system demarcation

8.3.1 Other asset types

This research was demarcated to the LV service cables, LV main cables, gas service lines and gas mainlines of Essent Netwerk in densely populated areas. The outcomes are consequently also applicant to this demarcated part. However, it might be interesting to see whether outcomes might also be applicant outside this scope.

In fact, the savings that can be obtained with combined replacement of the above presented asset types on for instance digging costs and street restoration costs, could also be obtained when other asset types like MV cables or HP pipelines are replaced in combination with another asset type, since also here the excavations are reduced with combined replacement. However, as said in chapter 2, many of the other asset types are not located in a trench together with another asset type, making the potential of combined replacement of such other asset types small. If Essent Netwerk however wants to consider possibilities to combine replacements of these other asset types in those situations that they are located in a same trench with other assets of Essent Netwerk, some further research is necessary to develop criteria on when to combine replacement of such asset types, as the costs for replacing these asset types are different from the asset types considered in this research.

As this research showed, the combined replacement of gas service lines and LV service cables tends to get more advantageous when these asset types are long. Since outside the densely populated areas, these connections are even longer, combined replacement can in these situations even be more favorable. However, as outside the densely populated areas the connections are far less consistently located in the same trench (Berg, 2007) possible advantages of combined replacement are only limitedly applicable here.

8.3.2 Relevance for other infrastructure operators

It is not solely the networks of Essent Netwerk that are ageing and need replacement in the upcoming decades; also other infrastructure operators in The Netherlands and even abroad face an ageing of their assets. Since the 1950s the amount of cables and pipes for water, gas, electricity and telecommunication in the Dutch underground has increased enormously (Pauwels and Wieleman, 2004). Still many of these cables and pipes are currently in operation and someday need replacement. Hence, the findings of this research might also be of interest for the parties that are operating these infrastructures.

The advice made by this research to coordinate the replacement of asset types is at least also applicable to the other distribution network operators of gas and electricity in The Netherlands since their situation is practically the same as for Essent Netwerk. Very likely the decision criteria they should use in such a coordinated approach, are quite similar. As this research was demarcated to the densely populated areas, since the negative effects of a stand-alone approach and the possible improvements were expected to be largest in these areas, a coordinated approach for the electricity and gas network operators in the Randstad, where population density is high, can lead to even more combined replacement possibilities and thus higher savings.

As Essent Netwerk operates both electricity and gas infrastructure, possibilities of combined replacement of its assets arise within one trench. As water and sewage operators are mono-disciplinary, they only have one asset type located in a trench; combined replacement of asset types in one trench thus does not arise for them. However, combined replacements of the main net and the connections might still be of interest for these parties. Telecom and CAI operators on the other hand do have multiple cables located at one route and thus in one trench, for the sake of reliability of supply and capacity (Pauwels and Wieleman, 2004). Therefore, for these operators a coordinated approach to replacement might be beneficial as well.

For all other infrastructure operators it holds that they should have some understanding of the failure behavior and expected replacement moments of their assets to see whether combined replacement and thus a coordinated approach can really be beneficial to them, both in terms of costs as in terms of reputation and compliance.

8.3.3 Demarcation of solution space; developments in the energy supply system

This research chose to search for alternative replacement approaches based on how replacement moments are planned and on the way replacements are physically executed and it thereby did not consider the possible future changes in the energy supply system.

Currently 98% of the energy supply in The Netherlands is coming from fossil fuels (Senternovem, 2007). The declining amount of fossil fuel reserves, the demand for a cleaner and more sustainable energy supply and the importance of becoming less dependent on the large oil and gas countries may however change the energy supply system in the future. The Dutch government aims at an energy transition to a more sustainable energy supply in 2050 (Senternovem, 2007). Possibilities mentioned for the energy transition are for instance the decentralized power generation by the application of micro-combined heat and power systems (micro-chp) in households, an increased use of sustainable energy sources, the use of hydrogen and the underground storage of CO_2.
Although many of such developments are still very uncertain and just in an experimenting or developing stadium it should be taken into account that they might demand changed characteristics of the current electricity and gas networks. An increased use of micro-chp's by households for instance may imply a changed configuration of the gas and electricity network; due to the decentralized production by using natural gas as a fuel the gas network should be capable of supplying relatively more gas to households, while the electricity grid should be capable of dealing with the returning of electricity by households. Would for instance the use of hydrogen by adding to natural gas increase, it could imply adjustments of gas pipelines in both size and material (Polman and Wolters, 2004).

It is likely more efficient to incorporate necessary adjustments that follow from the energy transition at the moment of replacing the aged assets than to adjust the network again afterwards. However, because of the very uncertainty of the energy transition developments, it is very difficult for distribution network operators to determine whether and which adjustments are necessary. Essent Netwerk should therefore closely watch the developments of energy transition and should research the possible implications. When it turns out that the replacement of assets should be combined with adjustments anticipating on a changing energy supply, the decision criteria developed in this research can still be used but should be verified and refined because of the different materials and dimensions of the gas and electricity assets that the adjustments imply.

8.4 Reflection on research approach

8.4.1 Reflection on fundamental assumptions

8.4.1.1 The moment of combined replacement

This research assumed that with separate replacement assets are replaced at their optimal replacement age and that combined replacement is initiated by an asset type that reaches its optimal replacement moment. It thus started from the idea that combined replacement takes place at the optimal replacement moment of one the concerned asset types. A consequence is that the research and the new approach are thus not developing *optimal combined replacement moments*, but consider whether combined replacement at the optimal replacement of one of the asset types is beneficial considering the optimal replacement moment of the other asset type.

Would this research have assumed that combined replacement is not necessarily to take place at the optimal replacement moment of one of the asset types it should have constructed a model that was both able to determine if combined replacement can be cheaper than separate replacement and if it is, when it would be the optimal moment to do so. Such an optimal combined replacement moment can then be seen as the optimal moment to combine replacements considered from the total of monetary expressed risks of not replacing the asset types at a certain moment and the costs of combined replacement of these asset types at a moment. The calculation model should have incorporated the failure behavior of assets, e.g. complex failure models should have been included for each specific asset type that calculates the risks of not replacing assets at a certain moment. The difference in these risk costs and the costs of combined replacement at each moment should have been compared to the difference in the total of risks costs of separate replacements and the total costs of the separate replacements. Such an approach might then result in a replacement moment that is later than the optimal replacement moment of the asset type that needs replacement first, since the risks of not replacing that asset type tolerate a somewhat later replacement when the costs of replacing are lower.

A consequence of the assumption made is thus that no optimization is made within combined replacement moments. However a consequence of developing an approach that searches for combination possibilities and for optimal combined replacement moments within these combination possibilities is that it makes both decision-making for the asset engineers and the planning of replacements more complex and time-consuming; The asset engineers would then not only have to find combination possibilities but also the best moments to execute them. In addition, it is expected that such an approach would yield only a marginal extra benefit. Moreover, such an approach allows a larger risk of failure for one of the asset types and it is doubtful whether this is desirable.

8.4.1.2 Using optimal ages moments from the long-term optimization research

With conducting the evaluation for the five cases this research used the optimal replacement ages that were found by the long-term optimization research. As already depicted, the long-term optimization research derived its conclusions for about 70 asset sub types, while in reality there are much more. The long-term optimization research for instance did not distinct in subtypes for the gas service lines and only provided one optimal replacement age for these service lines. In addition for the electricity cables it only provided information for two subtypes, while in reality there are more.
The question might arise whether using these roughly determined optimal replacement ages somehow influences the validity of the outcomes of this research. The answer is that it does not influence the validity of the decision criteria, but that it can only influence the potential of combined replacement in reality. After all, the derived decision criteria show break-even points, based on the whole set of possible differences in optimal replacement moments of assets and thus on the whole set of possible replacement ages of assets. The fact that optimal replacement ages in reality may diverge from those used in this research does not influence these break-even points, but influences whether differences in optimal replacement moments of assets are within these break-even points, and thus whether combined replacement is a better option than separate replacement.
To make appropriate decisions for combined or separate replacement the trick for Essent Netwerk is thus now to determine the correct optimal replacement ages, either by developing replacement policies or by developing temporary additional decision criteria, as described in 7.2.

8.4.1.3 Market development

This research assumed that the different replacement costs are not subject to changes in the market and therefore these costs were assumed to remain stable. This also provided a reason not to vary with these costs in the analysis of case results and parameter variation effects. The future development of these costs however might be uncertain.

Because of a tightening availability of contractors prices for digging/assembly and street restoration might increase. On the other hand, when network operators tend to combine replacements on a larger scale, contractors might also provide higher discounts on the digging/assembly and street restoration costs for combined replacements. For most of the combination options the above developments increase the potential of combined replacement, which make that the optimal replacement moments of asset types can diverge more for combined replacement to be cheaper.

With regard to the material costs the development of the raw material reserves might increase material costs. For instance with a decreasing availability of aluminum the material prices for the new electricity cables made of aluminium might be pushed. Since material costs remain the same regardless of combining replacements or not, no savings can be obtained on material costs with combined replacement. Therefore, higher material costs lead to a same increase in combined replacement costs as in separate replacement costs. However, since with separate replacement part of the material costs (namely those for the asset type that needs replacement later) are spent later and its present value is thus discounted, an increase in material costs leads to a smaller increase in separate replacement cost than in combined replacement costs. Therefore, increased material prices are not in favor of combined replacement at least for those combination options where the material costs of the asset which replacement is advanced are high. This might result in changed decision criteria with lower break-even points.

Hence, when the contractor or material costs are about to change in the future, it is necessary to verify the developed decision criteria.

8.4.2 Reflection on method

8.4.2.1 The use of cases

This research used an embedded study of 5 cases as its research strategy in determining whether combined replacement can be a better option than separate replacement. It also used the cases to derive decision criteria. The choice for this research strategy in this practice-oriented research seems obvious as both time and practical constraints make a survey or experiment as research strategy impossible.

A main concern of using cases is whether outcomes can provide a basis for scientific generalization (Yin, 1994). However, this research tried to depict the cases and the variation with input parameters such that the conclusions are representative for the entire demarcated system part and it moreover derived decision criteria such that they form secure lower limits.
Due to time and information constraints however it was not possible to endlessly vary with the values of input parameters; e.g. with 5 cases and the different considered combination options this would have led to an enormous set of outcomes to analyze. It therefore chose to confine the variation of input parameter values.

With confining the variation of input parameter values, it demarcated the pavement types to normal and decorated paving thereby assuming that decorated paving is the most expensive pavement type and normal pavement is the cheapest. The research did not consider asphalt as pavement type, but as discovered later on street restoration costs for this type of paving can exceed the street restoration costs for decorated paving. Since high street restoration costs can for certain combination options increase the potential but for another combination decrease the potential, this finding might change the break-even points and thereby the decision criteria somewhat when an asphalt street is concerned.

A quick scan for the combined replacement of gas mainlines and gas service lines where gas mainlines need replacement first (the combination option where potential is decreased with high street restoration costs) however showed that even with doubling the street restoration costs for decorated pavement, the depicted break-even point remains the same. For the combination options whom combination advantage gets higher when street restoration are increased it might mean that combined replacement gets already cheaper when optimal replacement moments of the concerned asset types diverge even more than depicted, in situations where asphalt is used.

Should the wish exist to refine the derived decision criteria one could choose to validate the case results with a more extensive variation in input parameter values. This could for instance be done as follows:

- Consider more different pavement type categories; this research considered normal paving and decorated paving, but possibly in between those two there are other types or there might be some additional pavement characteristics like cycle stands or flower tubs.
- Consider more different categories for the length of connections
- Consider the double/single sidedness more extensively; instead of either single-sided or double-sided, consider different lengths of the main net.
- Consider the variation in costs dependent on the diameter of asset types.

However, as the decision criteria already are pretty refined (the steps are already pretty close with regard to the break-even points) it is questionable whether such a refining would increase the quality of decision-making.

8.4.2.2 Quantification of performance indicators

This research chose for a partly quantitative evaluation of the approaches. It chose to express some of the performance indicators in costs and to thereby evaluate approaches based on their overall costs. This was followed by a qualitatively discussion of the effects on the soft factors.

Another method available to evaluate alternative approaches would have been to conduct a multi-criteria analysis for all performance indicators. However, since the amount of criteria (performance indicators) was limited, a multi-criteria analysis would not have been useful. Moreover, since the performance indicators that were quantitatively expressed easily allowed for such quantification, the choice for a quantitative analysis was obvious.

9. Conclusions and recommendations

9.1 Conclusions

The majority of the Dutch gas and electricity infrastructure is already in operation for decades and will need replacement soon. Since many of the assets are constructed during a relatively short period, their failure is also expected to occur in a condensed period. As one of the largest network operators in The Netherlands, Essent Netwerk faces this new issue of expected upcoming large-scale replacements. Essent Netwerk recently started with the creation of replacement policies for its electricity and gas assets and it is now wondering whether its current approach might be improved. The purpose of this research was to recommend Essent Netwerk whether it should continue its current track or should adopt a new approach. The research question to be answered was *"What is the optimal approach for Essent Netwerk to the replacement of its regulated and aged gas and electricity assets such that goals and constraints of long-term network operation are maximally fulfilled?"*
The research was demarcated to the gas service lines, gas mainlines, LV service cables and LV main cables of Essent Netwerk, located in densely populated areas.
The fact that not only the infrastructure of Essent Netwerk is ageing, but that also network operators of gas and electricity networks in other parts of the country and operators of for instance the sewage and telecommunication infrastructure face this issue, shows the social relevance of this research.

Overall conclusion – the optimal approach

The optimal approach for Essent Netwerk to the replacement of its regulated and aged assets such that the goals and constraint of long-term network operation are maximally fulfilled is found to be: **a coordinated approach in which possibilities of combined replacement of the multiple existing asset types are considered during the bottleneck-identification step at the Strategy Realization units of the Asset Management department, and, in which the decision criteria developed in this research can be used to decide whether the replacement of these asset types should be combined or not**.

