A service-oriented approach to assessing the infrastructure value index

R. Amaral, H. Alegre and J. S. Matos

ABSTRACT

Many national and regional administrations are currently facing challenges to ensure long-term sustainability of urban water services, as infrastructures continue to accumulate alarming levels of deferred maintenance and rehabilitation. The infrastructure value index (IVI) has proven to be an effective tool to support long-term planning, in particular by facilitating the ability to communicate and to create awareness. It is given by the ratio between current value of an infrastructure and its replacement cost. Current value is commonly estimated according to an asset-oriented approach, which is based on the concept of useful life of individual components. The standard values assumed for the useful lives can vary significantly, which leads to valuations that are just as different. Furthermore, with water companies increasingly focused on the customer, effective service-centric asset management is essential now more than ever. This paper shows results of on-going research work, which aims to explore a service-oriented approach for assessing the IVI. The paper presents the fundamentals underlying this approach, discusses and compares results obtained from both perspectives and points to challenges that still need to be addressed.

INTRODUCTION

Mounting international evidence suggests that the integrity of urban water infrastructures is at risk as they have accumulated alarming levels of deferred maintenance and rehabilitation (e.g., AWWA 2012; CSA 2014). For instance, in the USA the estimated capital funding gap in 2010 was nearly $55 billion; if current trends persist, this amount will escalate to $84 billion in 2020 and to $144 billion in 2040 (ASCE 2011). In Portugal, the recent national strategic plan for the sector (MAOTE 2015) warns of a clearly insufficient rehabilitation rate. For the current rate to be sustainable, pipes would need to last on average 100 and 200 years for water and wastewater networks, respectively. Furthermore, more than 3.5 million people (over 33% of the population) are served by utilities that do not ensure cost recovery. A large number of utilities do not even know the true cost of their services. As a result, many national and regional administrations are currently facing challenges to ensure long-term sustainability of urban water services.

Service sustainability requires a concerted effort to improve long-term planning, which involves, among other aspects, the assessment of the value of the infrastructure over time, the need for reinvestments, and the impact of long-term reinvestment policies (Alegre et al. 2014). Different approaches to supporting long-term planning have been proposed over time (e.g., PARMS-PLANNING – Burn et al. 2005; KANEW – Kropp & Baur 2005) but dealing with the balance between performance, risk and cost and with the integration of linear (e.g., pipes) and vertical assets (e.g., treatment plants, pumping stations) in a combined and coherent manner is still a major challenge. Also, the water industry must improve its ability to communicate the reinvestment needs to policy-makers and utility CEOs. Therefore, it is essential that simple and understandable approaches and tools are available.

The infrastructure value index (IVI), proposed by Alegre (2008) and broadly explored in recent years in various R&D and industry projects, has proven to be an effective tool to support long-term planning, in particular by facilitating the ability to communicate and to create awareness. IVI is the ratio between the current value of an infrastructure and its replacement cost and may conceptually be assessed in several different ways, derived from two main perspectives: asset-oriented and service-oriented.
In the asset-oriented approach, the calculation of the current infrastructure value is based on the concept of useful life of individual components. This approach has the advantage of being very intuitive and easy to use. However, the standard values assumed for the useful lives can vary significantly, which leads to an estimation of current value of an infrastructure and an estimation of reinvestment requirements that are just as different. In fact, the useful lives should be an output of service adequacy rather than an input for investment planning. Furthermore, with water companies increasingly focused on the customer, effective service-centric asset management is essential now more than ever (e.g., Jones et al. 2014).

This paper shows results of on-going research work, which aims to explore a service-oriented approach for assessing the IVI. The paper presents the fundamentals underlying this approach, discusses and compares results obtained from both perspectives and points to challenges that still need to be addressed.

