Finding new trends through data analytics in infrastructure asset management – rehabilitation investments versus operational management

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Abstract
Water utilities sustainable management is a leading challenge in which data and information analysis play a key role. Nowadays data generated in information systems is too much, evolves too fast and is too diverse, requiring innovative information processing forms to enhance organization's management. Driven by reporting requirements, legal obligations in developing Infrastructure Asset Management (IAM) plans and the implementation of an asset management policy inside the Group, AGS (Administração e Gestão de Sistemas de Salubridade, S.A.) designed, developed and implemented a dynamic tool to support data management and information analysis. Based on tool's capabilities, a case study is presented, analysing rehabilitation investment impact on water systems performance. Results have shown that the relations between rehabilitation rates and non-revenue water (NRW) levels tend to normalize, being possible to establish the financial effort to reduce NRW in a given value for the case study's period.

Keywords
Asset management; dynamic platform; operational management; non-revenue water; performance assessment; rehabilitation investments.

INTRODUCTION

Data management is a key step towards the development of an Infrastructure Asset Management (IAM) approach, in any organization. Defining rehabilitation priorities in water distribution systems (WDS) requires reliable and accurate data on the individual components of the system and on the system's behaviour as a whole. Making rehabilitation decisions based on incomplete or incoherent data may have technical and financial implications compromising systems' sustainability.

This is particularly relevant when managing several utilities with long-term responsibility, geographically dispersed and with different management models and contexts as AGS (Administração e Gestão de Sistemas de Salubridade, S.A.), a Portuguese multi-utility operator that manages water utilities in Portugal and Brazil, having as shareholders Marubeni Group and INCJ (Innovation Network Corporation of Japan).

The role of AGS as a holding entails reporting obligations to shareholders, banks, national regulator (ERSAR – National Water and Solid Waste Services Regulator), among other stakeholders. These requirements promoted a step forward in information analysis and data management inside the organization.

This paper aims to present how AGS overcomes data management and information analysis requirements by developing a multi-user online platform that fulfils reporting duties, legal obligations in developing IAM plans and supports the implementation of an asset management policy inside the Group. A case study is described based on the tool's capabilities.

ASSET MANAGEMENT IN A MULTI-UTILITY GROUP

In Portugal, as in most countries, generalized implementation of strategic IAM of urban water systems requires a considerable mindset shift for the water sector as well as for decision-makers, politicians, the media, and the society in general (Leitão *et al.*, 2013).

Decisive actions occurred in the recent years in Portugal which are contributing for this change: the development of an integrated IAM methodology (Alegre & Covas, 2010) materialized in the publication of two technical guides by the Portuguese Water, Wastewater and Waste Regulator (ERSAR) and of specific national legislation (Decree-Law no. 194/2009), in force in 2012, which requires all water supply services and urban wastewater management services serving more than 30,000 inhabitants to develop IAM plans.

The IAM methodology considers that proper long-term planning should be achieved through the balance between cost, performance and risk at strategic, tactical and operational levels, taking into account three key competences: engineering, information and management (Alegre *et al.*, 2013).

This methodology requires the alignment between the planning levels in order to set-up a clear course of action from organization's strategic objectives to operational activities. For a multi-utility operator, this request can be achieved through the alignment between the holding company and its subsidiary organizations in which utilities' strategic decisions are hierarchically linked with holding's tactical goals (Figure 1).

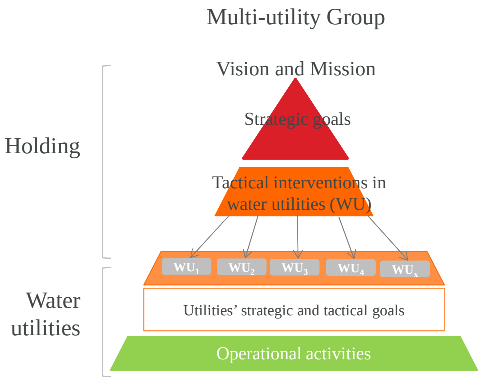


Figure 1. From strategic to operational planning in a multi-utility group.