Combined replacement of the gas service lines, LV service cables, gas mainlines and LV main cables of Essent Netwerk in densely populated areas, reduces the number of necessary excavations at one location, because of the geographic proximity of these demarcated infrastructure elements. This results in reduced total digging and assembly costs and in reduced street restoration costs.
Because of the expected replacement wave many assets need replacement closely after each other and for these asset types hence the optimal replacement moments are relatively proximate. Because of the lower digging, assembly and street restoration costs when combining replacements and because of the proximity of optimal replacement moments, combined replacement of above mentioned infrastructure elements can turn out cheaper than separate replacement. The total savings that can at least be obtained by adopting the new approach, and thus by choosing to combine replacements if this is beneficial, is over 100 million Euros, which is over 6% of the total replacement value of the totality of concerned asset types.
Whether combined replacement is really cheaper than separate replacement mainly depends on the advancement of replacement of one of the asset types with combined replacement, on the sum of the street restoration costs depending on the pavement type, on the length of connections and on the configuration of the main net.

Besides the cost savings that can be obtained, combining replacements also turned out to be in certain situations the only option to comply with the municipal ‘no-dig period’ regulation and it turned out to decrease inconvenience and thereby contribute to a better reputation of Essent Netwerk.
Because of the above mentioned benefits that can be obtained with combined replacement as compared to separate replacement, a coordinated approach in which possibilities for combined replacement are considered and the choice to combine or separately replace assets is deliberated, is therefore expected to better fulfill Essent Netwerk’s goals and constraints of long-term network operation. This research derived decision criteria that indicate when to combine replacement and these criteria can be used with the new approach. Since these decision criteria comprise secure lower limits showing when to combine replacements, they are rather generally applicable. Essent Netwerk can however choose to verify and fine-tune them by using the provided calculation model.
Implementation of the approach implies that tasks of asset engineers change and that more cooperation between asset engineers is required. Implementation of the new approach demands that, as long as there are no replacement policies for all asset types, an explicit framework should be made by the Strategy Development unit, enabling asset engineers to determine when the asset types need replacement. When freeing time for the additional work and adjusting the new procedures based on comments from the Strategy Realization units, adoption and acceptation of the new approach by these units is expected to be relatively easy. The new approach additionally demands intensified cooperation of the different departments within the Infra Services units and the need for focus on replacement activities within these units. Moreover, the monitoring and controlling process by Asset Management is expected to get more complicated with the new approach because of more departments are involved. A suggestion is to set up a separate replacement department within the Infra Services units. At least enough attention should be paid to the adoption and acceptance of the new approach by the Infra Service units. Moreover, the Infra Services units should search for more multidisciplinary contractors to execute combined replacements.

A reflection on the research findings showed that the expected outflow of personnel supports the need to adopt the new approach and it shows that findings of this research might also be relevant for other infrastructure operators.

9.2 Recommendations

This research recommends Essent Netwerk to adopt a coordinated approach to the replacement of its aged assets. To get the new approach implemented and let it work as smoothly as possible this research would like to do the following recommendations:

- The Strategy Development unit should translate the results of this research into new procedures for their replacement activities. It can thereby choose to use the presented decision criteria and guidelines in their new procedures. It can however also decide to prescribe the use of the calculation model to determine for each situation the obtainable combination advantage and thereafter use the qualitative decision criteria to finalize its decision.
- The Strategy Development unit should set up a clear and explicit framework that enables the asset engineers at the Strategy Realization units to determine the replacement moments of those asset types for which currently no replacement policy is available. The framework should be easy and unambiguous and verified based on criticisms and suggested improvements of asset engineers.
- The Strategy Realization units should get comfortable with making the decision for combined or separate replacement based on the decision criteria and guideline and/or the calculation model

developed in this research and the additional criteria of the Strategy Development unit. Therefore an extensive introduction of the new approach to these units is recommended.

- Essent Netwerk should consider the possibilities of setting up a separate unit within the Infra Services unit specially dedicated to the replacement of assets.
- Essent Netwerk should pay extra attention to the introduction of the Infra Services department to the new approach and its implications. They should thereby show them the advantages of the new approach.
- The Strategy Development unit should continue with the development of the currently lacking replacement policies.
- After the first combined replacements have been executed the decision criteria should be verified and could be refined when considered necessary with help of the constructed calculation model. For this purpose, the costs and the proceedings of the first combined replacements should be observed and registered very precisely.
- Regarding the next replacements in the far future and the improvement of the order of the underground infrastructure, an additional recommendation for replacements in general is to clearly register the information (like location, construction year) of the new assets, as it turned out during this research that information on the aged assets was not was always complete (e.g. as said there was no information on construction year of the LV service cables).

Furthermore, this research would like to do some recommendations on possibilities to extend the new approach:

- Except for coordinating replacements of multiple asset types it might also be valuable to coordinate replacements with other work streams. During a workgroup the author joined, it became clear that sometimes reconstructions are executed while a year later the concerned asset type is replaced. The coordinated approach can possibly be extended and cover multiple work streams of Essent Netwerk. Except from combined replacement options one could then also consider combined reconstruction and replacement options for instance.
- In order to take into account personnel capacity for the longer term and thereby anticipate on changing capacity, one could extend the replacement approach by considering combined replacement options for the longer term. Within the Strategy Realization units asset engineers could search for aged assets per residential area or street for instance and determine when these assets need replacement in the upcoming years. Based on personnel capacity one could then plan possible combined replacement such that it uses the available capacity as efficient as possible. It should be noted here that this requires more extra work on the short term for the Strategy Realization units.
- As this research claimed, combining replacements with other infrastructure operators can be beneficial, but there appear to be some bottlenecks and lacunas to be overcome first. Therefore further research might be done on the advantages, disadvantages and possibilities of combining replacements with other infrastructure operators.

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Appendices

Appendix 1- Persons interviewed

Person	Date	Function	Interview subject	Referenced as
Aarssen, Kees van der	31/05/07, 22/06/07, 12/06/07	Network designer. Essent Netwerk; IS; AE&I; A&E Breda.	Quantifying combined and separate replacement; Cost components replacement activities; Cost specification replacement	Aarssen, 2007
Bakker, Roland	03/09/07	Senior strategy developer. Essent Netwerk; AsM; SO.	Organizational implications of incorporating the combine-separate decision	Bakker, 2007
Berg, Arthur van den	April, 2007 28/08/07	Strategic Engineer. Essent Netwerk; AsM-SR; Strategy Realization unit Breda	General information on asset types; Selecting cases	Berg, 2007
Dijk, Tjark van	April 2007	Senior strategy developer. Essent Netwerk; AsM; SO.	Trenchless replacement electricity assets	Dijk, 2007
Goedhart, Francois	04/06/07	HSE advisor. Essent Netwerk; HSE.	Safety incidents caused by digging activities	Goedhart, 2007
Jager, Saskia de	26/04/07	Strategy developer. Essent Netwerk; AsM-SO.	Current replacement approach; Conceptualization of combined and separate replacement	Jager, 2007b
Kerst, Jan-Eric	27/03/07	Contract engineer. Essent Netwerk; AsM-SR; Strategy Realization unit Breda.	Current replacement approach; Communication between Asset Management department and Infra Services department	Kerst, 2007
Martijn Korn	12.04.07 and 10/06/07	Risk analyst, AsM-SO, Essent Netwerk	Current replacement approach; Long-term optimization report; Quantifying combined and separate replacement	Korn, 2007
Mischgofsky, Erik	30/05/07	Head corporate research. Geodelft	Combining replacement with other network operators	Mischgofsky, 2007
Jurgen Mutsaers	27/03/07 And 24/08/07	Manager of Strategy Realization unit Breda. Essent Netwerk; AsM-SR.	Current replacement approach; Communication between Asset Management department and Infra Services department; Organizational implications of incorporating the combine-separate decision	Mutsaers, 2007
Pepijn van Oort	08/06/07	Researcher. University of Wageningen; centre of Geo-Information.	Quantifying combined and separate replacement: Digging incidents: probability and effect	Oort, 2007
Maaike Pol	09/05/07 and 07/09/07	Network strategist. Essent Netwerk; AsM-SO.	Current replacement approach; Organizational implications of incorporating the combine-separate decision	Pol, 2007
Marco Poorts	20/08/07	Manager Strategy Development unit. Essent Netwerk; AsM-SO.	Municipal rules Organization implication of incorporating the combined-separate decision	Poorts, 2007
Henk Schimmel	28/08/07 and 06/09/07	Senior asset engineer. Essent Netwerk; AsM; SR; Strategy Realization unit Groningen.	Organizational implications of incorporating the combined-separate decision	Schimmel, 2007
Fer Siegersma	06/06/07	Senior purchaser. Essent Netwerk; Purchase & Logistics.	Quantifying combined and separate replacement; Cost components replacement activities	Siegersma, 2007
Johan Slegers	11/04/07	Manager AE&I.	Current replacement approach;	Slegers, 2007

		Essent Netwerk; Infra Services unit West-Brabant	Municipal rules- no dig period; Communication between Asset Management department and Infra Services department	
Peter Verbeek, and Tjark van Dijk	03/09/07	Senior strategy developer. Essent Netwerk; AsM; SO. (both).	Potential of trenchless replacement	Dijk and Verbeek, 2007
Auke Versteeg	16/07/07	Account manager. Essent Netwerk; IS; Infra Services unit West-Brabant.	Municipal rules: 'no-dig period'	Versteeg, 2007
Paul Vissia	04/04/07	Manager O&S. Essent Netwerk; Infra Services unit West-Brabant.	Current replacement approach; Municipal rules- no dig period; Communication between Asset Management department and Infra Services department	Vissia, 2007
Hanneke Vroom	06/04/07	Communication advisor. Essent Netwerk; Communication department	Reputation of Essent Netwerk; influence of replacement activities.	Vroom, 2007
Bas Wehman	05/04/07	Manager Strategy Realization. Essent Netwerk; AsM-SR.	Current replacement approach	Wehman, 2007
Ype Wijnia	21/03/07 23/04/07; 08/05/07; 06/07/07; 24/08/07	Risk Manager. Essent Netwerk: AsM	Long-term optimization report; Current replacement approach; General information on asset replacement; Conceptualization of combined and separate replacement Alternative approaches; Quantifying combined versus separate replacement; Discounting costs for separate replacement (NPV)	Wijnia, 2007

Table 19 Persons interviewed. AsM = Asset Management department, SO= Strategy Development unit, SR = Strategy Realization unit, IS= Infra Services department.

Appendix 2A – Sub division of asset types

This (sub) division is based on the division made in the long-term optimization research.

Underground electricity assets:

- LV service cables:
  - LV service cable GPLK
  - LV service cable alkudi
- LV main cables:
  - LV main cable GPLK
  - LV main cable alkudi
- MV distribution cables:
  - MV cable GPLK
  - MV cable XLPE
  - MV cable VPE waterboom
- MV transport cables:
  - MV transport cable GPLK
  - MV transport cable XLPE
  - MV transport cable VPE waterboom
- MV connection cables
- HV cables

Underground gas assets:

- Gas service lines
  - Gas service lines
- Low pressure mainlines:
  - Low pressure 100 mbar mainline PE
  - Low pressure 100 mbar mainline AC
  - Low pressure 100 mbar mainline Crude iron
  - Low pressure 100 mbar Steel
  - Low pressure 100 mbar PVC
  - Low pressure 30 mbar mainline PE
  - Low pressure 30 mbar mainline AC
  - Low pressure 30 mbar mainline Crude iron
  - Low pressure 30 mbar mainline Steel
  - Low pressure 30 mbar mainline PVC
- High pressure gas mainlines:
  - High pressure 8 bar PE
  - High pressure 8 bar Crude iron
  - High pressure 8 bar Steel
  - High pressure 4 bar PE
  - High pressure 4 bar Crude iron
  - High pressure 4 bar Steel
  - High pressure 1 bar PE
  - High pressure ‘Nod. Gietijzer’
  - High pressure 1 bar crude iron

- High pressure 1 bar Steel

Electricity asset above surface:

- HV poles and lines:
- Switchgear
  - HV switches
  - MV transport open power switches
  - MV transport closed oil power switches
  - MV transport closed air/gas power switches
- Substations/transformers:
  - HV/MV
  - Open installation
  - Installation synthetic
  - Installation metal
  - LV kast
  - LV rek
- Protection equipment:
  - HV protection equipment
  - MV protection equipment electric
  - MV protection equipment digital

Gas assets above surface:

- District stations
- Supply stations
- Transfer stations

Appendix 2B – Replacement activities per asset type

By reviewing the internal documents concerning replacements and by conducting interviews, it is found for which asset types, replacement activities for the large-scale replacement have been undertaken. The table shows that for the gas service lines and for a specific type of MV installation the entire process has been preceded and that for those asset types the first replacement are now executed. By further analyzing how these processes were preceded, the current approach to replacement can be characterized.

Asset type	Activities taken	Current status
Electricity		
Switchgear	-	
Protection equipment	-	
HV lines	-	
HV cables	-	
HV poles	-	
Substations		
MVT protection installations	-	
MV transport cables	-	Expected in 2009
MV distribution cables	Mentioned in Strategic Asset Management Plan	
MV connection cables	-	Replacement policy expected in 2009
Transformers:HV/MV, MV/LV	**Major part:** Mentioned in Strategic Asset Management Plan Integral inventory of MS installations subtypes and brands that need advanced preventive replacement ***COQ:*** *RA COQ-installations* *Long-term replacement plan COQ (comprises strategy and tactic)* *Translated in annual plan for 2007* *Translated into SLA's for IS for 2007*	***COQ:*** *First part is now executed at IS*
LV cables	Mentioned in Strategic Asset Management Plan	Replacement policy expected in 2009
LV connections	-	
Gas		
Stations (district, supply, transfer)	-	
High pressure pipelines (8, 4 and 1 bar)	-	
Low pressure pipelines (100 and 30 mbar)	Mentioned in Strategic Asset Management Plan	Risk analysis is being made
Gas Service lines	*RA, Strategy, Tactic finished* *Translated in annual plan for 2007* *Translated into SLA's for IS for 2007*	*First part is now executed at IS*

Table 20 Replacement activities and current status per asset type

Appendix 2C – System demarcation

1. System demarcation

For each asset type it is determined whether they fulfill the characteristics of the demarcated system part as determined in chapter 2:

- Located underground
- Located in densely populated areas
- High proximity to other assets of Essent Netwerk

	Located underground?	Located in densely populated areas?	High proximity to other assets of Essent Netwerk?	Within demarcated system part?
Electricity				
Switchgear	No			No
Protection equipment	No			No
HV lines	No			No
HV cables	Yes	No		No
HV poles	No			No
Substations	No			No
MVT protection installations	No			No
MV transport cables	Yes	No		No
MV distribution cables	Yes	Partly	No	No
MV connection cables	Yes	No		No
Transformers:HV/MV, MV/LV	No			
LV main cables	*Yes*	*Yes*	*Yes*	*Yes*
LV service cables	*Yes*	*Yes*	*Yes*	*Yes*
Gas				
Stations (district, supply, transfer)	No			No
High pressure pipelines (8, 4 and 1 bar)	Yes	Partly	No	No
Low pressure *pipelines (100 and 30 mbar) (gas mainlines)*	*Yes*	*Yes*	*Yes*	*Yes*
Gas Service lines	*Yes*	*Yes*	*Yes*	*Yes*

Table 21 System demarcation. MVD = MV distribution cables, MVT = MV transport cables

2. Quantification of demarcated system

From the above, it follows that the research is demarcated to the LV main cables, the LV service cables, the low pressure gas mainlines and the gas service lines of Essent Netwerk that are located in densely populated areas. The following formulas were used to quantify these demarcated infrastructure elements:

- **# of connections (gas service lines and LV service cables) in densely populated areas = % of people in densely populated areas * # of total connections**

In which it is assumed that the percentage of people in densely populated areas of the total amount of people is the same as the percentage of households in densely populated areas of the total amount of households. And in which one connection per household is assumed.