**WHAT IS THE IVI AND HOW IS IT ASSESSED?**

The IVI is the ratio between the current (fair) value of an infrastructure and the replacement cost on modern equivalent asset basis (Alegre 2008), as stated in Equation (1).

\[
\text{IVI} = \frac{\text{infrastructure current (fair) value}}{\text{infrastructure replacement cost}}
\]  

(1)

IVI shall refer to a specific date, as it changes over time, and ranges from 0 to 1. The infrastructure current value would be, in a competitive market activity, its market value. In a monopolistic activity, as in urban water services, alternative valuation approaches must be adopted. The infrastructure replacement cost is the expected cost of a modern equivalent if the infrastructure was built in the year IVI refers to.

Conceptually, the IVI is a very simple and easy to understand index, enabling communication between stakeholders. It helps asset managers to inform decision-makers about the long-term impacts of current and alternative levels of financing and management strategies. The evolution of IVI over time allows it to be understood if the level of investment is of the same order, higher or lower than the rate at which the infrastructure’s service potential is being consumed. Moreover, it allows the comparison, in a long-term time window, of utilities with each other, infrastructures of a different nature (e.g., water supply with wastewater or storm water), or different areas of the systems (e.g., drainage sub-basins, district metering areas (DMAs)).

Although formally simple, IVI can be assessed in many different ways, derived from two main perspectives, as discussed in Alegre et al. (2014):

- **Asset-oriented**: calculation based on useful life of each asset, depreciation curves and replacement costs for each category of asset.
- **Service-oriented**: calculation based on performance of functional units of the infrastructure and cost and risk considerations.

The following sections briefly present and discuss these two basic formulations and the conditions applied in the analysis carried out in this study.

**Asset-oriented approach**

Whenever an asset-oriented strategy is applied, IVI may be determined considering the individual contribution of each asset, as presented in Equation (2).

\[
\text{IVI}(t) = \frac{\sum_{i=1}^{N} (rc_{i,t} \cdot \text{rul}_{i,t} \cdot \text{euli}_{i})}{\sum_{i=1}^{N} rc_{i,t}}
\]  

(2)

where:  
- \(t\): reference time; \(IVI(t)\): IVI at time \(t\) (dimensionless);  
- \(N\): total number of assets;  
- \(rc_{i,t}\): replacement cost of asset \(i\) at time \(t\);  
- \(rul_{i,t}\): residual useful life of asset \(i\) at time \(t\);  
- \(euli_{i}\): expected useful life of asset \(i\).

Alegre et al. (2014) present this formulation in detail and explain why most accounting implementations fail to correctly encapsulate the true fair value of the infrastructure. This approach is implemented in the open-source AWARE-P software (available at www.baseform.org) and has been successfully applied in many water utilities. Figure 1 shows a screenshot of an application of the IVI tool. It illustrates the IVI and the reinvestment needs in the alternative where assets were replaced at the end of their expected lives. Different rehabilitation strategies can be tested and compared.

An essential part of the asset-oriented formulation is the definition of useful lives. In the context of water and wastewater services, determining when an asset’s useful life will end is no simple task, as assets do not ‘die’. The useful life ends when assets are no longer fit for purpose due to their condition (e.g., leaks, structural resistance), capacity, ease of operation and maintenance, relative balance between risk and renewal costs, etc. Then, there is no single criterion to objectively determine the end of life.

Several approaches have been proposed for modelling remaining useful life (a review of these models can be found in WERF (2009)). Available models tend to focus on...
pipe breaks, as they are the main indicator used for pipe renewal decisions by utilities (e.g., USEPA 2013). For small diameter pipes, commonly with relatively low replacement costs and consequences of failure, statistical failure models are an economically viable approach (e.g., USEPA 2013). In the case of high risk pipelines, with costly and severe consequences of failure, more extensive and complex approaches are often recommended (e.g., Kane et al. 2014). The abovementioned models require detailed data and a level of training and expertise that are not always available within utilities (e.g., Ambrose et al. 2014; USEPA 2013). As a result, standard useful life values based on expert opinion are still frequently applied in the water industry to estimate the current value of an infrastructure and the long-term renewal requirements (e.g., Renaud et al. 2014). This is the case in Portugal where most utilities often have to cope with incomplete, inaccurate, or limited historical data.

