Investing in the Future

Long-Term Optimization of Asset Replacement in the Collective Regional Gas Grids of The Netherlands

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Abstract

In this paper we present the results of a study on the effects of asset ageing on the safety of and replacement investments in the collective regional gas grids of The Netherlands.

1 Introduction

A challenge for DNOs (Distribution Network Operators) is the realization of a socially optimal trade-off between reliability, safety and customer costs. After all, a perfectly reliable grid comes at a prohibitive price. As a result of ageing of grid components, or *assets*, postponement of replacement investments can lead to a deterioration of reliability and safety. At the same time, early replacements will have adverse consequences for the (short-term) affordability for customers. Knowing that the future is uncertain, it is the challenge for and also the craftsmanship of a DNO to replace aged or otherwise vulnerable parts of the grid infrastructure at the right time, in order to achieve the desired future-proof quality of service and low customer costs.

Since the current Dutch regulatory regime does not contain a direct financial stimulus for replacement investments in gas grids, it is paramount that DNOs obtain insight into the expected effects of planned investments. This has given rise to a study, conducted under the flag of *Netbeheer Nederland*, the association of Dutch electricity and gas grid companies, by a delegation of experts from all Dutch DNOs for gas. In alphabetical order, these are: *Cogas*, *DNWB*, *Endinet*, *Enexis*, *Liander*, *Rendo*, *Stedin*, and *Westland Infra*. Its objective: to obtain a collective view on the effects of asset ageing on reliability, safety and affordability, and to provide insight into replacement policies to anticipate these effects. This (first) study was completed in 2011 and was presented at the 2012 World Gas Conference [1].

An recommendation adopted from the first study was a biennial evaluation and recalibration of the study, where model assumptions and estimations are adopted to advancing knowledge. This has resulted in an updated study, conducted in 2013, which we describe in this paper.

2 Approach

The following phases were completed:

1. Determination of the current structure, asset population and age distribution of the collective Dutch regional gas grids.
2. Determination of the current and estimation of the expected future failure behaviour of assets.

3. Adjustment of the numerical model, which predicts future asset failures and their effects on safety, reliability and affordability, and which calculates the theoretically optimal replacement policy.
4. Determination and evaluation of common scenarios.

The study adopts an umbrella approach, in which different types of gas components, or asset *types*, are combined in one model, which forms an outline representation of the current grid. The central question is what the optimal replacement policy is for these asset types during the next decades. The optimization problem has been formulated as a Linear Program. The objective function is the net present value (NPV) of a weighted sum of expected risk costs and preventive replacement costs, minimized over a planning horizon of up to 100 years. A horizon of 100 years is used to avoid boundary effects; in our discussion of the numerical results we will confine ourselves to the consequences for the next 10 to 50 years. The discount factor used in the NPV calculations is based on the weighted average cost of capital (WACC) as determined by the Dutch energy regulator for the current regulation period for the DNOs.

The reference date for collected input data and hence also the start date of the planning horizon is 1 January 2013. In the remainder this date refers to the present. The model input comprises the following elements.

2.1 Grid structure

The structure of the collective Dutch regional gas grids has been determined by means of a collection of asset types. In total, 24 asset types are distinguished, distributed over 4 asset categories: gas stations, transmission mains (1-8 bar), distribution mains (<1 bar), and service lines. Asset types for mains include varieties of material, such as grey cast iron, steel, and respective generations of polyethylene (PE) and polyvinyl chloride (PVC), the latter being the most commonly used material for distribution mains in The Netherlands.

Each asset type has a current age distribution. By way of illustration, Figure 1 shows the cumulative remaining length, in km and per year of construction, of first generation PVC distributions mains that are currently (still) present in the grid.