In AGS, soon became clear that controlling and monitoring its subsidiary organizations demanded a performance assessment process based on coherent, reliable and audited data that would allow the calculation of standardized performance indicators (PI). This was accomplished with the design, development and implementation of a multi-user online tool – AGS platform.

From the holding's perspective, the tool supports AGS' tactical decision level providing utilities' assessment, its performance evolution and ranking, benchmarking, and identification of intervention priorities with proper solutions. From the utilities' perspective the tool supports strategic planning through system's global assessment and PI monitoring.

Aware of the need for a "new way" of managing water services, AGS is promoting a second edition of PGPI (Infrastructure Asset Management Program) – a 18 month-long collaborative project (Feliciano *et al.*, 2013) – that aims at the development of an asset management plans in the Group utilities, promoting capacity building and reinforcing the need for long-term planning and service sustainability. AGS platform plays an important role in this project as it enables to easily follow each utility's path in IAM through performance monitoring evaluation, particularly with regard to ease of access to data, concept standardisation and data quality control.

TURNING DATA INTO INFORMATION – AGS PLATFORM DEVELOPMENT

The development of the platform was one result of the awareness regarding data and information management. It was the result of a continuous learning process and comprised three main stages: i) data collection, processing and quality assessment; ii) information systems integration; and iii) large scale information use.

The tool's flexible structure (Figure 2) provides a dynamic analysis, allowing to quickly change selections and globally assess performance grouped in several ways (*e.g.*, by administrative area, management model, hydrographical basin, among others).

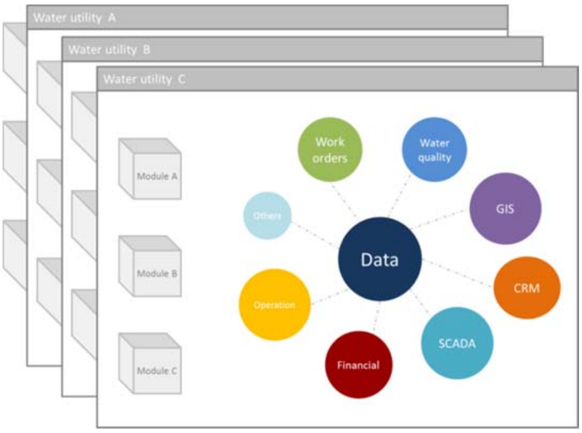


Figure 2. AGS platform data structure.

The tool is composed of different modules and is directed to different audiences, from board management to technical staff. One of the platform's modules was developed focusing on water utilities regulation and ERSAR's quality of service assessment system. This module is described in this paper to demonstrate the added value of the information made available by the platform.

Since the publication of the first Quality of Service Assessment Guide for Water and Urban Solid Waste Utilities, in 2004, the Portuguese regulator promotes performance assessment and benchmarking between water utilities through a set of standardized PI. The quality of service assessment system had a high leverage effect on AGS' control of its utilities performance, fulfilling the goal of seeking excellence and contributing for evolving the information management process.

Although ERSAR's assessment system is commonly used by water utilities to assess their own performance, AGS platform promoted a global holding's evaluation and an easier benchmarking process. This became even more important after 2012 due to the universal regulation of all Portuguese water utilities. Until then, only the private sector was regulated.

The ERSAR platform module mirrors the regulator's assessment system and presents PI, in all the utilities in Portugal mainland for the publicly available data, including AGS' utilities, according to three strategic objectives: 1) *Protection of users' interests*, assessing how users' interests are protected mainly regarding the degree of access and the quality of the service provided; 2) *Operator's sustainability*, assessing the level of operator's technical and economical sustainability and their interests, concerning economical and financial, infrastructure, operational and human resources dimensions; and 3) *Environmental sustainability*, where a set of indicators is used to assess the protection level of environmental issues related with operator's activities.