Within the scope of IGPI 2015, Portugal’s 2015 National Initiative for Infrastructure Asset Management (http://igpi.aware-p.org), utilities were challenged to calculate the IVI of their infrastructures. In this regard, a broad discussion around ‘useful lives’ was carried out. Technicians from participating utilities were asked to assign useful lives for different categories of assets, aiming to achieve a global consensus on this issue. The results obtained are shown in Table 1. Table 1 also presents reference values in New South Wales (NSW 2014) for comparison purposes.

As can be seen above, the standard values adopted can vary significantly, which leads to infrastructure valuations that are just as different. In particular regarding pipe assets, the following main issues have emerged from the discussion:

- For the same material, do water and wastewater pipes have different useful lives? Some have argued that wastewater pipes may have shorter useful lives due to the more aggressive environment. Others argued that it should be the opposite as risk tolerance in water pipes is lower.
- For the same pipe material should useful lives vary for different diameters? Again, some have argued that larger diameters have longer useful lives because of better quality of construction, greater thicknesses, better maintenance practices, etc. Others argued that it should be the opposite since risk tolerance of larger diameters is lower.

It became quite evident that useful life is a complex and multifaceted concept. With all this, and in a context of

<table>
<thead>
<tr>
<th>Asset</th>
<th>IGPI</th>
<th>NSW Water supply (WS); Wastewater (WW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civil works</td>
<td>75</td>
<td>70</td>
</tr>
<tr>
<td>Equipment</td>
<td>10–15</td>
<td>30</td>
</tr>
<tr>
<td>Pumping stations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civil works</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>Equipment</td>
<td>17 WS; 10–15 WW</td>
<td>25</td>
</tr>
<tr>
<td>Reservoirs</td>
<td>75</td>
<td>100 Structure; 40 roof</td>
</tr>
<tr>
<td>Pipes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ductile iron</td>
<td>60</td>
<td>80 new mains; 50 relined mains</td>
</tr>
<tr>
<td>Concrete</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Polyvinyl chloride</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Polyethylene</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Asbestos cement</td>
<td>45–55</td>
<td>45</td>
</tr>
<tr>
<td>Vitrified clay</td>
<td>50–60</td>
<td>70</td>
</tr>
<tr>
<td>Relined</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>
preliminary analysis, it was decided not to differentiate useful lives for water and wastewater pipes and for different diameters. It was also assumed that the residual useful life of each asset was given by the difference between the expected useful life and the age of the asset (rul = cul – age). In case of assets in which the age was greater than the adopted expected useful life, the residual useful life was considered to be equal to zero.

Service-oriented approach

There are two important principles derived from urban water infrastructure properties, as follows:

(i) It is all about service, i.e. infrastructures only exist to provide a service to the public.

(ii) Urban water assets are network assets, creating the need to manage the assets on the basis of ensuring service and risk levels, rather than individual components (Reksten et al. 2013).

Taking these important fundamentals into account, it appears to be more reasonable to assess IVI according to a service-oriented approach. This is also in line with the principles adopted by water regulators such as OFWAT, in England and Wales (serviceability assessment process), and ERSAR (Entidade Reguladora dos Serviços de Água e Resíduos – the national water and waste services regulation authority), in Portugal (quality of service assessment system) (e.g., UKWIR 2012; ERSAR 2013).

The basic formulation adopted in the tests presented in this paper is as follows:

(i) Split the entire system into subsystems with a functional identity (e.g., DMAs in water distribution systems, drainage sub-catchment basins in wastewater or storm water networks).

(ii) Define/adopt the existing corporate assessment system, with service-oriented objectives, assessment criteria and metrics; select the relevant metrics depending on the infrastructure efficiency and effectiveness.

(iii) Standardise each metric for a 0–3 scale (0 – no service; 1: limit between poor and fair; 2: limit between fair and good; 3 – excellent).

