Strategic Asset Planning: Balancing Cost, Performance and Risk in an Ageing Asset Base

Ype Wijnia and John de Croon

Abstract In asset intensive organizations ageing of the asset base is a key concern, especially if a major part of the asset base is built in a relatively short timeframe. Even if current performance is adequate, it may deteriorate quickly if the assets approach the end of life. To address this concern, knowledge is needed on the development of failure rate, failure consequences, and how much capital is needed to maintain the current system performance. To help asset managers address their concerns we have developed a simplified approach to model the long term development of the asset base. This approach divides the asset base in a limited number of asset types, each with their own risk and age profile, and optimization of the replacement timing. Summing over the asset types results in the optimal capital requirement and associated total system performance. The effect of budget restrictions on risk and performance can also be demonstrated. This simplified approach provides adequate results with limited effort. In this paper we will describe the approach and discuss the rationale of the applied model.

1 Introduction

In asset intensive organizations ageing of the asset base is a key concern, especially if a major part of the asset base is built in a relatively short timeframe. This is for example the case in western infrastructure asset bases, like electricity, gas, water, roads and sewage [1]. A significant part of these infrastructures was constructed in the economic boom of the 60s and 70s. Up until today most of these assets have been functioning well, but it is uncertain how much remaining lifetime there is, how the failure rate will develop when assets approach end of life, what the conse-

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quences of failure will be and what the required capital is to maintain the current performance of the system.

A first order estimate on capital requirement may be derived from replacing assets once they are fully depreciated. However, this tends to result in an exaggeration. The depreciation period is more like the minimum age an asset will reach, in order to prevent disinvestments in the books. That means most assets are not worn out at the moment they reach this age. This strategy would thus be virtually risk free but also costly. Another estimate for future costs can be derived from replacing assets at their average expected lifetime. Unfortunately this typically results in an underestimate, as a significant fraction of the assets will fail before they reach this age. This replacement strategy therefore is uncertain in its execution, though it may be less costly than replacing after being depreciated. A flaw of both estimates is that they assume replacement at a fixed age. In reality this may be true for (most) planned replacements, but certainly not for assets that are run to failure. In order to arrive at a more realistic prognosis of future expenses a probabilistic model of future failure is needed. Probabilistic approaches can easily get very complicated, if many uncertain parameters are involved. This may result in findings beyond the comprehension of the asset manager and thus without any value to the organization.

To help asset managers address this challenge, we have developed a simplified approach to model the long term development of the asset base. Key in this approach is embracing uncertainty by means of what-if analysis, instead of focusing on the precise numbers. This approach is currently being implemented at several infrastructure asset managers in the Netherlands. In this paper we will describe the approach and discuss the rationale of the applied model, required data, model calibration, accuracy and robustness, and achieved results.

2 Approach

The fundamental idea of our approach is that the future is inherently uncertain [2, 3], so that focussing on precise forecasts is meaningless. Instead, it is much more valuable to understand what the effect of uncertainties is on the performance of the asset base. To achieve this, our approach consists of 5 separate steps.

1. Developing the valuation model
2. Decomposing the asset base
3. Failure modelling
4. Data collection and validation
5. What-if analysis

Each of these steps will be further detailed in this chapter.

2.1 The Valuation Model

The valuation model is about the translation of impacts on several values (e.g. financials, safety, reliability, reputation) into a single scale, so that comparisons can be made on the value of strategies [4]. The simplest and most straightforward method to do so is to translate every effect in its monetary equivalent. After all, people are trained in comparing values to prices [5]. This allows a formal trade-off between several effects of risks and potential interventions. A practical approach for such a fully monetized value system is the risk matrix that complies with basic design rules [6]. Figure 1 holds such a well-designed risk matrix. The price per unit of the quantified consequences is constant over the severity levels. Qualitative consequences can be replaced by the financial equivalent. For example, National Commotion would be regarded as a serious consequence. The financial consequences equally bad are costs between 1 and 10 million euro.