- **Length main cables or mainlines in densely populated areas = # of connections in densely populated areas * average net length per connection**

The percentage of people in densely populated areas is derived from the amount of people living in densely populated areas per province compared to the total amount of people in a province, based on data from CBS:

	People in densely pop.	People in rural areas	People in somewhat dens. pop.	total	perc. densely pop.
Drenthe (PV)	36,200	353,080	95,210	484,490	0.07
Friesland (PV)	100,300	461,270	102,150	663,720	0.15
Groningen (PV)	151,730	339,190	83,130	574,050	0.26
Limburg (PV)	299,940	608,030	223,970	1,131,940	0.26
Noord-Brabant (PV)	763,240	1,133,770	518,940	2,415,950	0.32
Overijssel (PV)	320,560	574,470	218,500	1,113,530	0.29

Table 22 Calculation of people in densely populated areas in Essent Netwerk working areas. (Calculations based on CBS, 2007).

The information on the number of connections, net length per connection and total cable and pipeline lengths is derived from the data indicator guide of Essent Netwerk (Essent Netwerk, 2007a). Since in reality in the province of Friesland Essent Netwerk only operates gas and no electricity, the province of Friesland is left out.

Province	% of people in densely pop. areas	# gas serv. lines	# gas serv. lines in densely pop. areas
Groningen/Drenthe	0.17	398,930	67,625
Limburg	0.26	466,975	123,738
Brabant-Oost	0.32	155,792	49,217
Brabant-West	0.32	292,977	92,556
Overijssel	0.29	319,331	91,928
Total		*1,634,005*	*425,066*

Table 23 Amount of gas service lines located in densely populated areas. (Calculations based on CBS, 2007 and Essent Netwerk, 2007a). Note: the lengths for LP pipelines include both the 100 mbar and the 30 mbar pipelines.

With an average net length of 0,018281 Km per service line as derived from the data indicator guide of Essent Netwerk (2007a), the total length of gas mainlines in densely populated areas becomes:
*425066 * 0,018281 = 7771 km* of gas mainlines in densely populated areas.

Province	% of people in densely pop. areas	# serv. cables	# serv. cables in densely pop. areas
Groningen/Drenthe	0.17	476,243	80,731
Limburg	0.26	510,711	135,328
Brabant-Oost	0.32	481,710	152,180
Brabant-West	0.32	487,206	153,917
Overijssel	0.29	455,786	131,210
Total		*2,411,656*	*653,366*

Table 24 Amount of LV service cables and LV main cables in densely populated areas. (Calculations based on CBS,2007 and Essent Netwerk, 2007a).

With an average net length of 0,03689 km per service cable as derived from the data indicator guideline of Essent Netwerk the total length of LV main cables in densely populated areas becomes:
*653366 * 0,03689 = 24104 km* of LV main cables in densely populated areas.

Essent Netwerk does not operate gas and electricity in exactly the same areas. In some parts of the country it only operates the electricity network. Since the system is demarcated to those situations where *multiple assets of Essent Netwerk are located*, as stated in chapter 2, not the entire amounts presented in the tables above are relevant. For the purpose of this research it is assumed that Essent Netwerk operates electricity in all areas where it operates the gas network. Based on this assumption, the number of LV connections that can be demarcated is the same as the number of gas connections. This also holds for the length of the LV cables. With this assumption, the total amount of gas service lines, gas mainlines, LV service cables and LV main cables then become:

	total	located in densely pop. areas and in proximity of other assets of Essent Netwerk	% of total
LV service cables(#)	2,411,656	425,066	18
LV cables (km)	81,032	7,771	10
LP service lines (#)	1,634,005	425,066	26
LP pipelines (km)	27,589	7,771	28

Table 25 Amount of infrastructure located in densely populated areas, divided per asset type.

Replacement value of the demarcated system part

To calculate the value of the assets to be replaced and to thereby give an idea of the amount on which savings can be obtained, the replacement value of the concerned asset types is determined. Since Essent Netwerk does not have information on the book value of these assets, the replacement value is taken. These replacement values are based on the costs of replacing these assets as calculated by this research.

asset type	amount		replacement value total system (Euro)	located in densely populated areas and in proximity of other assets of Essent Netwerk		replacement value demarcated part (Euro)
gas service line	1,634,005	(#)	901,970,760	425,066	(#)	234,636,432
LV service cable	2,411,656	(#)	1,210,651,312	425,066	(#)	213,383,132
gas mainline	27,589	(km)	2,345,065,000	7,771	(km)	660,535,000
LV main cable	81,032	(km)	5,996,368,000	7,771	(km)	575,054,000
			10,454,055,072			**1,683,608,564**

Table 26 Replacement values of demarcated amount of assets. (Calculated based on Wijnia et al., 2005).

Appendix 3A - Stakeholder and network analysis

For deriving the goals and constraints of long-term network operation, a stakeholder and network analysis is conducted. According to Bryson the success of an organization depends on the satisfaction of the needs of the key stakeholders. Therefore Essent Netwerk should take the interest of its key stakeholders central in its decision-making. This research first searched for the key stakeholders. In order to do so, it used the methodology used by Enserink et al. (2006); it first listed all stakeholders somehow involved with Essent Netwerk. Thereafter, it determined, based on substitutability and the resources of these stakeholders to influence Essent Netwerk, which stakeholders are critical. For these critical (key) stakeholders, a goal analysis is executed (see Appendix 3B). By considering the goals of the key stakeholders with regard to the network operation of Essent Netwerk, the goals and constraints should use in their decision-making can be derived.

3A-1 List of stakeholders

- **Authorities**
    - Dutch government
    - Ministry of Economic Affairs:
        - NMa
        - DTe
    - Ministry of VROM
    - European Union
    - Municipalities
    - Provinces
    - OvV (Research body for Safety)
- **Private/ semi-private organizations:**
    - Essent NV
    - TenneT
    - Gasunie
    - Other distribution network operators
    - Other infrastructure network operators
    - Contractors
    - Material suppliers
    - Energy producers, traders & suppliers
- **Representative bodies:**
    - EnergieNed
    - Environmental organizations
    - VNG
    - LTO
    - VEMW
    - Consumers’ union (‘consumentenbond’)
    - KLIC
    - ARBO
    - Unions
- **Non-organized stakeholders:**

- Small-scale consumers
- Large-scale consumers
- Private landowners
- Own/hired personnel

3A-2 Criticality of actors

Based on actors' resources, its possibilities for substitution and the dependence of Essent Netwerk on these actors, the criticality of the actors can be determined. Critical actors are thus the actors that can practice a certain amount of influence on the company of Essent Netwerk, for instance by giving sanctions, arrange protests, causing delays etc. The critical actors are seen as the actors that are important for determining a company's goals.

Actor	Resources	Possibilities for substitution	Dependence	Critical actor?
Essent NV	Market knowledge Technical knowledge	No	Large	Yes
Municipalities	Decision-making authorities Regulation and rules License allotment	No	Large	Yes
Provinces	Decision-making authorities Regulation and rules License allotment	No	Large	Yes
Ministry of Economic Affairs	Decision-making authorities Regulation and rules	No	Large	Yes
Ministry of VROM	Decision-making authorities Regulation and rules	No	Medium	No
European Union	Decision-making authorities Regulation and rules	No	Medium	No
Large-scale consumers	Blocking power	No	Small	No
Small-scale consumers	Blocking power	No	Small	No
Own personnel/ hired personnel	Blocking power	Yes	Small	No
Contractors	Blocking power	Yes	Small	No
NMa	Supervising	No	Large	Yes
DTe	Supervising	No	Large	Yes
OvV	Advising			No
Tennet	Market knowledge Technical knowledge	No	Medium	No
Gasunie	Market knowledge Technical knowledge	No	Medium	No
Other distribution network operators	Market knowledge Technical knowledge	Yes	Small	No
Other infrastructure network operators	Market knowledge Technical knowledge	Yes	Small	No
Energy producers, traders, suppliers in Essent Netwerk areas	Market knowledge Technical knowledge	Yes	Small	No
EnergieNed	Advising	Yes	Small	No
Unions	Advising Blocking power	Yes	Small	No
ARBO/VGM	Advising	Yes	Small	No

VEMW	Advising	Yes	Small	No
LTO	Advising	Yes	Small	No
VNG	Advising	Yes	Small	No
Consumers' union	Advising Blocking power	Yes	Small	No
Environmental organizations	Advising Blocking power	Yes	Small	No

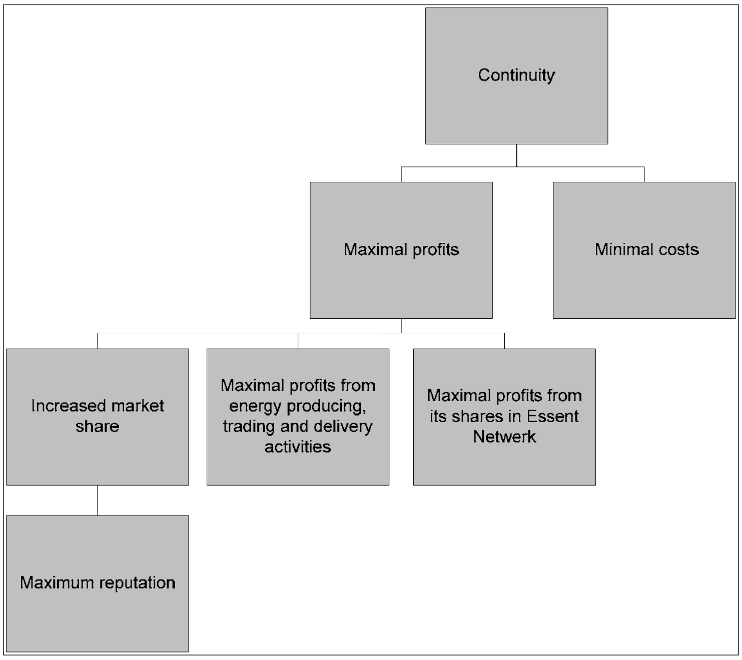
Table 27 Criticality of actors.

Some of the described substitutability's and dependencies are obvious. Others however might need some explanation. The OvV (Research body for Safety) is considered important, since it may advise the minister of Economic Affairs to adopt certain measures. Its influence however is indirectly and therefore OvV in itself is not considered a critical actor. The ministry of Economic Affairs, NMa and DTe are all considered critical actors. The NMa and DTe are independent official bodies, responsible for the execution and supervision of laws that are developed by the ministry. In the remainder of this stakeholder analysis, they are seen as one actor.

Appendix 3B- Goal analysis key stakeholders

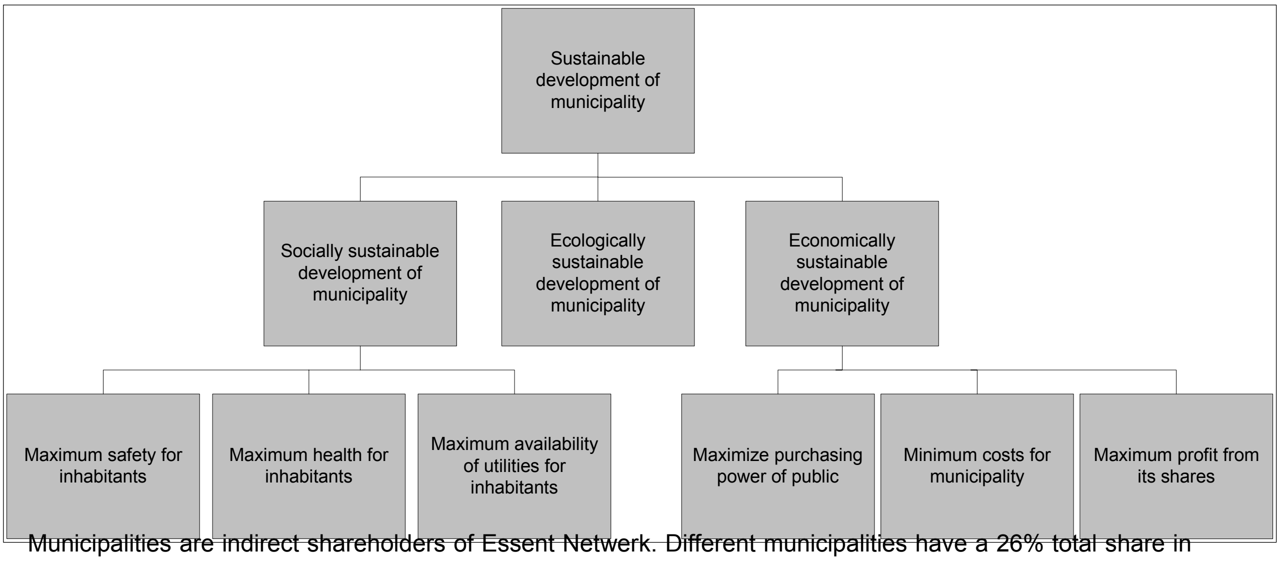
This appendix provides the goal analyses of the key stakeholders. The goals these stakeholders have with regard to the network operation of Essent Netwerk can thereafter be translated into the goals and constraints Essent Netwerk should use in its decision-making.