(iv) All metrics should be relevant and balanced between them but, if necessary, give different relative weightings to some metrics.

(v) Assess these metrics for each subsystem; standardise results.

(vi) Assess weighted average, i.e., global level of compliance with the objectives for each subsystem; express the final result in a 0–1 range by dividing the weighted average by the maximum value of the scale; this is taken as the IVI of that subsystem, as presented in Equation (3).

\[
IVI_{i,t} = \frac{\sum_{j=1}^{N} (w_j \cdot r_{j,t})}{\sum_{j=1}^{N} w_j}
\]

where: \(t\): reference time; \(IVI_{i,t}\): IVI of subsystem \(i\) at time \(t\); \(w_j\): weighting of metric \(j\); \(r_{j,t}\): standardised result of metric \(j\) at time \(t\); \(N\): total number of metrics; \(Max\): maximum value of the scale (\(Max = 3\), in a 0–3 scale).

(vii) Assess the global IVI using replacement costs of each subsystem as weightings, as presented in Equation (4):

\[
IVI_{global}(t) = \frac{\sum_{i=1}^{M} (rc_{i,t} \cdot IVI_{i,t})}{\sum_{i=1}^{M} rc_{i,t}}
\]

where: \(t\): reference time; \(IVI_{global}(t)\): global IVI at time \(t\); \(M\): total number of subsystems; \(rc_{i,t}\): replacement cost of subsystem \(i\) at time \(t\); \(IVI_{i,t}\): IVI of subsystem \(i\) at time \(t\).

This approach has the advantage of acknowledging that the value of an infrastructure actually depends on its quality of service (including efficiency and risk considerations). It therefore responds to the current trend of adopting risk-based investment decisions, endorsed by the ISO 5500x (e.g., BSI 2014). Another advantage is the recognition that useful lives should be an output of service adequacy rather than an input for investment planning. The main disadvantages are:

(i) it does not fully eliminate the subjectivity of the process pointed out for the asset-driven approach; (ii) it does not consider, in the calculation of the IVI at a certain time, the expected evolution of the service; (iii) it does not consider the level of investment required to recover the level of service.

ASSET-ORIENTED VS SERVICE-ORIENTED APPROACH: AN EXAMPLE OF APPLICATION

Case study description

The two different approaches to assessing IVI described were tested in three water distribution systems, with the aim of comparing and discussing the results obtained from each one. A total of 40 DMAs were evaluated. This analysis could also be done at system level. The pipe length of DMAs varies considerably, ranging from 1 to 200 km. Due to a very sound information management system and approach, these utilities have more accurate data (in quantity and quality terms) than most utilities in Portugal and internationally.
The useful lives adopted in asset-oriented calculations were the same for all DMAs and correspond to values defined by utility technicians in iGPI 2015 (as previously presented in Table 1). The definition of replacement costs was based on reference values provided by each utility, as they are considered very well known. It should be noted that replacement costs are just weightings in the IVI calculation. If the costs of a particular utility all have the same trend, it does not affect the value of the IVI.

The assessment system adopted in service-oriented approach, as well as metrics’ reference values, is presented in Table 2.

It should be noted that these four metrics and respective strategic objectives are defined and assessed for regulation purposes. The metrics’ reference values were also established in accordance with ERSAR.

<table>
<thead>
<tr>
<th>Strategic objectives</th>
<th>Metrics</th>
<th>Reference values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection of user interests</td>
<td>AA03 – Service interruptions</td>
<td>[0.0;1.0]; [1.0;2.5]; [2.5; +∞]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[n / (1,000 connections.year)]</td>
</tr>
<tr>
<td>Operators sustainability</td>
<td>AA08 – Non-revenue water (%)</td>
<td>[0;20]; [20;30]; [30;100]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[n / (100 km.year)]</td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>AA11 – Mains failures</td>
<td>[0;30]; [30;60]; [60; +∞]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[n / (100 km.year)]</td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>AA13 – Real water losses</td>
<td>[0;100]; [100;150]; [150; +∞]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[l /(connections.day)]</td>
</tr>
</tbody>
</table>

Results obtained from IVI calculations for each DMA are presented in Figure 2. Results presented in each graph only differ in the metrics used to assess service-oriented IVI. In graph (a) the quality of service was only assessed considering the main failures metric, while in graph (b) all mentioned metrics were considered.