2.2 Decomposition of the Asset Base

The asset base of any asset intensive organization easily consists of several 100s to several 1000s of asset types (= asset of specific make and model). Per asset type there may be many instances of assets, with the total numbering in millions. A utility company (electricity, gas, water) for example has at least 3 distinct assets per customer: joint, connection and meter. Each of these individual assets in theory has its own failure behaviour in terms of failure probability and failure

Potential consequences					Likelihood					
					Unlikely	Remote	Probable	Annually	Monthly	Weekly
Severity class	Finance	Safety	Reliability [customer days]	Reputation	<0,003	0,003-0,03	0,03-0,3	0,3-3	3-30	>=30
Extreme	> 10 M€	Several fatalities	> 100k CD	International commotion, >100k complaints	M	H	VH	U	U	U
Serious	1-10 M€	Single fatality or disability	10k-100k CD	National commotion, 10k-100k complaints	L	M	H	VH	U	U
Considerable	100k-1M €	Serious injuries and significant lost time	1k-10k CD	Regional commotion, 1k-10k complaints	N	L	M	H	VH	U
Moderate	10k-100k €	Lost time incidents	100-1000 CD	Local commotion, 100-1000 complaints	N	N	L	M	H	VH
Small	1k-10k€	Near misses, first aid	10-100 CD	Non-public discourse, 10-100 complaints	N	N	N	L	M	H
Negligible	<1k€	Unsafe situations	<10 CD	Internal discourse, <10 complaints	N	N	N	N	L	M

Fig. 1 Example risk matrix after [6]

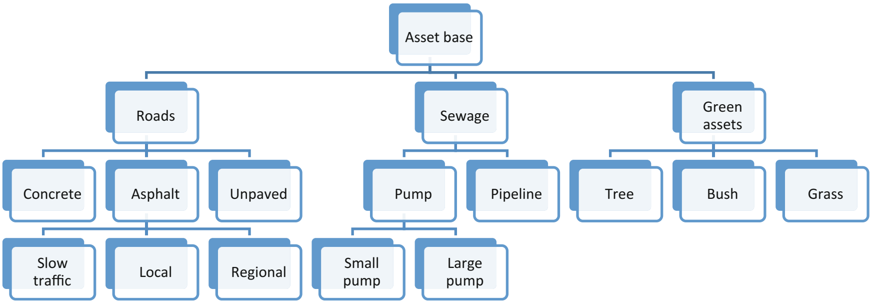

Fig. 2 Example of asset hierarchy

consequences. Yet, modelling millions of assets to forecast total asset base behaviour may be a bit extravagant. From a distance, assets of the same type will behave more or less similar. Even several types of assets may demonstrate very similar behaviour, creating some meta class of asset type. To reduce the modelling effort, we typically work down the asset hierarchy that is used by the organisation. In Fig. 2 a very high level representation is given for a typical municipality in the Netherlands.

The structure of such a hierarchy is not trivial. Roads for example could as well be clustered by their significance first (e.g. slow traffic, local, regional) and by their construction (asphalt, concrete, unpaved) afterwards. Two stop criteria are used in drilling down this asset hierarchy. The first is when the group can be described reasonably accurately by a single failure model (comparable aging, consequences and costs). The second is when the value represented by the group becomes insignificant, typically less than about 1% of the total asset base. In an asset base worth in total 1G euro, asset groups smaller than 10M euro do not need to be modelled to make a reasonably accurate forecast for the total.

2.3 *Failure Modelling*

For each of the asset types the development of asset costs is modelled. In its most basic form, only the time (age) dependent drivers need to be regarded: ageing/wear-and-tear resulting in repairs and corrective replacements, changing requirements (which often correlate with asset age) leading to functional replacements and planned preventive replacements. The costs resulting from the other drivers like growth, third party interventions and routine operations can be regarded as constant over the lifetime. Yet, in order to achieve more recognition (and options for validation of the outcomes!) it may be wise to include these non-time-dependent drivers. The BowTie like Fig. 3 shows these drivers and their associated reactions to restore asset adequacy.