Essent NV



Essent NV is the direct shareholder of Essent Netwerk. In its role as shareholder, Essent NV is obliged, according to the Gas and Electricity law 1998, to respect the independent position of Essent Netwerk (Jong, 2004). As a shareholder, Essent NV expects a good profit share from Essent Netwerk. Essent NV and Essent Netwerk are legally, organizationally and accounting wise separated. However, for the public they are most of the time still seen as one. This means that image-forming of the one can influence the other.

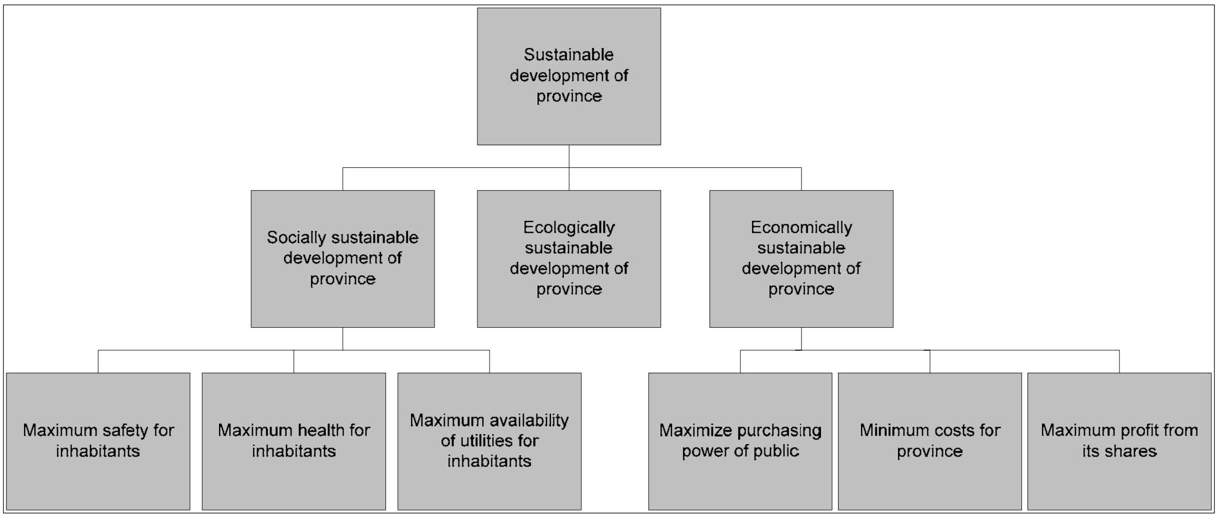
Municipalities



Municipalities are indirect shareholders of Essent Netwerk. Different municipalities have a 26% total share in Essent NV and indirectly expect a reasonable profit share from Essent Netwerk's activities.

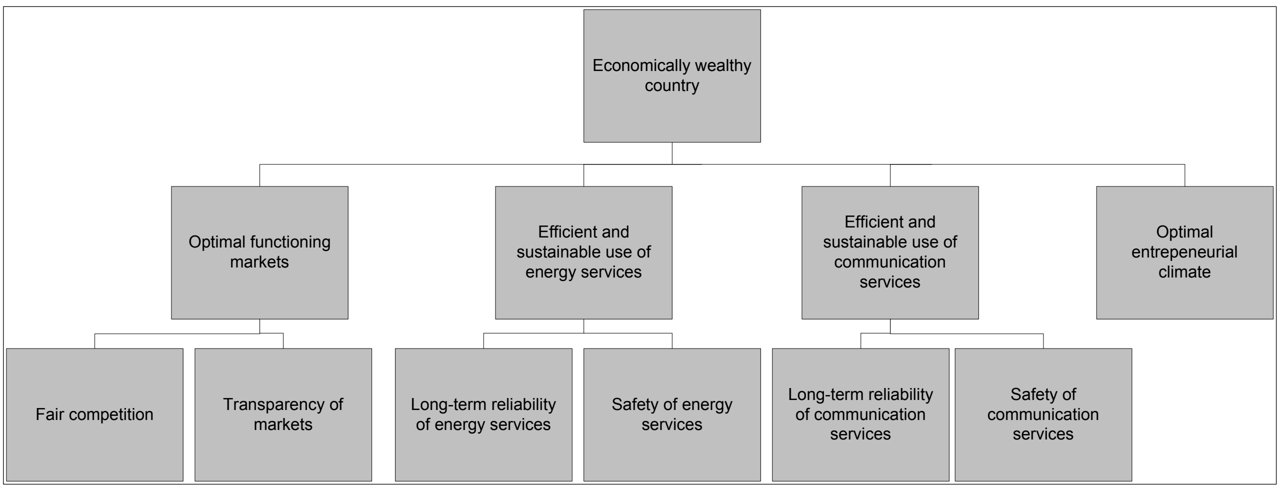
With regard to the activities of Essent Netwerk, a municipality formulates and provides certain licenses necessary for Essent Netwerk to execute its activities. Second, a municipality is a representative body for its residents; it desires an optimal living condition for its habitants, which also includes good working energy services (Chappin et al., 2007). Third, a municipality is an infrastructure operator, for instance of the public roads and sewer system. A municipality is consequently in many ways involved in the activities of Essent Netwerk and has various instruments to influence Essent Netwerk. Currently, there seems to be a decreasing confidence of municipalities and provinces in the reliability and safety of networks and municipalities appear to interfere more with network operators (Vroom, 2007). With its network operation Essent Netwerk should comply with the municipal rules, and to prevent that the increased interference lead to a tightening of these rules, Essent Netwerk is helped with a good reputation towards the municipalities (Vroom, 2007).

Provinces



Provinces are the other indirect shareholders of Essent Netwerk. Provinces have a 74% share in Essent NV and thus indirectly influence Essent Netwerk. Except from the influence provinces have as a shareholder, Essent Netwerk also has to cope with the different provincial rules and regulations.

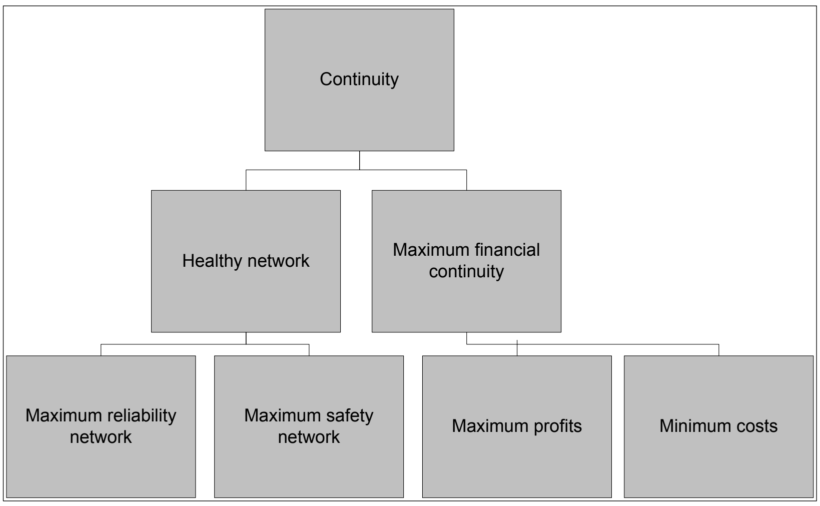
Ministry of Economic Affairs: NMa and DTe



The main vision of the ministry of Economic affairs is to create and maintain and economically wealthy country. With regard to the energy market, it desires an optimal functioning energy market, with long-term reliable and safe energy services (Ministry of Economic Affairs, 2007a). The main relevant laws for network operators that are supervised by the ministry are the Electricity and Gas law, the Competition law and with regard to activities in the underground the new 'Grondroerdersregeling' ('soil-stirring regulation').

The Competition law is aimed at preventing economic power positions and to stimulate fair competition in the Dutch market and it is executed and supervised by the separate body of the ministry; the NMa.
The execution and supervision of the Electricity Law 1998 and the Gas law is in hands of the independent body of the ministry; DTe. These laws legally sign up that energy networks should be accessible for other players, the market should be transparent and network operators should not misuse their market power towards consumers (DTe, 2007). In line with the Electricity and Gas law, different conditions are formulated with which Essent Netwerk should comply. To protect consumers from high tariffs the DTe uses 'price-cap regulation' in which tariffs are limited to a maximum. With price cap regulation, the revenues for Essent Netwerk thus become an independent factor, while it stimulates it to lower costs (Wijnia et al., 2005). To prevent network operators from focusing too much on cutting costs and thereby lowering quality, DTe introduced the q-factor, which is a measure for the quality (reliability) of supply (De Vries et al., 2004). This provides an extra reason for Essent Netwerk to keep its reliability at a sufficient level.
The 'Grondroerdersregelinng' is a new regulation to prevent incidents caused by digging activities. It amongst others obliges operators to notify digging activities and to guarantee careful digging (Ministry of Economic affairs, 2007b). Its supervision is in hands of an agency of the ministry of Economic Affairs.

Essent Netwerk BV



Essent Netwerk itself wants to keep its network healthy while remaining a good financial position. Regulation puts pressure on maximum tariffs, which creates an extra motivation for Essent Netwerk to minimize its costs.

Appendix 5A – Digging incident probability and effects

The report by Pauwels and Wieleman (2004) published the following table on digging incidents, divided per asset type.

Network[1]	Type	Size(km)	Depth[3](cm)	Damage probability[4]	Damage costs[5]
Electricity	High voltage (50/110/150kV)	3,500	100	Small	$$$$
	Medium voltage(3-25 kV)	103,000	80	Normal	$$$
	Low voltage (0.4kV)	150,000	60	Large	$$
Gas transport	High pressure (40-80 bar)	11,600	1.20	Very small	$$$$$
Gas distribution	Medium and high pressure (1-8 bar)	34,000	90	Small	$$$$
	Low pressure (<0.1 bar)	88,150	90	Normal	$$
City heating		3,600	80-100	Small	$$$$
Telecommunication (Group)	Routes (mostly 2 coats per route)	>15,000	30-60	Very large	$$
Telecommunication (KPN)	Routes	225,00	30-60	Very large	$$
CAI(Radio/TV)	Routes (mostly 2 coats per route)	>150,000	30-60	Very large	$
Sewage		82,406	110	Very small	$$$
Water	Main net and transport net	109,366	100	Small	$$$
Industrial pipelines	40-100 bar	3,500	120	Very small	$$$$$
Public lightning		<150,000		Very large	$
Connections[2]	(all nets)	>150,00	30-90	Very large	$
Remaining[6]	(unknown)	unknown			
Total		<1,279,122			

1. Numbers coming from Energiened, Rioned, Vewin, and from interviews with Gasunie, KPN and Telecom Group Graafrechten
2. The number of houses at January 1, 2003 was according to CBS 6.76 million. Length of connections therefore is roughly estimated at: 6.76 million* 4meter * (6 utilities) is approximately 150,000 km.
3. These are average indicating depths
4. Damage probability: Very large: on average >10,000 damages per year versus Very small: on average < 50 damages per year.
5. Impression of damage costs: $: <250 Euro versus $$$$$ > 75.000 Euro
6. There is an unknown amount (probably thousands) of kilometres of cables and pipelines of other parties (private and companies)

Table 28 Digging incidents probabilities and effects. (Translated from Pauwels and Wieleman, 2004).

By assuming a linear relation between the smallest and the highest probability of digging incidents and a linear relation between the damage costs, the different probabilities and amounts are calculated, presented in the table below:

	# damage per year	damage costs
very small	50	250
small	2.538	18.938
normal	5.025	37.625
large	7.513	56.313
very large	10.000	75.000

Table 29 Probability per year and costs per digging incident by assuming linear relation between qualitative probabilities and costs of the NEN research by Pauwels and Wieleman (2004).

It should be noted that these are estimations. It is unclear whether the relations are linear. An inquiry at the authors of the NEN report revealed that there is no detailed information available on the probabilities and damage costs, and that the information in their table was a qualitative interpretation of interviews with relevant network operators. However, it seems to be the only possible way to determine probabilities on digging incidents.

By using the total lengths of the infrastructures presented in the table of Pauwels and Wieleman (2004), the probability per km cable or line and the accompanying costs per damage are determined.

type	#km	chance	chance per km cable/line	damage costs	chance*damage (euro/km)
GAS					
gas low pressure	88,150	normal	0.05701	small	1,079.53
gas med/high pressure	34,000	small	0.07463	large	4,202.73
gas service line	27,040	very large	0.36982	very small	92.46
ELECTRICITY					
HV	3,500	small	0.72500	large	40,826.56
MV	103,000	normal	0.04879	normal	1,835.59
LV maincable	150,000	large	0.05008	small	948.45
LV service cable	27,040	very large	0.36982	small	7,003.51
TELECOM					
Telecom maincable	225,000	very large	0.04444	small	841.67
Telecom connection	27,040	very large	0.36982	very small	92.46
INTERNET					
CAI	150,000	very large	0.06667	very small	16.67
CAI service cable	27,040	very large	0.36982	very small	92.46
SEWAGE					
sewage mainline	82,406	very small	0.00061	normal	22.83
sewage serviceline	27,040	very large	0.36982	very small	92.46
WATER					
water	109,366	small	0.02320	normal	872.97
water serviceline	27,040	very large	0.36982	very small	92.46

Table 30 Probabilities and costs per digging incident per infrastructure and asset type.

Assuming that the service cables and lines and the main cables and lines are located very close to one another and assuming that once a digging incident occurs during an excavation, no other digging incident occurs, the average probability of a digging incident and the average damage costs can be determined. Hereby a distinction is made between the probability of a digging incident on a service cable or line and the probability of a digging incident on a main cable or line.

The results are as follows:

	Service cables/lines	Main cables/lines
Average probability of hitting	**0.369822485**	**0.040334702**
Average costs per hit	**92.4556213**	**630.3535846**

Table 31 Average probabilities and digging incident costs, divided in connections and main net.

Appendix 5B – Method quantitative analysis

The costs for separate replacement of asset type X and asset type Y can be determined as follows:

Costs SEP_X

Costs SEP_X = Replacement costs SEP_X + Costs CML SEP_X + Digging incident costs SEP_X

- **Replacement costs SEP_X =** Total replacement costs of separate replacement of asset type X. These are:
  - Digging costs = Digging costs per m. or # asset type X in case of separate replacement * m. or # asset type X
  - Assembly costs = Assembly costs per m. or # asset type X in case of separate replacement * m. or # asset type X
  - Street restoration costs = Street restoration costs per m. or # asset type X in case of separate replacement * m. or # asset type X
  - Material costs = Material costs per meter or # asset type X * m. or # asset
- **Digging incident costs SEP_X =** Total costs digging incidents of separate replacement of asset type X. These are determined by:
  - Probability of digging incidents per m. of ground excavated* length of ground excavated * damage costs per digging incident
- **Costs CML SEP_X =** Total costs of customer minutes lost of separate replacement of asset type X These are determined by:
  - Probability of interruptions per digging incident * probability of digging incident per m. of ground excavated * length of ground excavated * costs per customer minute lost

Costs SEP_Y

Costs SEP_Y = (Replacement costs SEP_Y + Costs CML SEP_Y + Digging incident costs SEP_Y)

These are calculated at the same way as for Costs SEP_x but then for asset type Y.

