Urban Water Infrastructure Asset Management Plan: A Practical Application

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ABSTRACT

This paper aims the application of the Portuguese infrastructure asset management (IAM) methodology to a case study. This methodology establishes that the IAM plan should have three distinct planning levels: strategic, tactical and operational. Each one of these levels follows a five-step structured sequence: (i) definition of objectives, assessment criteria, metrics and targets; (ii) diagnosis; (iii) plan elaboration, along with the identification, comparison and selection of alternative solutions; (iv) plan implementation; (v) plan monitoring and review. The paper will focus, mainly in steps (i) to (iii) and to the tactical level of planning. Results obtained are discussed and the main conclusions are presented.

Keywords: Infrastructure Asset Management, Performance, Planning, Urban Water Infrastructures

1 INTRODUCTION

While urban infrastructures inevitably age and deteriorate, water utilities face the challenge of keeping their systems operational, efficient and reliable. Therefore, infrastructure asset management (IAM) is of utmost importance for water utilities.

According to the Portuguese government law the country's 308 municipalities are responsible for providing water supply and sanitation services, either directly or indirectly through concessions. About 73% of the population in 243 municipalities receives water directly from municipalities (3.5 million people) or single-municipality companies established under public law (2.5 million people). 27% of the population receives water directly from companies established under private law, including 1.7 million from multi-municipal companies' majority-owned by the public company Águas de Portugal, S.A. (AdP) and 0.9 million from other municipal companies established under private law. Many municipalities do not control their sources of bulk water supply. Companies established under private law, particularly multi-municipal companies co-owned by AdP, sell water to municipalities, providing water indirectly to 53% of the population. In addition, as mentioned above, companies established under private law provide water directly to 27% of the population. Thus, a total of about 80% of the population receives water directly or indirectly from multi-municipal companies established under private law.

Many important measures have been undertaken in recent years to reverse the trend and to help equip the country's utilities with the means to redress the long-term sustainability of the existing assets. National legislation passed in 2009, effective 2013 (Decree-Law nº 194/2009), requires an IAM system in all water supply services and urban wastewater management services serving 30 000 people and over. Following this legislation, the national Water and Waste Services Regulation Authority (ERSAR), in conjunction with LNEC and the Instituto Superior Técnico of Lisbon, published two technical guides outlining an integrated IAM methodology and a set of supporting technologies [1,2].

This IAM approach was developed under the AWARE-P project (2009-2011), further developed in the scope of other R&D projects, such as iGPI (2012-2013), INFR5R12 (2013-2014), and, in a very significant way, in the TRUST EU 7th FP project (2011-2014) [3].

This methodology is a broad management process that addresses the need for a fundamental plan-do-check-act (PDCA) cycle at a utility's various decisional levels – strategic, tactical, operational – aiming at the alignment of objectives, metrics and targets, as well as effective feedback across levels. Each level is compounded of different stages (see Figure 1) and tasks.

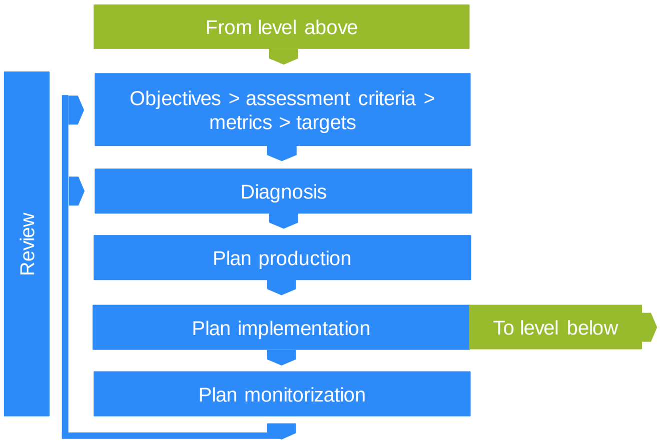

Figure 1. IAM planning process [4]

The current paper focuses a practical application on a Portuguese case study using the referred IAM methodology particularly at the tactical level. At the final, the main results are presented and discussed.

2 METHODOLOGY

Tactical planning and decision-making should be founded on the strategies and on the strategic objectives and targets. The aim of tactical planning is to define what are the intervention alternatives to implement in the medium term (typically 3 to 5 years). IAM tactical planning is not restricted to infrastructural solutions, as it should also consider the interventions related to operations and maintenance and to other non-infrastructural solutions [1,2,4].