This module is organized in several dashboards (Figure 3) enabling different analyses and statistics, such as: i) water utilities overview and detailed information; ii) geographical analysis of quality of service assessment (Figure 4); iii) ranking of water utilities by PI; iv) correlation functions between PI and data and supporting trends; and v) a customized report feature allowing water utilities comparison.

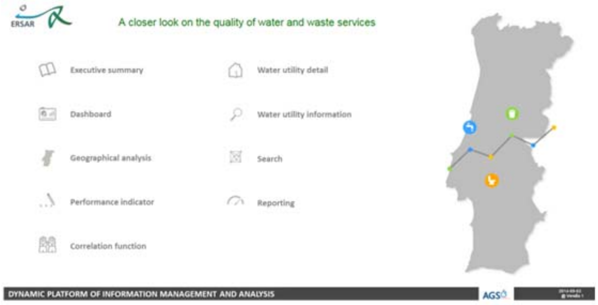


Figure 3. ERSAR module initial page.

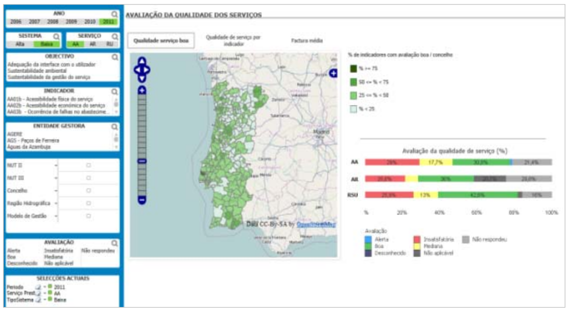


Figure 4. Geographical analysis page.

CASE STUDY DESCRIPTION

The case study herein presented followed IAM concerns and aims to analyse the relation between rehabilitation investments and systems performance and their evolution over time benefiting from AGS platform correlation function. To accomplish this, two PI from ERSAR's Quality of Service assessment system were selected: non-revenue water (NRW) and mains rehabilitation. PI definition (code, designation, units and calculation formula) and reference values are presented in Table 1 and Table 2, respectively.

Table 1. PI definition.

ERSAR code	Designation	Units	Definition
AA08	NRW [(1)]	%	$\frac{System\ input\ volume - Billed\ authorised\ consumption}{System\ input\ volume} \times 100$
AA10	Mains rehabilitation	%/year	$\frac{\begin{array}{c}Length\ of\ mains\ with\ more\ than\ 10\ years\ old\\ that\ have\ been\ rehabilitated\ on\ the\ past\ 5\ years\end{array}}{\frac{1}{5}\sum_{i=1}^{5} length\ of\ mains\ with\ more\ than\ 10\ years\ old\ at\ year\ i} \times \frac{100}{5}$

(1) Fi46 from International Water Association PI system (Alegre *et al.*, 2006).

Table 2. Reference values established by the Portuguese regulator.

ERSAR code	PI	Units	Reference values		
			Good 🟢	Fair 🟡	Poor 🔴
AA08	NRW	%	[0 ; 20]	]20 ; 30]	]30 ; 100]
AA10	Mains rehabilitation	%/year	[1.0 ; 4.0]	[0.8 ; 1.0[or]4.0 ; 100]	[0.0 ; 0.8[

With the assistance of the tool's geographical analysis module, it was possible to get an overview of Portuguese "retail services" water utilities (commonly at municipality's level) for AA08 and AA10 indicators, representing a sample of 285 utilities of ERSAR publicly available data (Figure 5).

