Infrastructure asset management – the TRUST approach and professional tools
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ABSTRACT

Strategic asset management (AM) of urban water infrastructures faces the challenge of dealing with expensive and long-lasting assets of a very diverse nature and wide-ranging useful lives and costs. Typically, utility managers inherit an infrastructure with assets in assorted conditions and stages in their lifecycle. They are expected to manage their value in order to ensure adequate service, and make sure that what they pass on to their successors is capable of continuing to do so. Long-term vision is needed, and sound transition paths must be sought in order to ensure that urban water services are sustainable, without jeopardizing the quality of the service provided during the transition. Focusing on the transition to more sustainable services, the TRUST project revisited the concept of sustainability, explored pressures and drivers, and developed and tested a roadmapping methodology to cope with the implementation of disruptive solutions. Leading-edge analysis and assessment methods and tools were developed, multiple technologies were tested, scientific and guidance publications were produced. All of this can be explored and absorbed into a coherent management process. This paper describes the TRUST approach for infrastructure AM, addressing strategic, tactical and operational planning, supported by professional-grade software.

Key words | asset management, decision-making, long-term, strategic planning, tactical planning, water infrastructure management

BACKGROUND

The TRUST approach and software tools to support infrastructure asset management (AM) inherited from a number of previous R&D efforts. The foundations were the CARE-W and CARE-S EU 5th FP research projects (Sægrov 2005, 2006), which identified the need for integrated approaches to system rehabilitation and produced scientific results to support them. This evolved into a coherent and professional approach and software suite developed under the AWARE-P project (2009–2011), further developed in the scope of other R&D projects, such as iGPI (2012–2013, www.iniciativaGPI.org), INFR5R12 (2013–2014, www.werf.org/c_/FinalReportPDFs/INFRA/INFR5R12.aspx), and, in a very significant way, in the TRUST EU 7th FP project (2011–2014, www.trust-i.net). The infrastructure AM approach developed is a broad management process that addresses the need for a fundamental plan–do–check–act 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. ‘Infrastructure’ is meant to include all the physical assets of the urban water systems, and not just the buried (linear) components. It incorporates the principles generally recommended and adopted in infrastructure asset management (IAM) by leading-edge research, consultant and utility organizations (Hughes 2002; Sægrov 2005, 2006; INGENIUM & IPWEA 2006; Sneesby 2010). Alegre & Coelho (2012) summarize the background and current state of the art.

The IAM approach developed in the AWARE-P project – together with its roll-out stages, the iGPI and PGPI projects (Coelho et al. 2014) – was the winner of...
the 2014 Europe and West Asia Project Innovation Award in the Planning category (PIA 2014, awarded by the International Water Association) and of the Mulheim Water Award 2014 (www.muelheim-water-award.com).

The AWARE-P project (www.aware-p.org; Alegre et al. (2013); Alegre & Covas (2010); Almeida & Cardoso (2010)) aimed at providing water and wastewater utilities with the know-how and the tools needed for efficient IAM decision-making in urban water services. All project results – from best-practice handbooks and software to business cases, training courses and e-learning materials – have been placed in the public domain and are freely distributed.

The TRUST project built on the AWARE-P results and further developed them by:

- incorporating the TRUST concept of sustainability (Brattebo et al. 2013);
- consolidating the process of building a sound assessment system, resulting from stakeholder consensus on the key objectives, criteria, metrics and reference values (leading-edge distributed software to support decision theatres was developed at a prototype level within TRUST (Ydreams & LNEC));
- developing, at a prototype level, a decision support system based on a metabolism model (University of Exeter & Addition);
- producing manuals of best practice at policy makers, for utility strategic managers and for utility mid-managers and other decision-makers (under finalization at the time of writing this paper; LNEC & IST);
- producing new modules of the AWARE-P software at a professional grade and enhancing the whole platform (Addition & LNEC).

Two other R&D projects ran in parallel with TRUST, in a symbiotic effort for a joint better result. There was contribution from iGPI with a broad testing environment and with some new modules (e.g. Financial Project). INFR5R12/ WERF contributed with some new wastewater network modules and the possibility of testing the methods and software in a very data-rich environment.