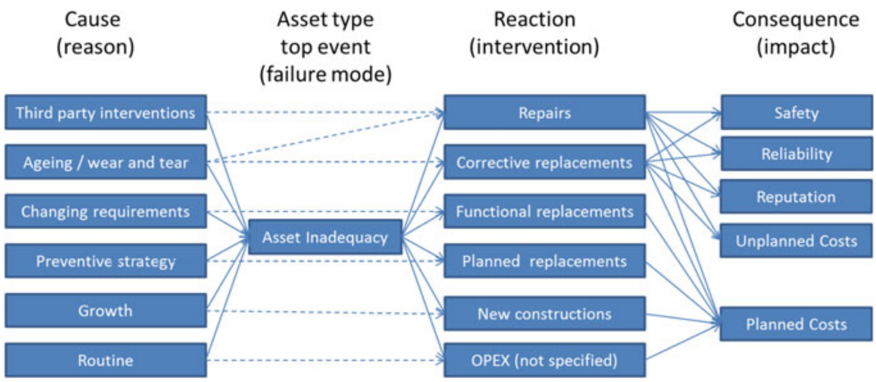

Fig. 3 BowTie diagram of asset inadequacy. The dashed lines indicate the dominant response

All causes in theory can be linked to all reactions. This is indicated by the solid lines running to and from asset inadequacy. However, in practice in most cases there is a dominant reaction, indicated by the dashed lines. There is one exception. Wear and tear for younger assets typically results in repairs, whereas the same inadequacy for an old asset may well result in a replacement. Because of the time dependence this is explicitly modelled in our strategic approach.

The typical function to describe end of life failures is the Weibull distribution [7]. However, for the assets at hand the data to derive such a distribution often are lacking. Furthermore, the field engineers find it very difficult to understand (let alone estimate) the parameters of the distribution.

Therefore we used a slightly different approach, based on a constantly growing failure rate. In this approach, two different parameters can be estimated: the undisturbed lifetime (T_{und}) which virtually all assets will reach (the depreciation period typically is a good first estimate) and the maximum age for the asset (T_{max}).

$$h(t) = c_0 e^{c_1 t}, \quad \text{conditions } h(T_{\max}) = 1,\ h(T_{\text{und}}) = 0,001 \tag{1}$$

Fitting a constantly growing failure rate to these points results in a Weibull like distribution as shown in Fig. 4.

Under the assumption that corrective intervention is more expensive (across all values) than a preventive intervention, this approach immediately provides a clue with regard to the optimal intervention strategy. That is when the cost of postponing the intervention (the risk) is larger than the benefit (i.e. depreciation and interest)[1]. This is shown in Fig. 5. This figure also shows a very important characteristic of optimization. As the optimum is a balance point between costs and benefits, which

[1]It does not matter whether absolute or conditional costs are used, as both depend on the same condition.