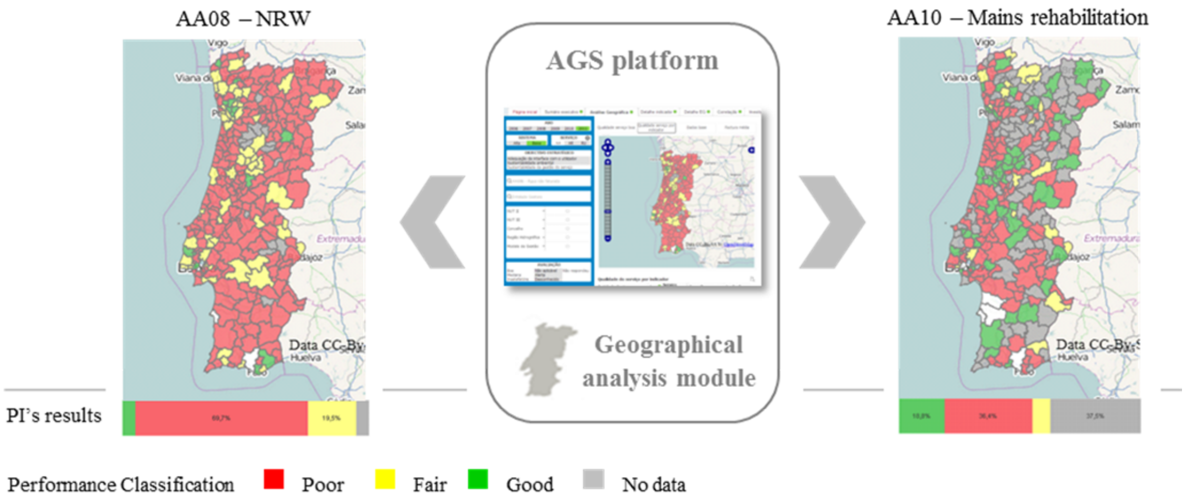


Figure 5. Portuguese "retail services" water utilities overview for AA08 and AA10 (2011).

From the available information, approximately 70% of the Portuguese water utilities have poor NRW levels (i.e. above 30%) and 35% have poor level in mains rehabilitation (less than 0.8%/year). Globally, 37.5 % of the utilities failed to report to the regulator the mains rehabilitation rates due to lack of data.

Audited and publicly available data from water utilities serving more than 30,000 inhabitants and with legal obligation of developing IAM plans were considered in the case study, corresponding about 30% of all Portuguese municipalities. Utilities for which data regarding all ERSAR's PI were neither complete nor reliable were excluded, which led to a final sample of 26 water utilities, representing approximately 40% of the entire Portuguese population. Table 3 presents an overview of the water utilities characteristics considered in the case study, presenting the minimum, median and maximum values for each variable.

Table 3. Overview of the water utilities analysed (2011).

Variable	Mains length km	Households with effective service No.	NRW %	Mains rehabilitation %/year	Mains failures No./(100 km.year)
Minimum	339	13,738	10.0	0.1	13
Median	875	53,846	27.5	1.0	34
Maximum	1,775	291,755	41.5	5.2	113

RESULTS AND DISCUSSION

The relation between mains rehabilitation and NRW in these 26 water utilities was analysed using the platform's correlation function (Figure 6). Results suggest a linear trend between NRW and mains rehabilitation and the existence of different behaviours among the utilities, being possible to identify two clusters in this analysis, A and B. Cluster B is a subgroup of the sample where all AGS' utilities are included, while cluster A corresponds to the remaining utilities. Both clusters present significant coefficients of determination (R^2) values, meaning that is possible to establish a relation between NRW and mains rehabilitation rate.

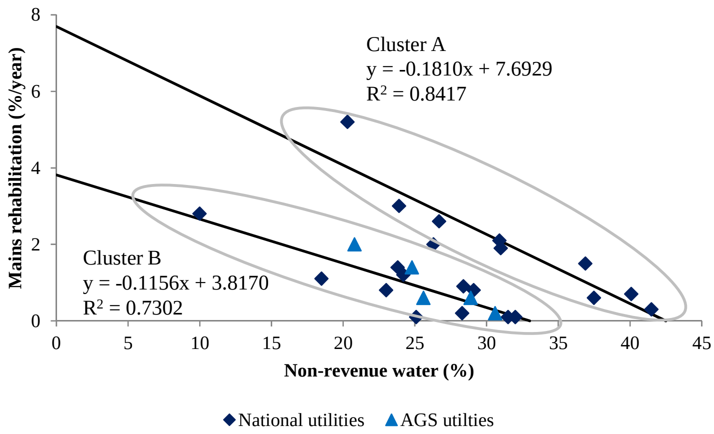


Figure 6. NRW and mains rehabilitation relation in 2011.