The tactical plan consists in the five stages as depicted in Figure 1. At a first stage, the tactical objectives, assessment criteria, metrics and targets are set up to clarify the course of actions. The objectives, metrics and targets need to be coherent and aligned with the strategic level. These metrics and targets are an essential basis for establishing the diagnosis, prioritizing intervention solutions and monitoring the results. The second stage is the diagnosis, and should be carried out based on the metrics selected, for the present situation and for the planning horizon.

The third stage is plan production and is one of the most work-intensive as it encompasses the demanding engineering processes involved in identifying and developing feasible intervention alternatives, and the assessment of their responses over the analysis horizon for the metrics selected. The different alternatives need to be compared, and the one which best balances the set of metrics for the chosen objectives, over the long-term, should be selected. The diagnosis, design and analysis of infrastructural and operational alternatives are not trivial tasks and often require the use of sophisticated modelling tools, such as EPANET [4].

The last stages of tactical planning are the implementation, monitoring and periodic review of the plan. Implementation is materialized via operational management. Monitoring and reviewing are critical for the continuous improvement process [1,2].

At each level of planning, especially at the tactical level, decision-making should consider three different points of view, specifically, cost, risk and performance.

3 CASE STUDY

3.1 Description

The case study is a sixty-year-old water supply system (WSS) located in Lisbon's metropolitan area, Portugal. The neighbourhood covers an area of 4 square kilometres and has a population of about 14,430 inhabitants living in buildings up to 11 floors. There also exists a few supermarkets, schools, a cemetery, a central hospital, some shops and industrial plants. The distribution network is about 36 km long and has about 2,180 service connections. Most pipes are made of asbestos cement (≈ 63%), PVC (≈ 34%) and HDPE (≈ 3%) with diameters varying from 32 to 400 mm. Years of reactive interventions have led the network to become aged and deteriorated. To reverse this trend, a 2% rehabilitation rate has been considered in the recent years.

Portugal is a favoured country and major groundwater unit of the Iberian Peninsula is the huge Tagus-Sado aquifer system which constitute the water source of the studied WSS. Groundwater abstraction is made from five wells which are operated non-simultaneously. The water is treated at the water wells location through chlorine injection. After treatment, water is transported to two storage tanks and after that is raised directly to the distribution network through a group of pumps. This WSS is managed by a municipality.

3.2 Tactical objectives, assessment criteria, metrics and targets

As mentioned above, the tactical planning starts with the definition of the tactical objectives which should be aligned with the strategies and strategic objectives and targets. The strategic plan was elaborated by the municipality for the period 2015-2035 and has three strategic objectives (SO), namely, social sustainability and adaptation to users' needs (SO1), technical and economical sustainability (SO2) and environmental sustainability (SO3). The defined strategies are eight namely, improve infrastructure value index (IVI); reduce water and energy losses; improve systems' preventive maintenance, safety, and resilience; improve information's quality and availability; improve relationship between users and the municipality; improve the social economic accessibility of the services; and, improve services economical management.

Based on these strategies four tactical objectives were outlined, specifically, (1) achieve an adequate IVI; (2) achieve an efficient water and energy level; (3) promote an appropriate maintenance system; and, (4) ensure social and economic sustainability. For each of these objectives, assessment criteria were defined and adapted to system's reality. Metrics were defined for each of the previously established assessment criteria, allowing constant and accurate evaluation of each objective.

As a result, twelve metrics were established based on three different dimensions (i.e., cost, risk and performance). These metrics will be used to perform system's diagnosis, through comparison with the previously established reference values. Based on the diagnosis results for the reference situation, and considering the medium-term investment plan, targets will be defined for the next planning years and the analysis horizon.

In Figure 2 the alignment between tactical objectives and the defined assessment criteria and metrics is shown.