Appendix 5C - Specification of data

5C-1 Cost composition Digging/assembly costs

The digging and assembly costs for the replacement are based on the costs contractors charge in Noord-Brabant and Limburg. The cost composition of these digging/assembly costs depends on the asset type and the combination option. Based on interviews with Essent Netwerk a cost composition for each asset type and combination option is derived.
For each cost composition the costs can be derived from the tariff manual of contractors in Noord-Brabant and Limburg.

SEPARATE REPLACEMENT

With regard to the gas service line and LV service cable the contractors uses cluster prices in which all actions for the replacement of the gas service line or LV service cable are included.

Gas service line

- Cluster price solo replacement gas service line (per gas service line)

LV service cable:

- Cluster price solo replacement LV connection cable (#)

Gas mainline:

- Cluster price solo construction gas mainline (m)
- Removal gas mainline (m): costs for removing the old gas mainline
- Installing (at 2 points): with replacing the gas mainline the new gas mainline needs to be installed at 2 places.
- Conversion (per gas service line): with replacing the gas mainline all service lines have to be converted to the new gas mainline.

LV main cable:

- Cluster price solo construction LV main cable
- Removal LV main cable (m): costs for removing the old main cable
- Installing (at 2 points); for installing the new main cable 2 assembly pits need to be made and 2 linkages are made;
    - assembly pits
    - linkages
- Conversion (per LV service cable): with replacing the LV main cable all service cables have to be converted to the new main cable.

COMBINED REPLACEMENT

Combined replacement of gas service line and service cable:

- Cluster price combi replacement gas service line (per gas service line)
- Cluster price combi replacement LV service (per LV service cable)

Combined replacement of gas mainline and LV main cable:

- Cluster price combi construction gas mainline (m)
- Cluster price combi construction LV main cable (m)
- Removal gas mainline (m)
- Removal LV main cable (m)

- Installing (at 2 points)
- Installing (at 2 points)
    - montage gat
    - verbindingsmof
- Conversion (per gas service line)
- Conversion (per LV service cable)

Combined replacement of gas service line and gas mainline:

- Cluster price solo replacement gas service line (#)
- Cluster price solo construction gas mainline (m)
- Removal gas mainline (m)
- Installing (at 2 points)

With the combined replacement of gas service line and mainline, the conversion of service lines to the mainline is only charged once, since this conversion only have to take place with combined replacement. The costs for conversion with combined replacement of gas service line and mainline are included in the cluster price for combined replacement of the gas service line.

Combined replacement of all asset types together:

- Cluster price replacement gas service line in combi trench (#)
- Cluster price replacement LV service cable in combi trench (#)
- Cluster price construction gas mainline in combi trench (m)
- Cluster price construction LV main cable in combi trench (m)
- Removal gas mainline (m)
- Removal LV main cable (m)
- Installing (at 2 points)
- Installing (at 2 points)
    - assembly pit
    - linkage

5C-2 Street restoration costs

In the cases two different paving types are considered:

- A combination of normal bricks and paving stones
- Decorated paving

For street restoration cost charged by contractors the following amounts are assumed:

- Normal bricks/paving E trench 6.72 p/m
- Normal bricks/paving G trench 8.44 p/m
- Normal bricks/paving combi trench 8.44 p/m (since it is assumed that a combi trench is the same as the G trench)
- Decorated paving E trench 11.31 p/m
- Decorated paving G trench 13.76 p/m
- Decorated paving combi trench 13.76 p/m

With regard to street restoration costs, the contractors also distinguish costs for restoration of boulders, of which the costs are between costs for normal bricks/paving and decorated paving. However, this research only considers either normal paving or decorated paving.

Remuneration costs municipalities

The precise composition of costs charged by municipalities depends on the agreements made between municipalities and contractors. However, for the cases and the constructed model the following fixed amounts are assumed:

- Normal bricks 23.70 p/m
- Normal paving 23.70 p/m
- Decorated paving 41.58 p/m

These costs are based on estimated averages of costs charged in the municipalities of Breda, and Bergen op Zoom. These costs include degeneration costs, costs for street restoration, maintenance costs and monitoring costs. In the calculations it is assumed that no trees or plants need to be recovered. Moreover no special situations like cycle stands are assumed.

5C-3 One fixed asset sub type for each asset type

The policy of Essent Netwerk with regard to new assets, prescribes that for all assets of a certain asset type that are replaced a fixed sub type replaces the old. In addition, this research assumes that the influence of differences in diameter of the asset types is very small and therefore one diameter type is assumed. As such, the following fixed asset sub types are used for each asset type:

Asset type	Chosen as fixed new asset sub types
Gas service line	Buis Peko 15cu/25PE L=2,50m +kopp. WD2,3 Buis Peko 15cu/25PE L=3,75m +kopp. WD2,3 Buis Peko 15cu/25PE L=5,00m +kopp. WD2,3 Buis Peko 15cu/25PE L=7,50m +kopp. WD2,3
LV service cable	Kabel LS 4* 6 VO-YMVKASMB 0,6/1KV
Gas mainline	Buis SLV-PVC 110,0*2,7 GL SDR41
LV maincable	Kabel LS 4* 50+4*2,5 750V VVMvKhsas as25

Table 32 One fixed sub type for each asset type.

5C-4 Optimal replacement ages of concerned asset types and sub types

Asset	Optimal replacement age
Gas service line	29
Gas mainline 100 mbar PE	29
Gas mainline 100mbar AC	46
Gas mainline 100 mbar crude iron	33
Gas mainline 100 mbar steel	34
Gas mainline 100 mbar PVC	29
Gas mainline 30 mbar PE	29
Gas mainline 30 mbar AC	29
Gas mainline 30 mbar crude iron	46
Gas mainline 30 mbar steel	34
Gas mainline 30 mbar PVC	29
LV main cable GPLK (both main and service cable)	51
LV main cable alkudi (both main and service cable)	20

Table 33 Optimal replacement ages per asset type. (Based on Wijnia et al., 2005).

Appendix 5D – Example set of input parameters

LENGTH OF ASSETS, PAVEMENT TYPE AND ASSET SUB TYPE

asset type	serviceline gas	servicecable LV	mainline gas	maincable LV
nr. of connections	48	48		
length of connections	2	2		
length of mainnet			400	400
type	steel	gplk	gietijzer 100	gplk
type of pavement	normal bricks and paving stones			

CONSTRUCTION YEAR AND OPTIMAL REPLACEMENT AGE

For combined replacement GS-ES

	GS	ES	
yr. construction	1953	1953	
opt. repl. age	56	94	
opt. repl. year	2009	2047	
years too early			38
combination advantage	reduced clusterprice combi replacement		

For combined replacement GM-EM

	GM	EM	
yr. construction	1953	1953	
opt. repl. age	67	94	
opt. repl. year	2020	2047	
years too early			27
combination advantage	reduced clusterprice combi replacement		

For combined replacement GS-GM

	GS	GM		
yr. construction	1953	1953		
opt. repl. age	56	67		
opt. repl. year	2009	2020		
years too early			11	
combination advantage	0,75 of total digging and street recovery conversion is charged once, only in clusterprice of connection			0,75

For combined replacement of all

	GS	ES	GM	EM
yr. construction	1953	1953	1953	1953
opt. repl. age	56	94	67	94
opt. repl. year	2009	2047	2020	2047
years too early	0	38	11	38
combination advantage	0,75 of total digging and street recovery conversion is charged once, only in clusterprice of connection			0,75

REPLACEMENT COSTS

Digging/assembly costs			
assettype/combi	*cost component*	*code in database*	*price*
SEPARATE REPLACEMENT			
GS	Clusterprice solo replacement gas serviceline (#)	GC79	389,8 #
ES	Clusterprice solo replacement LV connection cable (#)	EC79	368,6 #
GM	Clusterprice solo construction gas mainline (m)	GC01	9,99 m
	Removal gas mainline (m)	G289	6,52 m
	Installing (at 2 points)	GC22	253,4 #
	Convertion (per gas serviceline)	G591	84,05 Per serviceline
EM	Clusterprice solo construction LV main cable	EC01	8,75 m
	Removal LV main cable (m)	EO31	1,2 m
	Installing (at 2 points)		
	montage gat	E167	27,34 #
	verbindingsmof	S017	49,11 #
	Convertion (per LV service cable)		63,4 Per service cable
COMBINED REPLACEMENT			
GS-ES	Clusterprice replacement gas serviceline in combi trench (#)	GC80	348,5 #
	Clusterprice replacement LV service cable in combi trench (#)	EC80	334,3 #
GM-EM	Clusterprice construction gas mainline in combi trench (m)	GC03	7,11 m
	Clusterprice construction LV maincable in combi trench (m)	EC02	6,74 m
	Removal gas mainline (m)	G289	6,52 m
	Removal LV main cable (m)	EO31	1,2 m
	Installing (at 2 points)	GC22	253,4 #
	Installing (at 2 points)		
	montage gat	E167	27,34 #
	verbindingsmof	S017	49,11 #
	Convertion (per gas serviceline)	G591	84,05 per service line
	Convertion (per LV service cable)	S017	63,4 per service cable
GS-GM	Clusterprice solo replacement gas serviceline (#)	GC79	389,8 #
	Clusterprice solo construction gas mainline (m)	GC01	9,99 m
	Removal gas mainline (m)	G289	6,52 m
	Installing (at 2 points)	GC22	253,4 #
ALL	Clusterprice replacement gas serviceline in combi trench (#)	GC80	348,5 #
	Clusterprice replacement LV service cable in combi trench (#)	EC80	334,3 #
	Clusterprice construction gas mainline in combi trench (m)	GC03	7,11 m
	Clusterprice construction LV maincable in combi trench (m)	EC02	6,74 m
	Removal gas mainline (m)	G289	6,52 m
	Removal LV main cable (m)	EO31	1,2 m
	Installing (at 2 points)	GC22	253,4
	Installing (at 2 points)		
	montage gat	E167	27,34 #
	verbindingsmof	S017	49,11 #

Street restoration costs		
Tariff type	**normal bricks and paving stones**	
assettype/combi	*cost component*	*price*
GS	restoration costs A contractor included in clusterprice replacement A	
	remuneration costs municipality	23,7 m
ES	restoration costs B contractor included in clusterprice replacement B	
	remuneration costs municipality	23,7 m
GM	restoration costs contractor trench C	8,44 m
	remuneration costs municipality	23,7 m
EM	restoration costs contractor trench D	6,72 m
	remuneration costs municipality	23,7 m
GS-ES	restoration costs A and B included in clusterprice replacement A and B	
	remuneration costs municipality	23,7 m
GM-EM	restoration costs contractor trench CD	8,44 m
	remuneration costs municipality	23,7 m
GE-GM	restoration costs A contractor included in clusterprice replacement A	
	restoration costs C contractror trench C	8,44 m
	remuneration costs municipality	23,7 m
ALL	restoration cost A and B contractor included in clusterprices replacement A and B	
	restoration costs C contractror trench C	8,44 m
	remuneration costs municipality	23,7 m

Material costs	
GS	37 #
ES	2,63 m
GM	3,79 m
EM	4,95 m

DIGGING INCIDENT COSTS

	servicelines/cables	mainline/cables
Digging incident probability (per kn	0,369822485	0,040334702
Costs per digging incident (1)	92,4556213	630,3535846
total costs per km	34,19216762	25,42512399

CUSTOMER MINUTES LOST COSTS

	LV service	LV main
Probability of hitting LV cable	0,061637081	0,00672245
Probability of interruption per diggi	1	
CML per interruption (3)	1300	
CML costs	0,5	

Appendix 6A – Breakdown of savings obtained by combining replacements & additional information on combination options

This appendix shows for each combination option in each case the savings that can be obtained. The presented savings are the *maximal* savings that can be obtained, which implies that they are calculated without discounting the investment of the separate replacement that would actually take place later in time. The real combination advantage that can be obtained is thus also dependent on how much that asset type is replaced before its optimal replacement with combined replacement.

	GS-GM	GS-ES	GM-EM	All
Digging+assembly	21.9 %	10.0 %	12.0 %	31.5 %
As part of total costs	12.4 %	8.0 %	4.4 %	17.37 %
Street recovery costs	25.0 %	50.0 %	48.6 %	61.6 %
As part of total costs	9.1 %	7.5 %	27.1 %	23.6 %
Material costs	0.0 %	0.0 %	0.0 %	0.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Digging incident costs	25.0 %	58.3 %	58.3 %	91.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
CML costs	46.8 %	100.0 %	100.0 %	100.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.00 %
Total	21.6 %	15.5 %	31.5 %	41.0 %

Table 34 Maximum obtainable savings when combining replacements for case 1. The absolute and relative savings are shown.

	GS-GM	GS-ES	GM-EM	All
Digging+assembly	21.9 %	10.0 %	11.5 %	31.3 %
As part of total costs	12.6 %	8.0 %	4.3 %	17.6 %
Street recovery costs	25.0 %	50.0 %	48.6 %	61.7 %
As part of total costs	8.9 %	7.5 %	26.8 %	23.1 %
Material costs	0.0 %	0.0 %	0.0 %	0.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Digging incident costs	25.0 %	58.3 %	58.3 %	89.7 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
CML costs	46.0 %	100.0 %	100.0 %	100.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Total	21.5 %	15.5 %	31.1 %	40.7 %

Table 35 Maximum obtainable savings when combining replacement for case 2.

	GS-GM	GS-ES	GM-EM	All
Digging+assembly	23.1 %	10.0 %	10.4 %	31.9 %
As part of total costs	11.4 %	7.2 %	3.0 %	15.3 %
Street recovery costs	25.0 %	50.0 %	48.9 %	61.9 %
As part of total costs	11.3 %	11.8 %	32.3 %	29.2 %
Material costs	0.0 %	0.0 %	0.0 %	0.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Digging incident costs	25.0 %	58.3 %	58.3 %	87.4 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
CML costs	0.5 %	100.0 %	100.0 %	100.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Total	22.7 %	19.0 %	35.2 %	44.4 %

Table 36 Maximum obtainable savings when combining replacement for case 3.