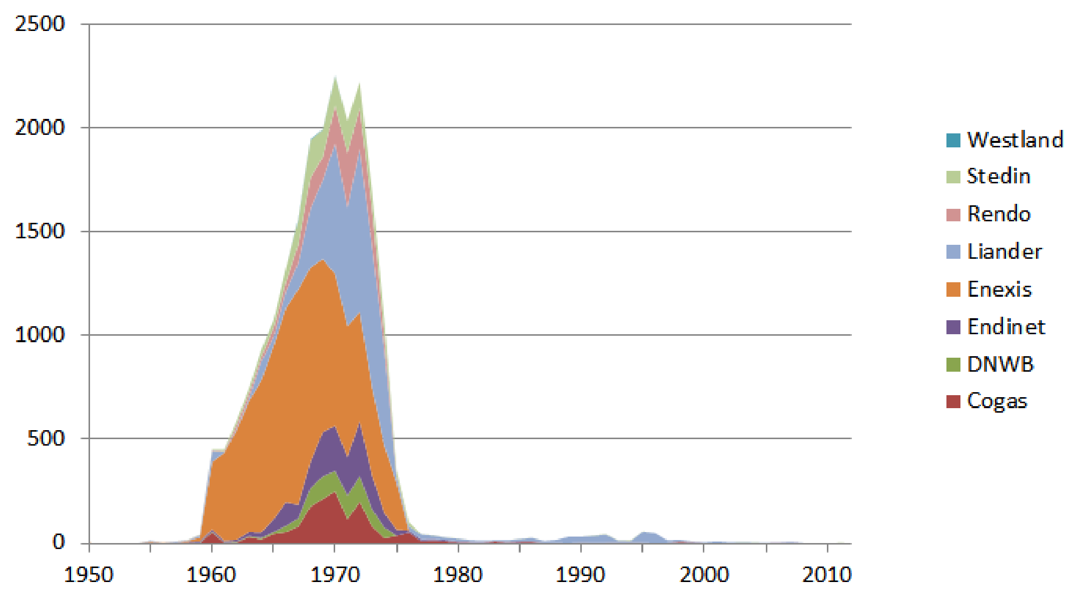

Figure 1 Age distribution of first generation PVC distribution mains

We note that in recent years the DNOs have put a lot of effort into enhancing the quality of the source asset data, including the correction of empty data fields. Consequently, one of the major improvements over the 2011 study is an enhanced source asset data quality, increasing the accuracy of the results of the study.

2.2 Reliability and safety

The model follows the Dutch methodology of *Nestor Registration*, used by the collective DNOs to assure a univocal reporting of failure data and common statistics, in particular the SAIDI and SAIFI. Nestor is based on the number of failures on the one hand and the risk per failure on the other; all asset failures are logged and broken down to characteristics such as the corresponding asset type, failure cause and resulting number of customer minutes lost. All this data is gathered nationwide since 1975 and comprises a large, ever-growing amount of failures and interruptions. We note that within the context of gas grids a “failure” is usually synonymous with a gas leakage, although station components can also fail without causing a gas leakage, but causing an interrupted or uncontrolled gas flow instead.

Furthermore, in accordance with the international PAS-55 framework, all Dutch DNOs have adopted a Risk Based Asset Management system, covering a collection of company values, which are mutually weighed by means of a monetary conversion. This leads to a quantitative valuation of each company value. With respect to safety the model follows the Dutch methodology of the *Safety Indicator Gas* (SIG) [2], developed by the collective DNOs in 2005. The SIG breaks safety incidents and their severity down to asset types and failure causes. It forms a relative measure of the safety of the grid, such that DNOs can be mutually compared.

The SIG distinguishes 6 categories, ranging from *Negligible* to *Catastrophic*, to classify the severity of an incident. The complete classification of incidents according to the SIG is shown in Table 1, which was taken from [2]. Note that the SIG does not only consider bodily harm, but also takes into account incidents with only financial consequences, such as collateral damage in case of an explosion without human presence, or social unrest in case of an evacuation, which is measured in terms of the duration of the evacuation multiplied by the number of stricken customers. In addition, note that the SIG adopts the so-called iceberg theory of Heinrich [3]. The categories are valued on an exponential scale, where for example an accident with injuries with absence is considered 100 times more serious than a dangerous situation and 100 times less serious than an accident with one fatality.