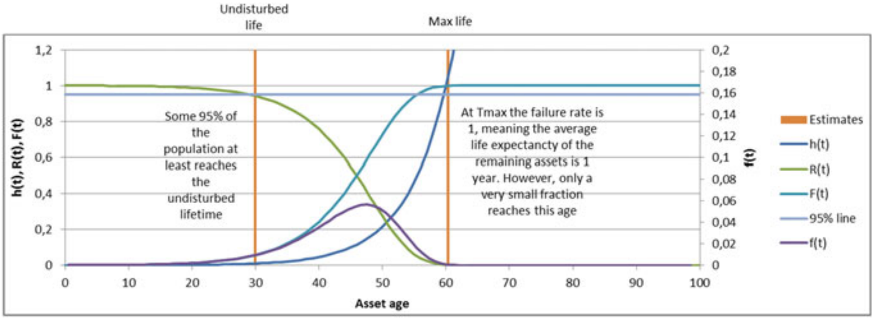

Fig. 4 Failure model based on undisturbed and maximum life

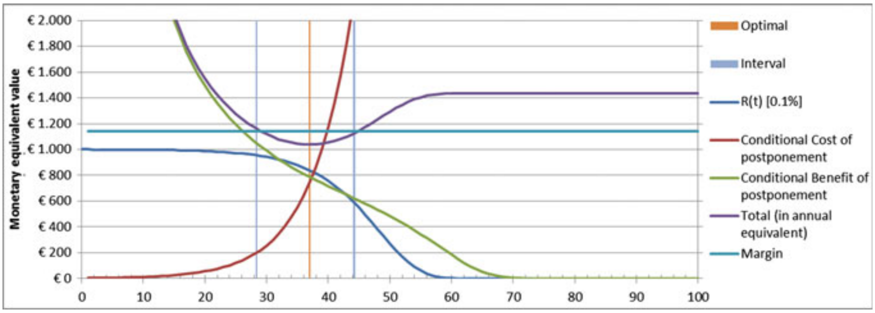

Fig. 5 Optimization of intervention interval

both develop slowly over time, being a few years off does not impact the total value much [8]. Typical intervals within 10% of the optimum span 10 years or more.

2.4 Data Collection and Validation

The approach needs relatively little data to produce a forecast. The required data is listed below per asset type.

- Asset data: Number of assets and its distribution over construction years
- Financial parameters: costs of new constructions, depreciation period, cost of planned interventions, costs of unplanned interventions, replacement value of group, book value of group
- Non-financial parameters: Undisturbed life, maximum (technical) life, non-financial consequences of failures, number of unplanned interventions over the past years

With these parameters, several validation options become available. For example, combining asset numbers with new construction cost should result in the replacement value. Correcting for depreciation (based on age profile) then should result in book value. The actual recorded number of failures can be validated by multiplying the age profile with conditional failure probability. In some cases, it may be difficult to validate the data for each individual asset. This happens for example if the asset hierarchy used in this approach does not match the hierarchy used in accounting. Failure costs for example may only be recorded as a lump sum, and not per asset type. Validation then happens on the asset portfolio instead of on the asset type.

2.5 What-if Analysis

To facilitate understanding the development of the asset base in an uncertain future, we use the approach of what-if analysis This allows the decision makers to compare several scenarios and alternative strategies within those scenarios. Typical alternatives are: a corrective strategy (reference), replacing at depreciation date, replacing at optimal age and a condition based replacement. These preventive strategies may be constrained by budget limits in several forms (corrective replacement cannot be constrained).

Typical scenarios address the following aspects:

- Growth rate of the asset base (reduction, constant, growth)
- Uncertainty in the value system, i.e. ratio between financials and non-financials
- Uncertainty in the input parameters (worst case, best guess and best case estimates)
- Innovations (coherent changes in parameters, e.g. life extension for certain maintenance action)

Because of the relatively simple approach, formulation and testing of strategies and scenarios can be done in a very short time. The typical evaluation time of a strategy or scenario is measured in seconds. This basically allows on the spot what-if analysis with the decision makers.

3 Results

3.1 Insight in Required Accuracy of the Input

Many asset managers presume that for a meaningful forecast lots of accurate data are needed. Using the what-if analysis of our approach, they learn that not all data is needed with the same accuracy, but that in many cases estimates can be used. For example, with regard to the age profile, the gradual development of the failure rate acts as a low-pass filter. This dampens year to year differences. As long as the age profile is not skewed too much, replacing the age profile by a uniform distribution of ages between the oldest and youngest assets often is good enough for accurate predictions.

Understanding the required accuracy of the input allows for a drastic increase of the speed of implementation. The first asset types to be modeled typically are discussed in full detail, with all arguments why every single asset is special. But aggregating the data into averages, and demonstrating that using averages has almost the same quality of an answer as a very detailed assessment removes the perceived need for details. The typical time spent on the first asset types is about half a day, whereas the speed at the end is more an hour per type. Combined with the limited number of asset types (several tens) this means the whole data collection, modeling and forecasting can be performed in several weeks. If more details are needed, this can be conducted in a (second phase) scaling up of the effort, in which every single asset is taken into account.