	GS-GM	GS-ES	GM-EM	All
Digging+assembly	22.8 %	10.0 %	10.7 %	31.7 %
As part of total costs	13.1 %	7.2 %	4.2 %	17.8 %
Street recovery costs	25.0 %	50.0 %	48.7 %	61.8 %
As part of total costs	9.0 %	11.3 %	26.0 %	23.3 %
Material costs	0.0 %	0.0 %	0.0 %	0.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Digging incident costs	25.0 %	58.3 %	58.3 %	83.5 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
CML costs	36.8 %	100.0 %	100.0 %	100.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Total	22.1 %	18.5 %	30.1 %	41.1 %

Table 37 Maximum obtainable savings when combining replacement for case 4

	GS-GM	GS-ES	GM-EM	All
Digging+assembly	24.3 %	10.0 %	8.5 %	32.3 %
As part of total costs	14.1 %	6.4 %	3.8 %	18.4 %
Street recovery costs	25.0 %	50.0 %	48.6 %	62.0 %
As part of total costs	8.7 %	15.0 %	23.6 %	22.8 %
Material costs	0.0 %	0.0 %	0.0 %	0.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Digging incident costs	42.2 %	58.3 %	58.3 %	75.3 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
CML costs	30.3 %	100.0 %	100.0 %	100.0 %
As part of total costs	0.0 %	0.0 %	0.0 %	0.0 %
Total	22.8 %	21.4 %	27.4 %	41.2 %

Table 38 Maximum obtainable savings when combining replacement for case 5.

The tables show for each combination option the savings per cost type that are obtained when combining replacements instead of separately replace these asset types. It shows both the absolute saving and the saving as part of the total costs accompanied with separate replacement of the concerned asset types. The row 'total' presents the total savings that can be obtained with combined replacement as compared to the total costs of separate replacement.

Combined replacement of gas service lines and LV service cables

With combining the replacement of a gas service line and LV service cable located in a same trench less ground is excavated and the total costs for digging/assembly are reduced. Although contractors charge special prices for replacing assets in a 'combi-trench', the costs are only however 10% lower than with separate replacement. With combining the replacement less paving needs to be restored; however, costs for street restoration for connection trenches are relatively low as compared to those of main trenches and therefore the relative savings from reduced street restoration costs are substantially less than for combined replacement of the gas mainline and LV main cable

Combined replacement of gas mainline and LV main cables

The savings are composed as follows: The costs for street restoration as well as the remuneration costs that municipalities charge make up a large part of the total costs and these costs are halved when replacement are combined. Too, the reduced amount of ground excavates is translated into reduced digging/assembly costs; contractors give a 25-30% discount on part of the digging/assembly costs when executing multiple replacements at once. However, combining replacement does not reduce the assembly costs for the conversion of the gas service lines to the mainline and the service cable to the new main cable and therefore the reduced digging/assembly costs with combined replacement are limited. The saving on the digging/assembly costs is lower as compared to combined replacement of the connections, since, in contrast to the connections, for the main net no package prices consist.

Combined replacement of gas service lines and gas mainlines (GS-GM)

Combining the replacement of gas service lines and gas mainlines turned out cheaper than separate replacement in all cases, as became clear in 6.2.2. With combining the replacement of these asset types a substantial saving can be obtained in the digging/assembly costs, as tables 34-38 show. With combined replacement the gas service lines only have to be converted once to the main line and therefore only be charged once. This substantially lowers the total costs charged for digging/assembly with combined replacement. The absolute saving on street restoration costs is smaller than for the other combination options because the reduced amount of ground excavated with combined replacement is limited.

Combined replacement of all asset types together

Combining the replacement of all four asset types together can obtain the highest savings as compared to replace these assets separately. Less ground is excavated than with separate replacement, less paving needs restoration and conversion of connections to the mains is required only once.

Appendix 6B – Analyzing case results & developing decision criteria

6B- 1. The influence of input parameter variation

The cases show different results. To find out more about these different results, the differences in input parameters were considered. Differences for the following input parameters are considered:

- Construction year
- Optimal replacement age of asset (this and the above together determine the optimal replacement moment)
- Pavement type and the accompanying street restoration costs per meter
- Length of connections
- Length of main net, which is divided in two type of lengths; the length when the net is located on one both sides of the street (double-sided) or when it is located in the middle of the street (single-sided)

This appendix shows the analysis of these factors with regard to the combination advantage.

Construction year and asset type: optimal replacement moments

The construction year and the asset type used influence the replacement moment. When optimal replacement moments diverge too much, combined replacement looses its potential to be cheaper than separate replacement. There is a strong relation between the difference in optimal replacement moments of the concerned asset types and the obtainable combination advantage. Analysis of the cases showed that there is always a certain difference in optimal replacement moments where the combination advantage turns out positive. These break-even points at which combined replacement gets cheaper than separate replacements are shown in the table below for each combination option in the cases. Thus; in case 1 combining the replacement of the gas service line and the gas mainline gets cheaper than separately replacing these assets when the optimal replacement moments of the gas mainline is within 12 years after that of the gas service line.

	Break-even points at which combined replacement gets cheaper
case 1	
GS-GM	12
GS-ES	7
GM-EM	24
case 2	
GS-GM	15
GS-ES	9
GM-EM	26
case 3	
GS-GM	20
GS-ES	11
GM-EM	34
case 4	
GS-GM	13
GS-ES	11
GM-EM	24
case 5	
GS-GM	21
GS-ES	13
GM-EM	21

Table 39 Break even points at which combined replacement get cheaper than separate replacement.

The higher the break-even point, the more potential combined replacement has. The table shows that the differences in optimal replacement moments at which combined replacement gets cheaper than separate replacement differ per combination option and case. Why for instance can optimal replacement moments for combination option of gas service lines and gas mainline diverge so much more in case 5 than in case 1?

Since there appears to be always a certain difference in optimal replacement moments at which the combination advantage turns out positive, namely the break-even point, it is interesting to see what happens with this break-even point when input parameters change. Later on, this break-even point can then be used as decision criterion; when optimal replacement moments of the concerned asset types differ less than this break-even point, the combination advantage is positive and replacement should thus be combined. The input parameters influence the obtainable combination advantage per combination and hence the break-even point. The remainder of this Appendix presents what the influence of the other named input parameters is on the break-even points. The information is used in chapter 6 to discuss the influence of these parameters on both the combination advantage and the break-even points.

Influence of street restoration costs

Street restoration costs vary per pavement type; the cheapest are the normal bricks and paving stones and the most expensive the decorated pavement. In cases 1, 2, 4 and 5 the paving was made of normal bricks and paving stones. The break-even points were researched when the pavement type changes from normal bricks and paving stones to decorated pavement for these cases. The results are shown in the table. The costs used for decorated pavement are found in Appendix 5C.

	case 1 + decorated paving
GS-GM	11
GS-ES	9
GM-EM	32
	case 2 + decorated paving
GS-GM	20
GS-ES	11
GM-EM	34
	case 4 + decorated paving
GS-GM	15
GS-ES	14
GM-EM	32
	case 5+ decorated paving
GS-GM	20
GS-ES	18
GM-EM	28

Table 40 Break even points when paving is decorated and consequently increased street restoration costs are charged.

Additionally the table below shows what happens when in case 3 the paving would not be decorated but would consist of normal bricks and paving stones.

	case 3 with lower street restoration costs
GS-GM	13
GS-ES	12
GM-EM	24

Table 41 Break even point of combination options in case 3 when paving is normal and thus fewer street restoration costs are charged.

The tables show that with increased street restoration costs (e.g. street restoration costs for decorated pavement):

- The break-even point for combined replacement of GS-ES (gas service lines and LV service cables) gets higher than in base case; thus combined replacement of gas service lines and LV service cables gets always more advantageous when street restoration costs are higher. This is because with higher street restoration costs the relative saving that can be obtained on the total replacement costs is higher.
- The break-even point for combined replacement of GM-EM (gas mainline and LV main cable) gets always higher than with normal pavement, thus , for the same reason as above, combined replacement of these asset types gets more advantageous when street restoration costs are higher.
- The break-even point for combined replacement of GS-GM (gas service line and gas mainline) gets higher in case 2 and 4, where the gas mainlines needs replacement earlier than gas service line.
- The break-even point for combined replacement of GS-GM (gas service line and gas mainline) gets lower in case 1 and 5 where gas service lines needs replacement earlier than gas mainline.

The difference in the effects for the combination option of gas service lines and gas mainlines has to do with the ratio of costs for separate replacement of the gas service line and gas mainline. This is further explained in the main text of chapter 6.

Influence connection length

In some cases connections were longer than in other cases. The length of connections influences the break-even points. As minimum length the minimum length present in the cases is assumed: 2 meters. In analyzing cases when connections are longer, a connections length of 7.5 meter is assumed. The results are shown in the table below.

case 1 longer connections	
GS-GM	14
GS-ES	13
GM-EM	24
case 2 longer connections	
GS-GM	13
GS-ES	13
GM-EM	26
case 3 longer connections	
GS-GM	13
GS-ES	18
GM-EM	34
case 4 longer connections	
GS-GM	12
GS-ES	13
GM-EM	24

Table 42 Break-even points when the gas and electricity connections are longer (7.5m.) than in the normal situation.

case 2 shorter connections	
GS-GM	16
GS-ES	7
GM-EM	26
case 3 shorter connections	
GS-GM	17
GS-ES	9
GM-EM	34
case 4 shorter connections	
GS-GM	14
GS-ES	7
GM-EM	24
case 5 shorter connections	
GS-GM	16
GS-ES	7
GM-EM	21

Table 43 Break-even points when the gas and electricity connections are shorter (2m.).

The tables show that when connections get longer:

- The break-even point for combined replacement of GS-ES (gas service lines and LV service cables) gets higher; thus combined replacement of these asset types gets more advantageous when connections are longer. This is because with longer connections the total costs for digging/assembly and street restoration are higher and thus the relative saving with combined replacement gets higher.
- The break-even points for combined replacement of GM-EM do not change.
- The break-even point for combined replacement of GS-GM (gas service lines and gas mainlines) gets lower than in the base case for cases 2, 3 and 4 where the gas mainline need replacement earlier than the gas service lines.
- The break-even point for combined replacement of GS-GM (gas service lines and gas mainlines) gets higher than in the base case for case 1 where the gas service line need replacement earlier than the gas mainline.

When connections are shorter the opposite happens.

Configuration of main net

The main net can be single or double. When it is double, it inherently is longer than when it is single. This implies that more excavation is necessary. The influence is shown in tables 44 and 45.

When the main net would be single sided:

- The break-even point for combined replacement of GS-GM (gas service lines and LV service cables) gets higher in cases 1 and 5 where the gas service lines need replacement earlier than the gas mainline.
- The break-even point for combined replacement of GS-GM (gas service lines and LV service cables) gets lower in cases 2, 3, 4 where the gas mainlines need replacement earlier than the gas service line.

- The break-even point for combined replacement of GM-EM gets lower; thus combined replacement of these asset types gets less advantageous when the main net would be single.

case 1 + single sided infra	
GS-GM	20
GS-ES	7
GM-EM	19
case 2 + single sided infra	
GS-GM	12
GS-ES	9
GM-EM	21
case 3 + single sided infra	
GS-GM	11
GS-ES	11
GM-EM	25
case 4 + single sided infra	
GS-GM	10
GS-ES	10
GM-EM	19

Table 44 Break-even points when the main is single-sided instead of double sided for those cases where in base situation the main net was double-sided.

case 5 double sided	
GS-GM	12
GS-ES	13
GM-EM	26

Table 45 Break-even points for case 5 when main net is double sided, while in real situation it is single-sided.

6B- 2 Deriving decision criteria

The break-even point at which combined replacement always gets cheaper than separate replacement can be used as a decision criteria; when we know that combined replacement of gas service lines and LV service cables always is cheaper when the optimal replacement diverge 7 years or less, it is easy to make the decision for combined replacement when for instance the LV service cable needs replacement 3 years after the gas service line. This part of Appendix 6 is aimed at finding the break-even points for each combination option at which combined replacement is **always** cheaper. To find these break-even points at which combined replacement gets always cheaper then separate replacement, the combination options are evaluated for each case by setting the conditions of the case at the least favorable for that combination option. The smallest found break-even point throughout the cases is then said to be the break-even point at which combined replacement always is cheaper than separate replacement for that combination option.

Moreover, this analysis is aimed at finding how much more these optimal replacement moments can diverge when conditions are changed; when for instance the paving type is decorated paving, what would then be the break-even point at which the combination advantage gets positive? To find these break-even points, one of the input parameters is constantly changed and again with that parameter changed the smallest found break-even point throughout the cases is taken as the break-even point under that specific condition.

The variation is as follows:

- Street restoration costs: normal bricks/paving stones (low costs) VS. decorated paving(high costs)
- Main net configuration: double VS. Single
- Connection length: Short (2-7.5m) and long (=>7.5m), in which the latter is valid until 16 m.

In those cases where short connections are least favorable the break-even point is found using a connection length of 2. For finding the break-even point when connections are long, a connection length of 7.5m is used. For all combination options it holds that the gas assets need replacement first. When for the combination options that concern a gas and electricity asset it is said that ‘optimal replacement moments can diverge *x* years for combined replacement to be cheaper than separate replacement it implies that combined replacement is cheaper when the electricity asset needs replacement within *x* years after the gas asset.

Gas service lines – LV service cables (GS-ES)

To find out when combined replacement of these asset types is always cheaper than separate replacement, this combination is tested under its the worst possible conditions. As became clear from the previous part of this Appendix, this is when connections are short and paving is normal. In this case the break-even points at which combined replacement becomes cheaper are as follows:

Normal street rest. costs + short connections					
	case 1	case 2	case 3	case 4	case 5
GS-ES	7	10	7	7	7

From this it can be said, that combined replacement of gas service lines and LV service cables **always** is cheaper when optimal replacement moments diverge **7 years or less**.

Combined replacement of gas service lines and LV service cables however can be cheaper when optimal replacement moments diverge more when some of the conditions are changed. The previous part showed that combined replacement of gas service lines and LV service cables gets more advantageous when:

- The connections are long
- When street restoration costs are high.