Classification	**Safety** **accidents with bodily harm**	**Financial** **accidents with collateral damage**	**Social unrest** **evacuation duration in customer hours**
Negligible	dangerous situation only	< 1k€	< 10
Small	near-accident or first-aid	1k€ - 10k€	10 - 100
Moderate	injury with absence	10k€ - 100k€	100 - 1,000
Considerable	serious injury with absence	100k€ - 1M€	1,000 - 10,000
Serious	one fatality	1M€ - 10M€	10,000 - 100,000
Catastrophic	multiple fatalities	> 10M€	> 100,000

Table 1 Classification of incidents according to the SIG

In its calculations our model considers one so-called *reference event* to represent the overall level of safety, where we have chosen an injury with absence. This refers to the classification *Moderate* in the SIG. In terms of the frequency of occurrence, this reference event corresponds to 100 dangerous situations and 0,01 accidents with one fatality. For the valuation we use the upper limit of the assigned financial range; this means we value a reference event at € 100,000.

It can be derived from the SIG [4] that the total current effect, over all asset types and DNOs, amounts to approximately 103 reference events per year. This number excludes incidents regarding failures of gasmeters, an asset type which is included in the SIG, but which has been excluded from our study. Including gasmeters, the total current number of reference events amounts to approximately 117. The reason why we have excluded gasmeters from our study is that nearly 95% of the recorded safety hazard is caused by (age-independent) assembly errors.

2.3 Failure curves

Ideally, the decision if and when to replace assets is taken on the basis of as much information as possible, preferring factual observations to assumptions. In our study we have subdivided the determination of the failure behaviour of assets into historical failure behaviour and expected future failure behaviour. Although future failing will manifest itself only with the lapse of time, it can be estimated by means of available historical failure data and expert judgement. The model considers *age-dependent* failures, e.g., as a result of corrosion or wear, and *age-independent* failures, e.g., as a result of third party interference, in particular excavation work.

For each asset type we have defined a failure curve, which incorporates both age-dependent and age-independent failure behaviour. For each age the failure curve indicates the failure probability in the next year. The model is flexible to such an extent that both curves can take arbitrary shapes. Using extensive failure data from Nestor, the failure curves have been constructed and calibrated such that for each asset type the number of failures in the coming year as projected by the model equals the actual average yearly number of failures over the last few years.

2.4 Failure costs

Besides the number or probability of failures, the expected adverse effects of failures are considered. These include repair costs and (monetized) safety incidents and interruptions. To avoid failures, assets can be replaced preventively; this leads to preventive replacement costs. The expected costs of failures and preventive replacements have been determined using index prices and subsequent calculations for real, finished projects.

With respect to interruptions we note that because of a high degree of redundancy due to the fine-mesh structure of the Dutch regional gas grids, the (expected) effects of failures on reliability will in advance pale into insignificance compared to the (expected) effects on safety and affordability. The average SAIDI over the last 5 years is well below 1 minute per year.

With respect to safety, for each asset type, the expected number of reference events in case of a failure has been derived from the SIG. A refinement compared to the 2011 study is that we have subdivided the risk per failure into material type and failure cause (either age-dependent or age-independent). Not surprisingly, the risk per failure turns out the be highly dependent on its nature; age-independent failures due to excavation or assembly work usually involve human presence, whereas with age-dependent failures this is only the case with a certain probability. Nor is it surprising that it turns out from our data that grey cast iron is the most risky material; its risk per failure is substantially higher than that of the other materials.

2.5 Policy constraints

The model allows for a variety of constraints, which can be used to enforce certain replacement policies. For the purpose of our study we have implemented three constraints in particular. The first concerns minimum and maximum numbers of preventive replacements, which can be specified per year and per asset type (or group of asset types). Minimum amounts can be used to effectuate replacements commissioned by supervisory authorities (for example with respect to mains composed of brittle material), maximum amounts to model capacity or budget constraints, and fixed amounts to evaluate existing replacement programmes.