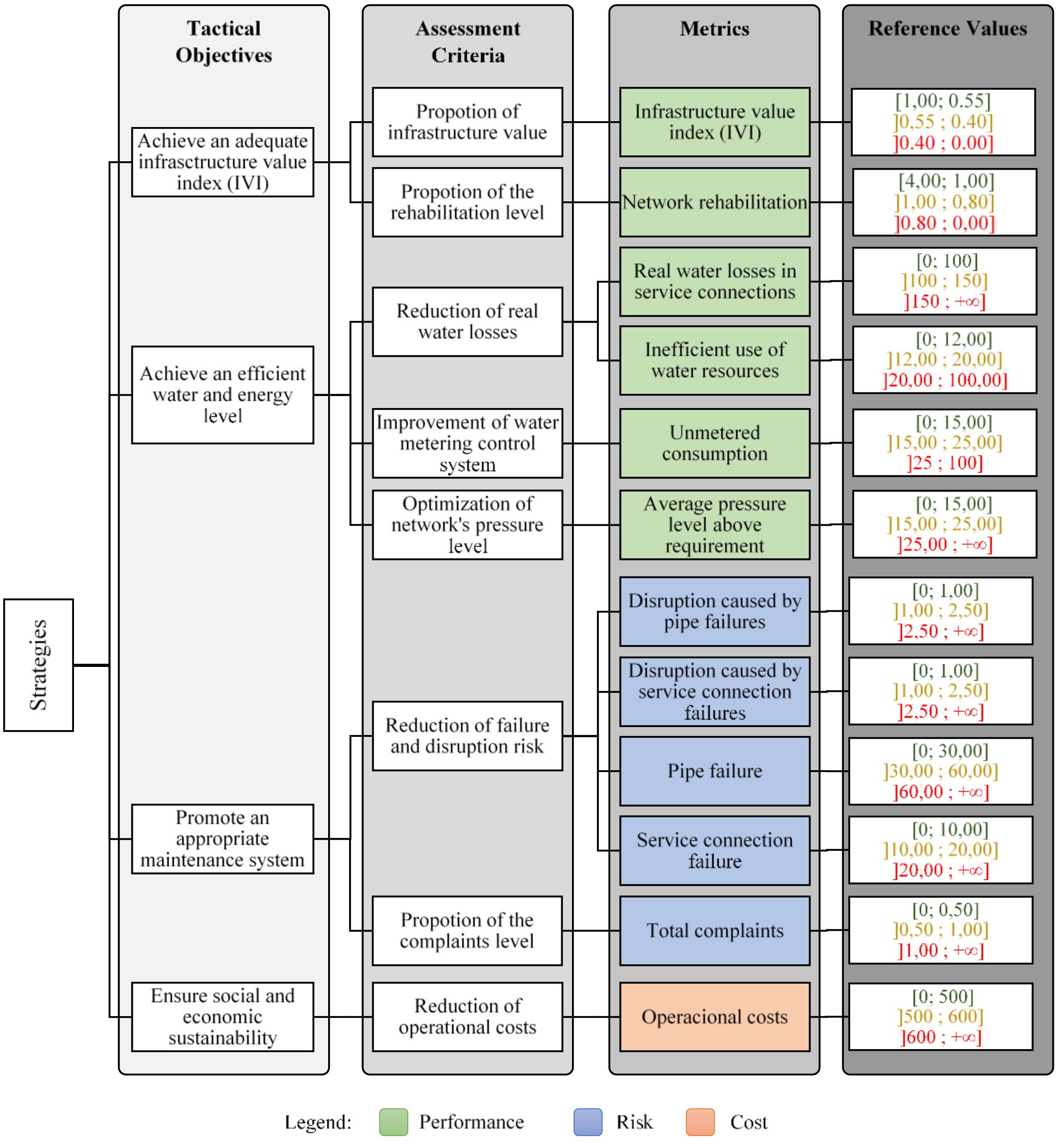

Figure 2. Alignment between tactical objectives, assignment criteria and metrics

Performance

Infrastructure value index – IVI (P1). This is a performance indicator that represents the ratio between the current value of the infrastructure and the respective replacement value.

Network Rehabilitation (P2). This performance indicator translates the percentage of the network that was rehabilitated in the last year.

Real water losses in service connections (P3) and *Inefficient use of water resources (*P4). Real water losses are the physical losses of water from the distribution system, including leakage and storage overflows. These losses inflate the water utility's production costs and stress water resources since they represent water that is extracted and treated, yet not used. Real water losses volume was obtained through the water balance proposed by the International Water Association (IWA). P3 indicator is given by the ratio between the real water losses and the total number of service connections. P4 is obtained through the ratio between the real water losses and the system input volume.