Optimal replacement moments can hence diverge more when these input parameters are changed:

- **Street restoration costs are high:** Higher street restoration costs make the potential for combined replacement of the gas service lines and LV service cables increase. When connections are short and the street restoration costs are high, it results into the following differences in optimal replacement moments at and below which combined replacement is always cheaper:

Short connections and high street restoration costs					
	case 1	**case 2**	**case 3**	**case 4**	**case 5**
GS-ES	9	9	9	9	9

  So, when street restoration costs are high (thus when paving is decorated) combined replacement of gas service line and LV service cable is always cheaper when optimal replacement diverge 9 years or less.

- **Connections are long**: The potential of combined replacement of gas service lines and LV service cables increases when the connections are longer. What happens when the street restoration costs are normal and the connections are long, is shown in the table below.

Long connections and normal street restoration costs					
	case 1	case 2	case 3	case 4	case 5
GS-ES	13	13	13	13	13

- **Connections are long and street restoration costs are high**: And what happens when both connections are long and the street restoration costs are high? This information is shown in the table below:

Long connections and high street restoration costs					
	case 1	**case 2**	**case 3**	**case 4**	**case 5**
GS-ES	18	18	18	18	18

For case 5 and case 3 this information can be found in respectively table 40 and table 42. It shows that when both connections are long (=>7.5 meter) and street restoration costs are high, optimal replacement moments can diverge 18 years.

Gas mainline - LV Main cable (GM-EM)

When the main net is single-sided and the costs for street restoration are low, the potential for this combination option is smallest. In these situations the break-even at which combined replacement gets cheaper are as follows:

Normal street rest. costs. + single sided					
	case 1	**case 2**	**case 3**	**case 4**	**case 5**
GM-EM	19	21	19	19	21

Thus combined replacement of these asset types is **always** cheaper than separate replacement when optimal replacement moments diverge 19 years or less.

The previous part of this Appendix showed that combined replacement of gas mainline and LV main cable gets more advantageous when:

- The street restoration costs are high
- The main net is double sided

Optimal replacement moments can thus diverge more when these conditions are changed:

- **Double-sided main net**: When the net is double-sided the potential for combined replacement increases; In this case as the table below shows, combined replacement is always cheaper when the optimal differences in replacement moments of the gas mainline and LV main cable (GM-EM) diverge 24 years or less.

Double sided and normal street restoration costs					
	case 1	**case 2**	**case 3**	**case 4**	**case 5**
GM-EM	24	26	24	24	26

- **Street restoration costs are high**; with high street restoration costs the potential of combined replacement increases for combined replacement of gas mainlines and LV service cables. However, when the net is single sided, the amount of main net to be replaced is shorter and thereby the ground to be excavated and the street to be restored, which decrease the obtainable savings from combined replacement. With a single-sided net and high street restoration costs the differences in optimal replacement moments from below which combined is always cheaper are calculated and presented in the table below:

Single sided and high street restoration costs					
	case 1	case 2	case 3	case 4	case 5
GM-EM	26	28	25	26	28

Thus when costs for street restoration are high, because of decorated pavement and when the net is single sided, combined replacement is always cheaper when optimal replacement moments diverge 25 years or less.

- **Street restoration costs are high and net is double-sided**: The potential for combined replacement of the main net is higher when the net is double-sided than when it is single-sided; after all table 44 show that when the main net is single sided the optimal replacement moments of gas main and LV main can diverge less than when the net is double-sided (as in table 39 for cases 1-4). This implies that when the net is double-sided and the street restoration costs are high, there is high potential for this combination option. The maximal differences in optimal replacement at which combined is always cheaper are calculated and presented in the table below. For case 3 this information can be derived from table 39 and for cases 1, 2 and 4 from table 40; for case 5 a separate calculation is made.

Double sided and high street restoration costs					
	case 1	case 2	case 3	case 4	case 5
GM-EM	32	32	34	32	34

Since the break-even point at which combined replacement always gets cheaper when either the main net is double-sided or the costs for street restoration are high are very close, it is decided in the decision guideline to take them together as one decision step; when optimal replacement moment diverge 24 years or less and either the main net is double sided or the street restoration costs are high, the replacements should be combined.

<u>**Gas service line-Gas mainlines (GS-GM)**</u>

Gas service line – Gas mainline with gas service lines that need replacement first

As this is the situation in case 1 and 5, break-even points for this combination option are derived from these cases.

When the main net is double-sided, the connections are short and the street restoration costs are high, this combination option has the smallest potential as became clear from the previous part. As the table below shows, in these situations combined replacement would always be cheaper only when optimal replacement moments diverge 9 years or less.

Double-sided and short connections		
GS-GM	case 1	case 5
high street rest. costs	11	9

With short connections it is assumed here connections of 2 meter; moreover it is assumed that 2 meter is the minimal length of connections.

The analysis in the previous part showed that combined replacement of gas service lines and the gas main when the service line need replacement first, gets more potential if:

- The connections are longer
- When the main net is single sided

The influence on the break-even point is described below:

- **Longer connections:** With longer connections the combined replacement of gas service lines and mainline gets more potential. With a double-sided net and long connections (7.5 meter), the differences in optimal replacement moments at and from below which combined is always cheaper are calculated and presented in the table below:

Double-sided and short connections		
GS-GM	case 1	case 5
normal street rest. costs	14	12
high street rest. costs	14	12

As the table shows, the costs of street restoration do not influence the differences. When the connections are longer combined replacement of gas service lines and mainline always gets cheaper when optimal replacement moments diverge 12 years or less.

- **Single-sided configuration of main net:**

Single-sided and short connections		
GS-GM	**case 1**	**case 5**
normal street rest. costs	20	16
high street rest. costs	17	14

When the net is singe sided, combined replacement always is cheaper than separate replacement when the optimal replacement diverge 14 years or less with decorated paving and 16 years or less with normal paving.

- **Longer connections and single sided configuration of main net:** when the net is single sided and the connections are long the potential for combined replacement of gas service lines and gas mainline is highest. In case of decorated paving, the optimal replacement moments can diverge 20 years or less and with normal paving 21 years or less.

Single-sided and long connections		
GS-GM	**case 1**	**case 5**
normal street rest. costs	26	21
high street rest. costs	25	20

When optimal replacement moments diverge 9 years or less, the replacement of gas service lines and the gas mainline should thus always be combined. When the connections are long or there is a single configuration of the main net optimal replacement moments can diverge more. In the decision guideline it is assumed that when optimal replacement moments diverge *15* years or less and the main net is single-sided, replacements should be combined, which is the average of a situation with high street restoration costs and normal street restoration costs. When the main net is single-sided *and* the connections are long, the decision guideline assumes that optimal replacement moments can diverge 21 years; the difference that exist in a situation with high and normal street restoration costs is thus nil.

Gas mainline with gas service lines when gas mainline needs replacement first

As this is the case in cases 2, 3 and 4, the break-even points are found based on these cases. For this combination option, the worst conditions are a single-sided net, long connections and low street restoration costs. The break-even points for this situation are shown in the table below:

norm. street rest. costs., single sided, long con.			
	case 2	**case 3**	**case 4**
GM-GS	10	9	10

This means that combined replacement is **always** cheaper than separate when optimal replacement moments diverge 9 years or less. This was tested with a connection length of 7.5 meter. However, a quick-scan showed that the same holds for connections up to 16 meters. By assuming that in densely populated areas the connection length is not longer than 16 meter, the 9 year difference in optimal replacement moments gives a representative view.

The analysis in the previous part showed that combined replacement has more potential when:

- Street restoration costs are high
- The net is double-sided
- Connections are shorter

Optimal replacement can hence iverge more when:

- **The street restoration costs are higher:** When street restoration costs are higher while the main net is single sided and the connections are long, optimal replacement moments can diverge a little bit more, namely:

high street rest. costs, single sided, long con.			
	case 2	case 3	case 4
GM-GS	11	10	10

- **The net is double-sided;** In this case the optimal replacement moments can diverge:

norm. street rest.costs, double sided, long con.			
	case 2	case 3	case 4
GM-GS	13	13	12

- **The net is double-sided and the connections are shorter than 7.5 m:** When the net is double-sided and the connections are shorter than 7.5 m (2m-7.5m), which is assumed to be the case when houses don't have front yards, optimal replacement moments can diverge 12 years.
- **The street restoration costs are high and the net is double sided:** Then the optimal replacement moments can diverge:

high street rest.costs, double sided, long con.			
	case 2	case 3	case 4
GM-GS	15	13	14

- **The street restoration costs are high, the net is double-sided and the connections are shorter than 7.5 m:** In this case the optimal replacement moments can diverge 15 years, as can be derived from table 39 for case 3 and 40 for 2 and 4.

It should be noted that it is a coincidence that the break-even point for the combined replacement of the gas mainline and gas service line regardless which one needs first replacement is 9 years. Actually they can be seen as two different combination options; the conditions that make these options more attractive are also different.

Appendix 6C – Average replacement moments of asset sub types

Asset	Average age (in 2005)	Optimal replacement age	Average Replacement moment in yrs from 2005
Gas Service lines			
Gas service line	29	56	27
Gas Mainlines			
Gas mainline 100 mbar PE	29	67	38
Gas mainline 100mbar AC	46	67	21
Gas mainline 100 mbar crude iron	33	67	34
Gas mainline 100 mbar Staal	34	50	16
Gas mainline 100 mbar PVC	29	121	82
Gas mainline 30 mbar PE	29	67	38
Gas mainline 30 mbar AC	29	67	38
Gas mainline 30 mbar crude iron	46	67	21
Gas mainline 30 mbar Staal	34	50	16
Gas mainline 30 mbar PVC	29	121	82
LV maincable GPLK (both main and service cable)	51	95	44
LV cable alkudi (both main and service cable)	20	51	31

Table 46 Current average ages, optimal replacement ages and average replacement moment in years from 2005. Presented per asset sub type; average ages are average ages in 2005 (Based on Wijnia et al., 2005).

Remember that these are *average* replacement moments; in reality already a part of the asset population needs to be replaced much earlier and that some already reached their optimal replacement moment. Based on the information above the average difference in optimal replacement moments for each combination option is derived and presented in table 17 in chapter 6.

The table above shows that in some situations the LV main cable on average needs replacement earlier than the gas mainline when it concerns the LV main cable 'alkudi'. This research does not consider combination options in which the LV main cable needs replacement first and would thus initiate the combined replacement. It chose so because in general it is expected that more of the gas assets need replacement first. Based on the table above, it can be expected that in reality also situations may arise in which not the gas mainline, but the LV main cable needs replacement first. For estimating the potential of combined replacement in general it is assumed that in those situations the break-even points do not derive substantially from those determined in this research (where thus the gas mainline always needs replacement earlier than the LV main cable).

Additional information on combination options based on differences in optimal replacement moments of total asset population is found below.

Gas service line – Gas mainline

As said, with a difference of 9 years or less combined replacement always is cheaper, but there are situations in which optimal moment can diverge more. As table 17 in chapter 6 shows there are quite some combination options of gas service lines and mainlines for which average replacement moments are within or just over the 9 year limit below which combined replacement is always cheaper. This amplifies the potential of this combination option. The fact that optimal replacement of the gas mainlines and gas service lines are relatively close as table 46 shows, implies that when gas infrastructure in a street is constructed around the same period differences in optimal replacement moments are in many cases within or just out the 9 year limit, making the potential for combined replacement of gas service lines and mainlines substantial.

Gas service line – LV service cable

In the majority of the cases the advantage of combined replacement of gas service lines and LV service cables turned out highly negative. The reason was that in these cases the assets were constructed in the same period and since the type of LV cable used has a very long life time as compared to the gas service line, the optimal replacement moments diverged much and thus the investment in combined replacement would be too early to turn out cheaper then separate replacement. However, table 17 in chapter 6 shows that when LV cables are of the 'alkudi' type, average replacement moments are within the theoretical limits, meaning that there is potential if LV service cables are made of 'alkudi'.

Gas mainline – LV main cable

In the cases combined replacement of the gas main and LV main only turned out cheaper for one case. In the other cases the optimal replacement moments of the gas main and LV main diverged very much, at least more than the maximum theoretically determined difference. The main cables in these cases were 'gplk' cables with a high optimal replacement age and gas and electricity infrastructure was constructed in the same period. In those situations where gas and electricity infrastructure are constructed in the same year and cables are of the 'gplk' type, separate replacement is therefore expected to remain cheaper. However as table 17 in chapter 6 shows, based on the average ages of asset types there are situations in which optimal replacement moments of a 'gplk' and a gas mainline diverge less and were thus combined replacement can be cheaper. This is the case where the electricity infrastructure is constructed earlier than the gas infrastructure or gas infrastructure has already been replaced before. Moreover when LV cables are of the 'alkudi' type, optimal replacement moments of gas mainline and main cable are closer, making the potential for combined replacement higher.

Appendix 6D Total savings with coordinated approach

The analysis of the results of the cases and effect of input parameter variation showed that combined replacement can be cheaper than separate replacement. An interesting question is what the total savings for Essent Netwerk could be when adopting the new approach and combine replacements if beneficial. This appendix is dedicated to determining these total savings.

Chapter 2 and Appendix 2C indicated the total replacement value of the assets demarcated for this research. Based on information in Appendix 6C the average differences in optimal replacement moments for the relevant combination options (divided per asset subtype) were derived and presented in table 17 in chapter 6. It showed that the average differences in replacement moments of some of the combination options are within the smallest determined break-even points, which means that for these combination options combined replacement is *always* cheaper than separate replacement. In the table below the combination options (divided per asset subtype) for which the difference in optimal replacement moments is within the smallest determined break-even points are presented, together with their accompanying average difference in optimal replacement moments.

combination	avg. difference in optimal replacement moments
Gas service line- Gas mainline 100 mbar AC	6 (GM first)
Gas service line- Gas mainline 100 mbar crude iron	7
Gas service line- Gas mainline 30 mbar crude iron	6 (GM first)
Gas service line – LV service cable alkudi	4
Gas mainline 100 mbar PE – LV main cable GPLK	6
Gas mainline 100 mbar crude iron– LV main cable GPLK	10
Gas mainline 30 mbar PE – LV main cable GPLK	6
Gas mainline 30 mbar AC – LV main cable GPLK	6
Gas mainline 100 mbar PE – LV main cable Alkudi	7
Gas mainline 100mbar AC – LV main cable Alkudi	10
Gas mainline 100 mbar crude iron– LV main cable Alkudi	3
Gas mainline 100 mbar steel – LV main cable Alkudi	15
Gas mainline 30 mbar PE – LV main cable Alkudi	7
Gas mainline 30 mbar AC – LV main cable Alkudi	7
Gas mainline 30 mbar crude iron – LV main cable Alkudi	10
Gas mainline 30 mbar steel – LV main cable Alkudi	15

Table 47 Average differences in replacement moments for those options that will be combined replacement with the coordinated approach.