Results obtained through the two assessing approaches show spread dispersion, particularly when service is measured considering only one metric (as illustrated for main failures). This means that some old functional areas (in average terms) are providing a better quality of service than expected (DMA in zone (1)) and some more recent areas are providing a worse service than expected (DMA in zone (2)). Therefore, it becomes clear that while age of individual assets is an important input, it is not sufficient to allow the quality of service actually provided by a system or a subsystem to be inferred. There is no biunivocal relation between these two variables. Among other things, it is important to realise the function of assets in the system.

When considering a global level of compliance with the objectives based on the four metrics defined in the assessment system, results obtained are less dispersed. As can be seen in Figure 2, results appear to present a more linear trend. This effect probably occurs due to compensation
between metrics. Older areas tend to present at least one more serious problem. More recent areas tend to have all metrics more balanced and globally better.

In addition to analysing each metric one by one, it is important to look at the performance in a global point of view (taking into account the different metrics), as some metrics are not correlated to each other. A good performance in regards to one metric does not necessarily mean a good performance in another. Even for the two metrics main failures and real water losses, which would be expected to be highly correlated, this is not always the case (as illustrated in Figure 3).

Comparison between results obtained from the two approaches is very useful as it allows the assessing, in general terms, of whether useful lives are well defined for different metrics or groups of metrics. For example, if there is a tendency to have lower service-oriented IVI than those obtained through the asset-oriented approach, it can be said that useful lives are over-estimated. This reasoning is illustrated by comparing Figure 2(b) with Figure 4. Figure 4 presents the same situation as Figure 2(b), but the useful life assumed in the asset-oriented calculation is 100 years (instead of values around 50/60 considered in Figure 2(b)).

The performed analysis encourages further research work and testing. The following main challenges should be addressed:

- **Network vs individual assets** – the value of an infrastructure should reflect the quality of service provided by the system, instead of the sum of performance of individual components. However, should two systems with the same quality of service, but one with local problems and another with dispersed problems, present the same value?

**CONCLUSION**

This paper has shown results of on-going research work, which aims to explore a service-oriented approach for assessing the IVI.

Two different approaches for assessing the IVI were presented and tested in three water distribution systems, aimed at comparing and discussing the results obtained from each one. The asset-oriented approach is based on the concept of ‘useful life’ of individual components. In order to apply it, a broad discussion around this concept was carried out within the scope of the iGPI project. Technicians from participating utilities were asked to assign useful lives for different categories of assets, aiming to achieve a global consensus on this issue, at least for a starting point of analysis. Different points of views were discussed, the complexity and difficulty associated with this apparently simple concept becoming clear. The asset-oriented approach has the advantage of being very intuitive and easy to use, but it does not always reflect the quality of
service provided (as seen by the dispersion of the results obtained from the two approaches). The tested service-oriented approach represents a mind shift from more traditional approaches that are centred on an asset basis. Despite promising results, there is still a long way to go. It has the advantage of acknowledging that the value of an infrastructure actually depends on its quality of service. Nevertheless, it introduces a level of subjectivity into the process and does not consider the expected evolution of the service and the investment required to recover the level of service. Comparison between results obtained from the two tested approaches was shown to be very useful as it allows, in general terms, the ‘calibrating’ of useful lives for different metrics or groups of metrics. The analysis performed has revealed a good complementarity between the two approaches. The crossing of the results allows the exploitation of the benefits and points of view of each one, producing additional information. These approaches are also complementary to other deeper and detailed analyses, such as risk-based approaches, which define ‘what’ (which assets) and ‘how’ to rehabilitate, contributing to sound investment decisions as required by the ISO 5500x standards.

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