Unmetered consumption (P5). This metric translates the percentage of water supplied to the system that is not measured. It is given by the ratio between the unmetered water volume and system's input water volume.

Average pressure level above requirement (P6). This is a performance index that allows to check if the minimum required service pressure is supplied at each service connection. According to Portuguese legislation the minimum required service pressure is given by 100+40n, where n is the number of floors above ground.

Risk

Disruption caused by pipe failures (R1) and Disruption caused by service connection failures (R2). According to Portuguese legislation, water utilities have a six-hour deadline to repair any system failure that may occur within the network without having to notify their users. The disruption's time extension is only considered if the six-hour period (permitted by law) is exceeded. The disruption's time extension of pipe failures is calculated with the R1 indicator - it results from the ratio between the disruption's time extension and total number of users.
R2 indicator calculates the disruption's time extension of service connection failures. It is given by the ration between the disruption's time extension caused by service connection failures and total number of users.

Pipe failure (R3). This metric quantifies the number of interventions caused by pipe failures. It is given by the ration between the number of interventions caused by pipe failures and the total pipe's length.

Service connection failure (R4). This metric quantifies the number of interventions caused by service connection failures. It is given by the ration between the number of interventions caused by service connection failure and the total number service connections.

Total complaints (R5). It is possible to detect certain hydraulic dysfunctions through complaint analysis. The R5 metric is obtained through the ratio between the total number of complaints regarding network's performance and total number of users.

Cost

Operational costs (C1). Inadequate performance means an increase of the operational costs. The C1 metric is obtained through the ratio between the network related operational costs and the total network's length.

The case study integrates a mainly and well established residential area, where no significant development is expected in terms of water consumption. For that reason, scenarios of consumption evolution were not considered.

3.3 Diagnosis

Diagnosis assesses the existing system using the established metrics for performance, cost and risk dimensions [5]. So, metrics were calculated and evaluated based on the defined reference values (see Figure 1).

Most of information needed for metrics calculations were provided by the Municipality. For the metric P3 the water balance proposed by the International Water Association (IWA) was used. To compute P6 a network model in EPANET was used and to determine the minimum required service pressure a number of five floors were considered.

Based on the diagnosis results for the reference situation, and considering the medium-term investment plan, targets were defined for the tactical planning horizon (2018-2022) and the strategic analysis horizon (2035) as presented in Table 1.

Table 1. WSS diagnosis

ID	Designation	Current situation (2017)	Targets at planning horizon	
			Tactical (2022)	Strategic (2035)
P1	Infrastructure value index	0.30	0.36	0.50
P2	Network Rehabilitation	2.00	5.00	3.00
P3	Real water losses in service connections	121.65	105.0	75.00
P4	Inefficient water resource use	15.96	14.50	9.00
P5	Unmetered consumption	28.93	19.00	15.00
P6	Average pressure level above requirement	7.52	5.00	5.00
R1	Disruption caused by pipe failures	1.31	1.00	0.50
R2	Disruption caused by service connection failures	1.81	1.00	0.50
R3	Pipe failure	45.80	30.00	15.00
R4	Service connection failure	22.16	18.00	10.00
R5	Total complaints	0.63	0.30	0.10
C1	Operational costs	642.25	540.00	420.00

3.4 Plan production

To select the most adequate solution, tactical alternatives need to be established and analysed. Solutions with the potential to improve the System's performance are developed as the evaluation's results for the reference situation are considered. Four rehabilitation alternatives were considered:

A_0 - the status quo alternative (i.e., keeping operation and maintenance practices and 2% of annual rehabilitation);

A_1 - ongoing 2% of annual rehabilitation and optimization of pump operation scheme;

A_2 – maintaining the 2% of annual rehabilitation, optimization of the pump operation and renewal of the water meters;

A_3 – increasing annual rehabilitation to 5% in the following years, optimization of the pump operation and renewal of the water meters.

Table 2 presents the results for the four alternatives, within the tactical planning horizon (2022) and the analysis horizon defined at the strategic level (2035).