Figure 6 indicates that for the same NRW level, a higher effort on rehabilitation investments is required by cluster A than by cluster B. At the same time, for equal rehabilitation rates, cluster B presents better NRW levels than cluster A.

The difference between clusters A and B can lead to several conclusions, such as the efficiencies gained through good operating practices due to utilities NRW concerns (*e.g.*, implementation of operating practices to control water losses and leakage, proper flow monitoring, among others). This analysis should be carried out as a next step; however it was not possible, for the time being, to conduct this analysis due to a lack of detailed data from the utilities contained in cluster A.

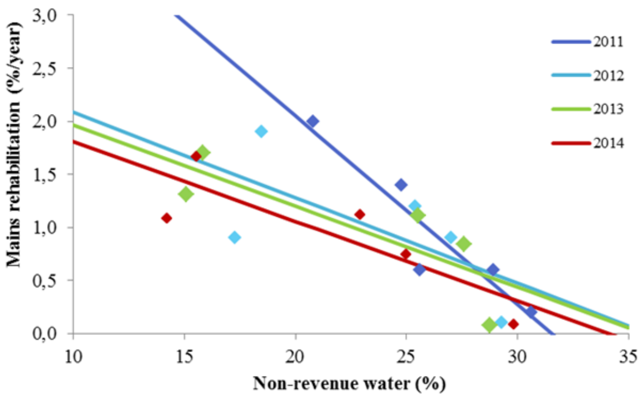
Based on one of the possible conclusions, raised in the last paragraph, the second step was to analyse the evolution from 2011 to 2014 in AGS' utilities where rehabilitation rates have been steady. For these utilities it was possible to conduct a detailed analysis.

AGS' utilities have different dimensions, from 20,000 to 100,000 served households and from 700 to 1,300 km of water mains length. In addition, initial NRW levels ranged from 23.4 to 27.8% while mains rehabilitation rate varied from 0.1 to 0.6%/year (**Error! Reference source not found.**). These utilities are also characterized by having implemented information systems such as geographical information systems, supervisory control and data acquisition, work orders applications, presenting a mature level of knowledge regarding the water supply systems.

Table 4. Overview of AGS water utilities (2010).

Variable	Mains length km	Households with effective service No.	NRW %	Mains rehabilitation %/year	Mains failures No./(100 km.year)
Minimum	689	19,685	23.4	0.1	27
Median	856	57,257	25.6	0.6	53
Maximum	1,364	103,397	27.8	0.7	77

Since 2011 a great effort has been made by these utilities to improve operating practices to control water losses and to reduce NRW. Figure 7 presents linear regressions between AA08 and AA10, computed for the 2011-2014 period in AGS' utilities.



Correlation functions:

2011
$y = -0.1778x + 5.6076$, $R^2 = 0.8698$

2012
$y = -0.0803x + 2.8872$, $R^2 = 0.4336$

2013
$y = -0.0762x + 2.7246$, $R^2 = 0.6804$

2014
$y = -0.0751x + 2.5593$, $R^2 = 0.7183$

Figure 7. Linear regression between NRW and mains rehabilitation in AGS' utilities (2011-2014).

The linear regression of 2011 is very different from the following years. In 2012 NRW levels are significantly lower than in 2011 considering equal rehabilitation rates. This difference is explained by operating practices' efficiency gained in 2012, such as, mandatory hydraulic modelling, geographical information system aligned with the billing system, meter's reading cycle aligned with the correspondent district meter area, work-orders detailed management, flow monitoring real-time analysis, more accurate water balance, among others. Comparing 2012 with the following years the difference between yearly linear regressions is not so noticeable. In 2014 efforts made in operating practices' efficiency are closer to "maximum" or "optimal" results and, therefore, the slope of the linear regression is similar to 2012 and 2013. In conclusion, results show that improving efficiency with operational practices, the relation between NRW levels and rehabilitation rates tends to normalize, and it's possible to establish a reliable relation between these two dimensions.