For the above presented combination options and their accompanying average differences the total savings are calculated when the coordinated approach is adopted and thus indeed these replacements will be combined. This is done by determining the average combination advantage for the above presented combination options at their average difference in optimal replacement moment. (e.g. for the combination option gas mainline 100 mbar PE – LV main cable GPLK it is determined what the average combination advantage is when the optimal replacement moments of these asset sub types differ 6 years. The average combination advantages are based on the average combination advantage obtained in the cases for that specific difference in optimal replacement moments.

Based on data used in the long-term optimization research the amount of a certain asset subtype as compared to the total amount of that asset type is determined (e.g., it is determined which part of the gas mainlines is of the 100 mbar PE type). Based on the average combination advantage, the ratio of subtypes as compared to the total amount of an asset type and based on the replacement value of each asset type calculated in chapter 2, it is determined for each combination option how much can be saved by combining these replacements.

Saving combination of subtype of asset X and subtype of asset Y =
*Combination advantage of combination of subtype of asset X and subtype of asset Y **
*(amount subtype asset X/total amount asset X) * (amount subtype asset Y/amount asset Y) * (replacement value asset type X + replacement value asset type Y)*

Consider for instance again the combination option gas mainline 100 mbar PE – LV main cable GPLK. Databases used for the LTO showed that 5% of all gas mainlines are of the 100 mbar PE type and that 40% of all LV main cables are of the GPLK type. This means that replacement of 5% of all main lines can be combined with replacement of LV main cable in 40% of the cases. With a combination advantage of 12% and a replacement value of all gas mainlines and LV main cables of 1.24 billion, the total savings that can be obtained by this combination option can thus be calculated by: 0.12*0.05*0.40*1.24 billion, as is also shown in the table on the next page. Since no distinction is made in subtypes of the gas service line, the ratio *amount subtype asset X/total amount asset X* is consequently 1 and not separately presented in the table.

The calculations are shown below. The total amount that can be saved is the sum of all savings for each combination option: 7,175,569 + 32,311,171 + 36,807,149 + 31,366,350 = **107,630,239 (Euros)**..

GS-GM combination option	**avg. combination advantage**	**ratio GM subtype of total GM**	**replacement value GM+GS**	**total savings**
Gas service line- Gas mainline 100 mbar AC	12.9%	0.00	895,171,432	444,487
Gas service line- Gas mainline 100 mbar crude iron	12.0%	0.04	895,171,432	3,988,823
Gas service line- Gas mainline 30 mbar crude iron	12.9%	0.02	895,171,432	2,742,259
				7,175,569

GS-ES combination option	**avg. combination advantage**	**ratio ES subtype of total ES**	**replacement value GS+ES**	**total savings**
Gas service line – LV service cable alkudi	12.0%	0.60	448,019,564	32,311,171
Total				**32,311,171**

GM-EM combination option	**avg. combination advantage**	**ratio GM subtype of total GM**	**ratio EM subtype total EM**	**replacement value GM+EM**	**total savings**
Gas mainline 100 mbar PE – LV main cable GPLK	21.4%	0.05	0.4	1,235,589,000	5,736,484
Gas mainline 100 mbar crude iron– LV main cable GPLK	16.0%	0.04	0.4	1,235,589,000	2,948,660
Gas mainline 30 mbar PE – LV main cable GPLK	21.4%	0.01	0.4	1,235,589,000	717,060
Gas mainline 30 mbar AC – LV main cable GPLK	21.4%	0.01	0.4	1,235,589,000	1,075,591
Gas mainline 100 mbar PE – LV main cable Alkudi	20.0%	0.05	0.6	1,235,589,000	8,041,800
Gas mainline 100mbar AC – LV main cable Alkudi	16.0%	0.00	0.6	1,235,589,000	301,567
Gas mainline 100 mbar crude iron– LV main cable Alkudi	25.5%	0.04	0.6	1,235,589,000	7,049,140
Gas mainline 100 mbar steel – LV main cable Alkudi	9.6%	0.08	0.6	1,235,589,000	5,548,842
Gas mainline 30 mbar PE – LV main cable Alkudi	20.0%	0.01	0.6	1,235,589,000	1,005,225
Gas mainline 30 mbar AC – LV main cable Alkudi	20.0%	0.01	0.6	1,235,589,000	1,507,837
Gas mainline 30 mbar crude iron – LV main cable Alkudi	16.0%	0.02	0.6	1,235,589,000	2,814,630
Gas mainline 30 mbar steel – LV main cable Alkudi	9.6%	0.00	0.6	1,235,589,000	60,313
Total					**36,807,149**

All combination option	**avg. combination advantage**	**ratio GM subtype of total GM**	**ratio EM subtype total EM**	**replacement value all**	**total savings**
GM 30 mbar crude iron - LV alk main - GS - LV alk serv.	26.2%	0.02	0.6	1,683,608,564	6,280,145
GM 100 mbar crude iron - LV alk main - GS - LV alk serv.	25.0%	0.04	0.6	1,683,608,564	9,416,794
GM 100 mbar AC - LV alk main - GS - LV alk serv.	28.5%	0.05	0.6	1,683,608,564	15,639,411
					31,336,350

Table 48 Savings obtained with coordinated approach.

NB.: Considering the average replacement moments in table 46 shows that when it concerns combination options of a gas mainline with a LV main cable *alkudi,* in some cases the main cable on average needs replacement earlier. The break-even points were determined for combination options in which the gas asset always needs replacement first and would therefore not automatically apply to the above mentioned situations. However, as the costs for separate replacement of the gas mainlines and the LV main cables are relatively similar, discounting either the one or the other does not yield enormous differences in results. Therefore it is expected that the break-even points found for the gas mainline-LV main cable combination option in which the gas mainline needs replacement first are approximately the same as when the LV main cable needs replacement first. For calculating the savings that can be obtained from the combination options where the LV main cable needs replacement first these break-even points are thus assumed. Average combination advantages for these options are on the other hand separately derived and calculated for the situation that LV main cable really needs replacement first.

Appendix 6E – Instructions on using the Replacement calculation model

The replacement calculation model calculates for a single street if combined replacement or separate replacement is the cheapest option. The calculation model is constructed for this research for calculating combination advantages for 5 cases. The calculation model was also used to derive decision-criteria and it can calculate the break-even points frm which combined replacement gets a cheaper option. Essent Netwerk can use the calculation model for verifying the decision criteria after the first combined replacements have taken place. They can also use it in their replacement planning to balance the combined-separate choice for each situation.

The calculation model is able to calculate combination advantages for the following combination options:

- Combined replacement of gas service lines and electricity service cables
- Combined replacement of gas mainlines and electricity main cables
- Combined replacement of gas service lines and gas mainlines
- Combined replacement of all four asset types

Although in fact most of the possible combination options are expected to be initiated by a gas asset, the model is also able to calculate combination advantages when an electricity asset initiates replacement.

Information Digging/assembly, street restoration and material costs

In using the calculation model for the cases, fixed material costs per asset type were assumed. Moreover, Remuneration costs depend on municipality, but a fixed amount was assumed in the research.

Information for verifying decision criteria

Would the calculation model be used to refine the decision criteria derived in the research based on executed combined replacements, the input parameters that were fixed per meter (e.g. they only varied per asset type or combination option) for the cases can be changed. These consequently are:

- Digging/assembly costs
- Remuneration costs
- Material costs

<u>Sheet 1: INPUT</u>

This sheet collects all input data necessary:

- Construction year
- Optimal replacement ages
- Length of assets
- Digging/assembly costs
- Street restoration costs:
  - Restoration costs charged by contractor
  - Remuneration costs charged by municipalities
- Material costs

Moreover it comprises fixed values for:

- The digging incident probabilities

- The average digging incident costs
- The customer minutes lost per digging incident

The input data are retrieved as follows:

Data	Database
Construction year	Geoversum
Optimal replacement ages	Geoversum
Length of assets	Geoversum
Digging/assembly costs	Tariff manual Noord-Brabant and Limburg
Restoration costs charges by contractor	Tariff manual Noord-Brabant and Limburg
Remuneration costs	Tariff manual street restoration
Material costs	SAP

Table 49 Databases where data is retrieved

By filling out the input data for the combination options that need to be considered, it can both be calculated whether combined replacement is cheaper than separate replacement and what the break-even point for the concerned combination option is (e.g. how much the maximal difference in optimal replacement moments can be for combined replacement to be cheaper).

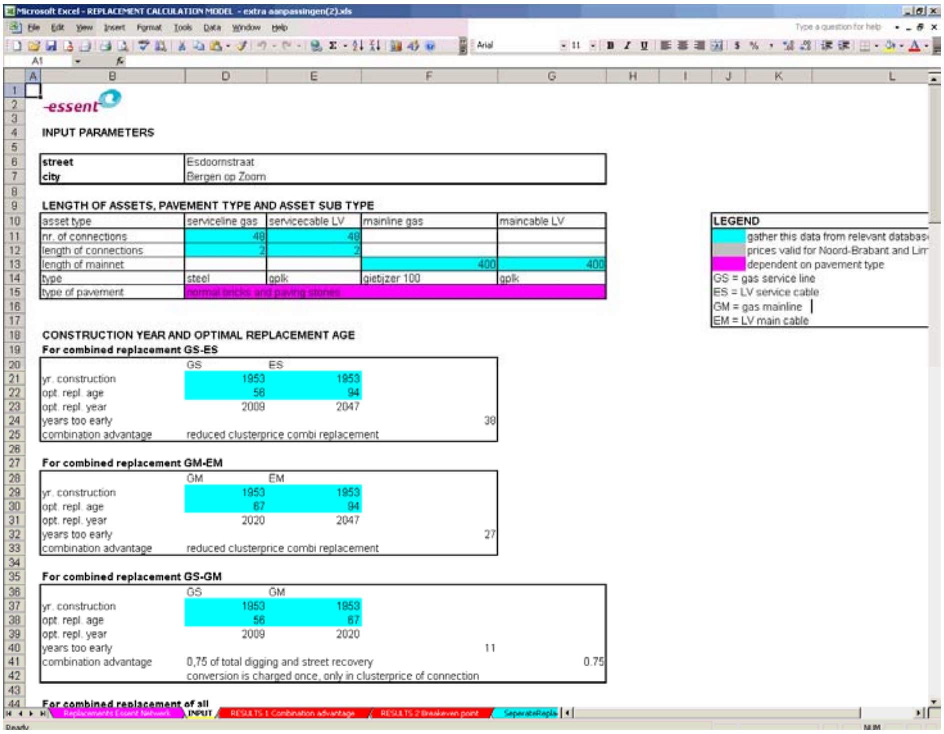


Figure 28 Excel sheet: Input parameters

Based on the construction year and the optimal replacement age this sheet already determines the optimal replacement moments of the concerned asset types and it calculates how many years later the asset that needs replacement later is replaced than the asset that needs replacement first (e.g. it calculates the differences in optimal replacement moments). For the first three combination options it does so by taking the difference in optimal replacement moments of the asset that needs replacement later and the asset that needs replacement first (with help of a function as (=MAX(D23:E23)-MIN(D23:E23)). For the combination option that considers replacement of all 4 asset types together it takes the difference between the optimal replacement of each asset and of that one that needs replacement first (with help of a function as (=E48-(MIN(D48:G48)). The calculated differences are used in sheet 6 to calculate the present value of the investment of the separate replacement that is actually executed later in time.

Sheet 2: RESULTS 1: Combination advantage

This sheet presents for each relevant combination option the obtainable combination advantage in percentages. It thus shows whether combining replacements would be cheaper than separately executing these replacements.

Sheet 3: RESULTS 2: Break-even point

This sheet shows for each combination option at which difference in optimal replacement moments, combined replacement gets cheaper, depicted by a colored bar.

- It shows the costs for combined replacement of a certain combination option, the costs for separate replacement of the asset type that need replacement first and the progression of the present value of the costs for replacement of the asset type that needs replacement later, dependent on the difference in optimal replacement moments.
- It compares the costs of combined replacement with the sum of the costs for separate replacement of the asset type that needs replacement first and the present value of the costs for separately replacing the asset type that needs replacement later, for all feasible differences in optimal replacement moments.
- It then determines for which differences in optimal replacement moments, the costs for combined replacement are lower than those for separate (with help of a function as (=IF(C8<F8,1,0).
- Then it determines when for the first time the costs of combined are lower than for separate replacement (with help of the function (=IF(N20=0,0,IF(N21=0,1,0))) and searches the corresponding difference in optimal replacement moments (with help of a function as (=MATCH(1,O8:O53,0)-1

Sheet 4: Calculation of Separate Replacement costs

This sheet calculates, based on the input parameters, the costs of separately replace the relevant asset types in a specific street.

Sheet 5: Calculation of Combined Replacement costs

This sheet calculates based on the input parameters, the costs of combined replacement of the relevant asset types in a specific street and for the relevant combination option.

Sheet 6: Calculation of Combined – Separate

This sheet calculates compares for each relevant combination option the costs when the asset types are replaced separately and the costs when they are replaced simultaneously for a specific street.

- For calculating the total costs of separate replacement it sums up the costs of the replacement of the asset type that needs replacement first and of the present value of the replacement that needs replacement later.
- With regard to the first three combination options it thereto first determines which of the asset type needs replacement later and then based on the calculated difference in optimal replacement moments as calculated in the input sheet it calculates the present value (with help of a function as (=(1/(1.045)^INPUT!$F$32)*(IF($U$52=1,D63,D62)). In which 1.045 refers to the discount rate of 4.5, INPUT!$F$32 refers to the calculated difference in optimal replacement moment and the last part of the function determines which of the separate replacement costs needs to be discounted.
- For the ease of calculation, for the combination option of all 4 asset types together it calculates the present value of the separate replacement of each of the asset types and thereby takes for each separate replacement the difference in optimal replacement moments of that asset type and of that one that needs replacement first, as calculated in the input sheet. The present value for the asset type that needs replacement first is then obviously the same as its normal costs.