The second constraint, which is a new feature compared to the 2011 study, offers added control of the numbers of replacements. Per year a maximum increase or decrease in the number of replacements of both stations, mains and service lines can be specified. In this way a gradual yearly increase or decrease of the workload can be established.

The third constraint concerns a safety risk tolerance. For each year in the future a maximum expected number of reference events can be specified. The optimization routine will then determine the most favourable replacement policy that obeys this condition, or indicate that such a policy does not exist.

3 Results

In this section we discuss the numerical results obtained from our model.

3.1 Common scenarios

We consider the scenarios listed in Table 2.

scenario	strategy
0	No preventive replacements
1	Plans issued in 2013
2	Theoretically optimal
3	≤ 103 reference events / year

Table 2 Common scenarios

Scenario 0 is a (fictitious) base scenario, which evaluates the consequences of not carrying out any preventive replacements at all.

Scenario 1 evaluates the consequences of the replacement plans for the 5-year planning horizon 2014-2018 that were issued by the respective DNOs to the Dutch energy regulator in 2013. Table 3 outlines these plans in terms of the weighted average annual replacement percentages of the existing populations.

	Plans 2014-2018
Stations	1,57%
Transmission mains	0,66%
Distribution mains	0,92%
Service lines	1,33%

Table 3 Average annual replacement plans dated 2013

As part of scenario 1, these percentages are considered to be “structural”, i.e., they are considered to apply to the further future as well.

Scenario 2 considers the theoretically optimal replacement policy, based on the valuation of safety as previously discussed. Finally, scenario 3 considers the effect of a safety target. This embodies the strategic objective to maintain the current safety level towards the future. In this scenario the optimal replacement policy is computed under the explicit condition that each year the expected number of reference events does not exceed 103, which is the current level, as previously discussed.

3.2 Comparison of future safety

Below we discuss the numerical results obtained for the scenarios described above, focusing on the implication for safety and the level of replacement investments. The main result is captured by Figure 2, which shows the projected development of the yearly number of reference events over the next 50 years.

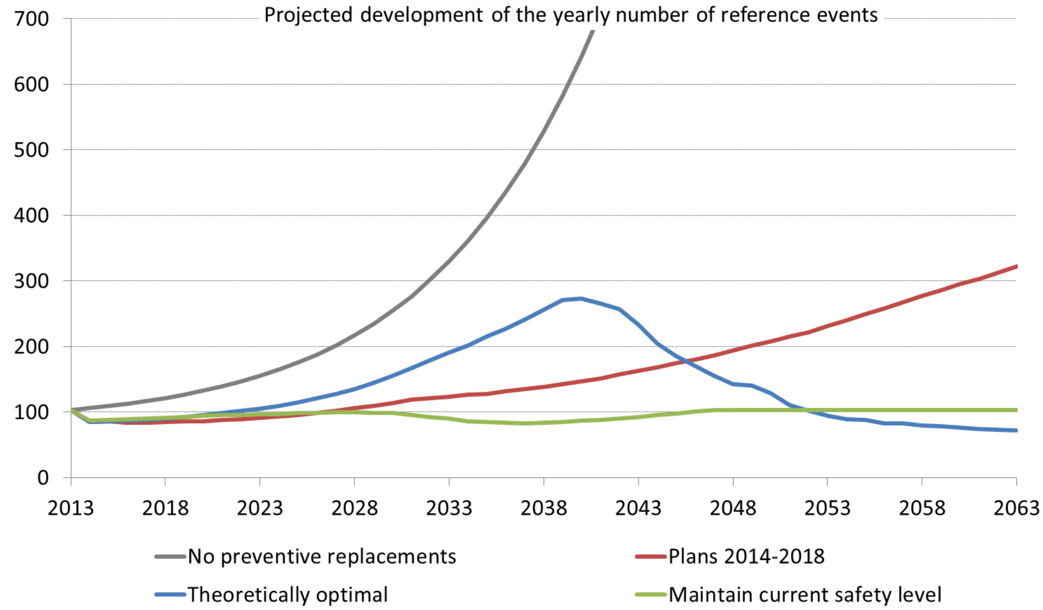

Figure 2 Projected development of the safety level

Scenario 0: No preventive replacements

The grey curve in Figure 2 shows that not replacing any assets preventively will lead to an accelerating increase in the number of reference events. This illustrates the importance of timely replacements.