Having met the first objective of determining a relation between NRW and mains rehabilitation, a new question was raised: how much financial effort is required to reduce NRW in a water utility? Taking AGS' utilities into account, operational expenditures (OPEX) and rehabilitation investments as capital expenditures (CAPEX) were computed against NRW reduction in a five-year period (2010 to 2014). Cost and investment annual figures, for each year (2014 constant prices), where investment was totally considered as a financial cash-out in the corresponding year of execution, were calculated. Figure 8 presents the relation between the previous described financial effort per mains length and NRW reduction in five AGS' utilities from 2010 to 2014.

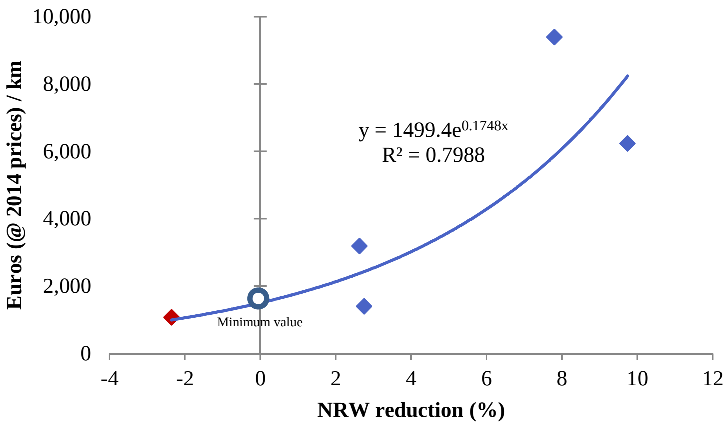


Figure 8. Relation between financial effort and NRW reduction in AGS' utilities (2010-2014).

Results indicate there is a clear relation between the financial effort and the NRW reduction.

Additionally, results suggest that there is a minimum effort required to maintain a *status-quo* situation, either by rehabilitating the network or by performing operational activities to decrease NRW. The minimum value attained was about 1,500 Euros/km. This idea is supported by one utility data where NRW reduction effort was below this threshold (1,072 Euros/km), having NRW increased in the analysed period.

The relation presented can also be used as a basis to estimate the resources required to achieve a given NRW reduction. It should be noted that results achieved with this case study are valid within AGS' subsidiary companies or companies with similar characteristics (i.e., NRW initial levels and mature level of knowledge regarding water systems). It is recommended to apply the evaluation herein described in other case studies, ensuring that a proper time frame is selected to include a period that allows the effort in NRW reduction to take place.

CONCLUSIONS

The IAM approach implemented is contributing to a "new way" of managing water services in Portugal. AGS is no exception, and taking in mind IAM principles of long-term planning based on cost, performance and risk, soon became clear that controlling and monitoring its subsidiary organizations demanded a performance assessment process based on coherent, reliable and audited data that would allow calculation of standardized performance measures.

As a response to this need, AGS designed, developed and implemented a multi-user online tool (AGS platform) which, among other features, enables the analysis of all national utilities' PI evolution, its performance ranking and the production of standardized reports. With the development of this tool, it was possible, for the first time, to have a complete vision of each system and to answer to stakeholders on a real-time basis with higher accountability.

Better IAM was a key driver for developing this platform. A use case regarding NRW reduction through rehabilitation investments and operational practices was analysed. Results show that, the relation between NRW levels and rehabilitation rates tends to normalize, and it is possible to establish the operating practices gains. This analysis enabled to determine the threshold in capital and operational expenditures above which AGS' utilities achieved their NRW reduction.

These results are important from a holding point of view and can also be relevant to support strategic decision-making processes where expenditures have an important role. The ability to compute "universal" and consistent relations based on reliable data are essential for decision-making processes when considering holding's tactical decisions and interventions in each utility.

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