3.2 Developing the Long Term Strategy

Implementing our approach provides the asset managers with an all value insight in the long term development of their asset base, which they previously found hard to achieve. This allows them to compare the value of several long term strategies in order to select the best option. Figure 6 shows 3 typical strategies that are compared:

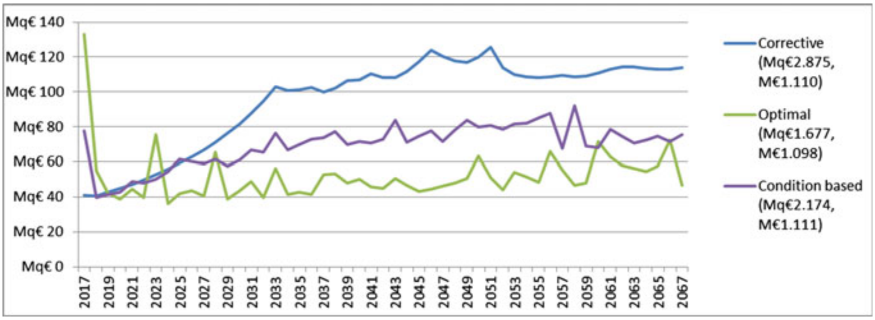

Fig. 6 Comparing several replacement strategies. The numbers in the legend represent the total present value of the strategies both in monetary equivalent (q€) as in true expenditure (€)

- Corrective, replacing assets upon failure
- Condition based, replacing assets at the minimally required condition
- Optimal, replacing assets when risks exceed benefits of postponing

As is clearly visible, the optimal strategy requires more capital upfront, but in the long run this reduces total costs of the system. The spike in 2017 is the backlog of overdue assets. This is also partly visible in the Condition based strategy. Interestingly, the strategies in the diagram do not differ much (if any at all) in terms of their Present Value costs. Financially, the strategies thus are comparable, though the timing of expenses differs. However, in terms of the total impacted value (safety, reputation, reliability) the difference is quite significant.

3.3 Understanding Limits for the Decision Maker

A relevant question in many organisations is how much can be squeezed out of the preventive budget. Yet, many asset managers feel that this is mortgaging the future: reduce the costs of maintenance will increase the future corrective costs. Our approach allows to demonstrate this, by implementing a budget constraint that is too tight. This is shown in Fig. 7. The implemented budget constraint is good enough for the first years. But after about 10 years, the corrective costs start to increase, and because of the budget constraint, this translates into a reduction of preventive actions. In about 25 years, there will be no preventive actions at all, so any increase in corrective costs will result in a budget overrun. The organization at this point has no control over its costs.

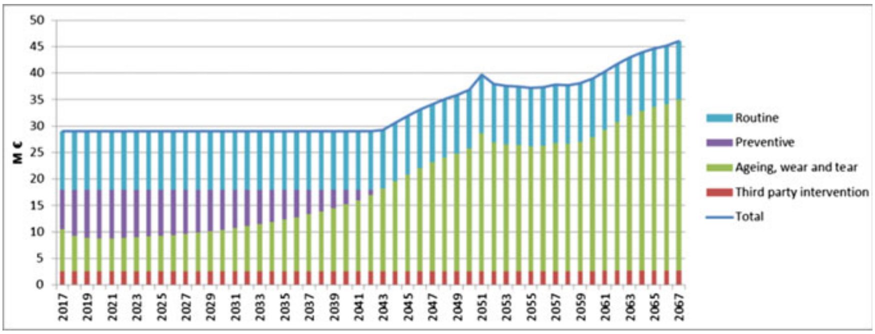

Fig. 7 Demonstrating the spiral of decline

4 Conclusion and Discussion

Many asset managers struggle with forecasting the development of their asset base in terms of costs, performance and risks. Available methods often are either too demanding in terms of effort and data, or too simple to provide a credible outcome. The resolution to this gap can be found in regarding the forecast as an optimization of the long term strategy. Optimization of slow developing risks by nature is robust in its outcome. Systematically testing for the effect of variability by means of what-if analysis allows for a controlled growth of complicatedness. The modelling effort can stop once adding more detail does not change the optimal decision anymore. For adequate strategic decisions, the required accuracy of data and model is often much less than anticipated. This means relevant outcomes can be delivered with relatively little effort in a relatively short time.

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