Scenario 1: Plans issues in 2013

We see from the red curve in Figure 2 that the current 5-year plans suffice to maintain the current safety well beyond the planning horizon it was issued for. With a prolongation of these plans, the current safety level can be maintained for the next 15 years. Thereafter, the number of reference events will start to increase steadily. Hence, a structural continuation of the replacement percentages as recorded from the 2013 plans will be insufficient to achieve a long-term continuation of the current safety level.

Scenario 2: Theoretically optimal replacement policy

By not imposing any fixed replacement numbers, we enable the model to compute the theoretically optimal replacement policy. We see from Figure 2 that the current valuation of safety incidents result in a gradual deterioration of safety. Apparently, this valuation, in combination with the failure behaviour and age distribution of the grid, does not outweigh the cost of preventive replacements. As a result of the optimal trade-off between safety and affordability, a much higher yearly number of reference events is accepted. By 2040 the age distribution of the grid will apparently have changed to such an extent that the yearly number of reference events will start to decline.

Scenario 3: Theoretically optimal replacement policy

By imposing an annual safety target of 103 reference events, we can assess the feasibility of the strategic objective to maintain the current safety level towards the future. We can see from Figure 2 that in expectation this is indeed possible. The other side of the coin is that this will inevitably require higher replacement investments. These consequences are discussed below.

3.3 Comparison of future replacement investments

For scenarios 1-3, Table 4 summarizes the financial consequences for the next 50 years of the resulting replacement programmes.

	scenario		
next 50 years	Prolongation of current plans	Theoretically optimal	Maintain current safety
Average preventive replacement costs (M€/yr)	262	495	436
Average per customer (€/yr)	*39*	*74*	*65*
Net Present Value (M€)	6.182	7.662	9.257

Table 4 Summary of projected replacement investments

We see that in the existing replacement plans, an average of 262 M€ is spent annually on replacements. The theoretically optimal policy spends an annual average of 495 M€ and the optimal policy with safety target spends around 436 M€ annually. The reason that the NPV corresponding to scenario 3 is higher than the NPV corresponding to scenario 2 is that in the latter the replacements are carried out later in time.

The reason that the total preventive replacement costs corresponding to scenario 2 can be lower than those corresponding to scenario 3 is that we cut off the results at 50 years. In its calculations the model considers a horizon of 100 years and it turns out that in scenario 2 the replacements investments in the "second" 50 years are reduced to a very low level, whereas in scenario 3 there is only a small reduction.

The average annual replacement percentages corresponding to scenario 3 are shown in Table 5. The percentages are based on the current asset populations.

	10 years		20 years		50 years	
Stations	0	0,00%	0	0,00%	908	1,58%
Mains (km)	346	0,28%	1.717	1,39%	2.106	1,70%
Service lines	42.921	0,64%	136.648	2,03%	106.488	1,58%

Table 5 Average annual replacements for scenario 3

In 2009 the International Gas Union (IGU) [5] stated that: "*Investment in distribution networks will increase, with a greater safety focus on renewal and maintenance of existing networks in mature markets. The estimated annual replacement level of networks will settle at around 1.6 percent of their total length.*" We see that in the long run, the replacement percentages resulting from our study are very much in line with this 1.6%. This holds for stations, mains as well as service lines.

With respect to mains, those of brittle material are of special interest. The DNOs have made agreements with the supervisory authorities concerning the replacement of these mains. Figure 3 shows the development of the remaining population, measured in km, of mains of brittle material, corresponding to the optimal replacement policy with safety target. We see that by 2030 all asbestos cement will have been replaced, and by 2060 practically all grey cast iron.