Table 2. Results for the considered alternatives against the defined horizons

	A_0		A_1		A_2		A_3	
ID	**Tactical planning horizon (2022)**	**Strategic horizon (2035)**	**Tactical planning horizon (2022)**	**Strategic horizon (2035)**	**Tactical planning horizon (2022)**	**Strategic horizon (2035)**	**Tactical planning horizon (2022)**	**Strategic horizon (2035)**
P1	**0.34**	**0.44**	**0.34**	**0.44**	**0.34**	**0.44**	**0.44**	**0.71**
P2	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**5.00**	**5.00**
P3	**106.67**	**83.27**	**106.67**	**83.27**	**106.67**	**83.27**	**84.12**	**51.70**
P4	**13.99**	**10.92**	**13.99**	**10.92**	**13.99**	**10.92**	**11.04**	**9.45**
P5	**17.37**	**11.80**	**17.37**	**11.80**	**12.01**	**10.32**	**12.01**	**10.32**
P6	**7.52**	**7.52**	**6.63**	**6.63**	**6.63**	**6.63**	**6.63**	**6.63**
R1	**1.15**	**0.90**	**1.15**	**0.90**	**1.15**	**0.90**	**0.91**	**0.56**
R2	**1.59**	**1.24**	**1.59**	**1.24**	**1.59**	**1.24**	**1.25**	**0.77**
R3	**40.16**	**31.35**	**40.16**	**31.35**	**40.16**	**31.35**	**31.67**	**19.46**
R4	**19.43**	**15.17**	**19.43**	**15.17**	**19.43**	**15.17**	**15.32**	**9.42**
R5	**0.55**	**0.43**	**0.55**	**0.43**	**0.55**	**0.43**	**0.44**	**0.27**
C1	**542.18**	**423.24**	**542.18**	**423.24**	**542.18**	**423.24**	**427.54**	**262.77**

From Table 2 it is possible to conclude that alternatives A_0, A_1 and A_2 still fall short of the established targets at tactical horizon of 2022. In contrast, alternative A_3 achieve almost all the targets established. For the strategic horizon of 2035, alternatives A_0, A_1 and A_2 fail to meet all the established targets but on the other hand the alternative A_3 fulfils all the targets.

The intervention alternatives' ranking was done through a simple multicriteria decision analysis method (i.e., weighted sum). Table 3 presents the intervention alternatives ranking obtained and the investment cost associated.

Table 3. Intervention alternatives ranking through multi-criteria decision

Alternative	Rank	Investment cost associated
A_3	1	1.9 M€
A_2	2	0.4 M€
A_1	3	no capital investment associated
A_0	4	no capital investment associated

The utility's available annual budget for rehabilitation interventions is about 0,5 M€. Therefore, the intervention alternative A_3 was vetoed since it has exceeded the available budget. This budget limitation implies choosing alternative A_2 and means that the targets established for some metrics at the end of the strategic and tactical planning horizons will not be achieved.

4 CONCLUSIONS

In this paper, an application of the Portuguese infrastructure asset management methodology to a case study was presented. The IAM plan should have three distinct planning levels: strategic, tactical and operational. Each one of these levels follows a five-step structured sequence: (i) definition of objectives, assessment criteria, metrics and targets; (ii) diagnosis; (iii) plan elaboration; (iv) plan implementation; (v) plan monitoring and review. This methodology was applied to a sixty-year-old water supply system (WSS) located in Lisbon's metropolitan area, Portugal. The strategic plan was elaborated by the municipality for the period 2015-2035 and has three strategic objectives. Based on these objectives eight strategies were outlined. Considering the strategic plan four tactical objectives were defined and for each of these objectives, assessment criteria were defined and adapted to system's reality. Metrics were defined for each of the previously established assessment criteria, allowing constant and accurate evaluation of each objective. As a result, twelve metrics were established based on three different dimensions (i.e., cost, risk and performance). The metrics were calculated and evaluated based on the defined reference values to diagnose the WSS. The WSS present a low IVI, a high unmetered consumption, high level of service connection failure and high operation costs due WSS aging and degradation. Four intervention alternatives were established and evaluated. Each alternative was evaluated by multicriteria decision analysis method, based on the performance, risk and cost assessment results. The best alternative which consist in increasing annual rehabilitation to 5% in the following years, optimization of the pump operation and renewal of the water meters was discarded due annual budget limitation. So, the alternative that should be implemented consider maintaining the 2% of annual rehabilitation, pump operation scheme optimization and renewal of the water meters. After production of the tactical plan, its implementation is performed at the operational level. Tactical plan monitoring and review is required.

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