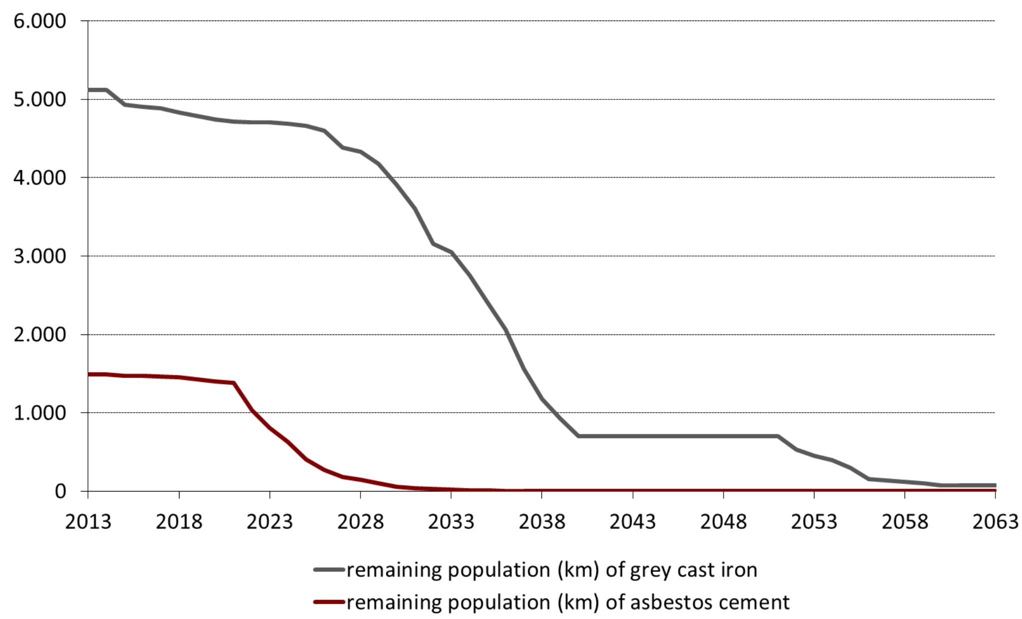

Figure 3 Remaining population (in km) of mains of brittle material

4 Conclusions and recommendations

A simulation based on the collective replacement plans of the Dutch DNOs for the planning period 2014-2018 shows the effect of the current replacement policy:

- 262 M€ per year worth of preventive replacements;
- until 2027, safety is maintained at the current level;
- subsequently, a gradual deterioration of safety.

To maintain the current safety level in the long run, for the next 50 years, an additional average yearly investment of 174 M€ (or 26 M€ per connection) will be required. The corresponding replacement percentages of 1,58% for stations, 1,70% for mains and 1,58% for house connections are very much in line with the estimated annual replacement level of networks of 1.6% mentioned in [5].

We emphasize that this current policy is based on plans drafted in the past and an extrapolation of these plans into the future. In reality, plans are periodically adapted to new circumstances and insight. In this paper we have provided insight into what plans are required to realize an optimal trade-off between company values, based on the current state of knowledge of asset ageing.

Based on the results and scope of our study, we make the following recommendations for further research and consultation:

- Further in-depth research into failure modes, failure behaviour and failure curves of components, in particular older generations of PE and PVC.
- A further intensification of the attention for data quality, since the quantitative results are highly dependent on complete and reliable data.
- Biennial evaluation and recalibration of the study, where model assumptions and estimations are adopted to advancing knowledge.

References

[1] G. Brouns and M. Poorts, *Investing in the Future – Long-Term Optimization of Asset Replacement in the Collective Regional Gas Grids of The Netherlands*, 25th World Gas Conference, 2012

[2] KIWA, *Statuut Veiligheidsindicator*, 2007, in Dutch

[3] Heinrich, H.W., *Industrial accident prevention: a scientific approach*, 1931

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[5] IGU, Natural Gas Industry Study to 2030, 24th World Gas Conference, 2009

Frequently used abbreviations

DNO	Distribution Network Operator
NPV	Net Present Value
SIG	Safety Indicator Gas