### The TRUST/AWARE-P Approach to Infrastructure AM

The TRUST/AWARE-P approach to infrastructure AM is designed as a continuous improvement management process. It is a service-oriented IAM planning for long-term sustainability, embedding key ISO 55000 requirements.

The cube shown in Figure 1 symbolizes an integrated IAM approach. It advocates that IAM must be addressed at different planning decisional levels: a strategic level, driven by corporate and long-term views and aimed at establishing and communicating strategic priorities to staff and citizens; a tactical level, where the intermediate managers in charge of the infrastructures need to select what the best medium-term intervention solutions are; and an operational level, where short-term actions are planned and implemented. It also draws attention to the need for standardized procedures to assess intervention alternatives in terms of performance, risk and cost, over the analysis period. The other relevant message is that IAM requires three main pillars of competence: business management, engineering and information.

At each level of management and planning – strategic, tactical and operational – a structured loop (Figure 2) comprises the following stages: (i) definition of objectives and targets; (ii) diagnosis; (iii) plan production, including the identification, comparison and selection of alternative solutions; (iv) plan implementation; and (v) monitoring and review. Most utilities already have several elements of this process in place. What is often missing is alignment and
coherence between the different elements of the entire planning process and a sound way to measure compliance with set goals. It is in general not feasible to quantify the effects on the strategic and tactical objectives and to justify the rationale of the decision of which assets to replace and by which new characteristics. It is very common that decisions regarding one management process (e.g. water losses management) ignore other management processes (e.g. energy management; AM). The section below about the PLAN tool provides information about the rationale and practicalities of this topic.

Above all, TRUST/AWARE-P is a transparent and well-structured planning methodology to support the identification of problems and in the comparison and selection of alternative solutions. This is key for effective communication. Its core is a sound, objective-driven assessment system. Diagnosis, priority-setting between areas of interventions, and comparison of the alternative solutions within each area of intervention are based on the deviations of metric values from their corresponding reference levels and targets.

THE TRUST/AWARE-P SOFTWARE

Objective and accessibility

The TRUST/AWARE-P software suite is designed for infrastructure AM and planning of urban water systems. It provides the tools for quantified, long-term impact assessment of both capital investment projects and continuous operations and maintenance (O&M) interventions in a defendable, repeatable and transparent way. It supports service-oriented IAM planning, promoting key ISO 55000 requirements and full consideration of system behavior, for both linear (pipelines) and vertical assets (e.g., pumping stations, storage tanks, treatment plants) of water supply, wastewater and storm water systems.

The TRUST/AWARE-P software platform offers a growing and customizable tool kit (baseform.org). PLAN and IVI, two of these tools, were developed within the TRUST project: IVI, which supports long-term planning, and PLAN, with a dedicated section further on in this paper, which is the most instrumental tool in the entire toolkit. PLAN allows for integrating in a common decision-making environment the synthesis of all relevant information for the decision-making (e.g. input variables to assess the performance, risk and cost metrics selected), regardless of where and how it was generated. The Infrastructure Value Index assesses the overall ageing degree of an infrastructure, and is calculated through the ratio between the current value and the replacement value of each asset or group of assets. It is an effective metric for the analysis of infrastructure value over time (Alegre et al. 2014, 2015).

TRUST/AWARE-P addresses the need for a plan–do–check–act cycle at the utility’s various decisional levels, in order to integrate all infrastructural interventions (both O&M and CIP) as well as those non-infrastructural investments (e.g., in information systems and data) that may have a direct effect on the ability to manage the infrastructural assets.

The software can be accessed in several ways (Coelho & Vitorino 2014):

• Web-based version: the TRUST software deployment (trust.baseform.org), accessible to all TRUST partners by a shared username and password with TRUST intranet (trust.baseform.org). It contains all the basic AWARE-P tools plus the DSS prototype. It also includes the TRUST library of performance indicators, organized according to the TRUST sustainability definition.

• Single-user, personal computer version: the AWARE-P Suite Community Edition, a freely downloadable,
open-source software system that contains all the basic AWARE-P tools (available from http://baseform.com/np4/awareDemo.html).

• Corporate deployments, customizable, available under licensing schemes from one of the TRUST partners.

The software and the underlying IAM approach will be from here onwards generically referred to as ‘TRUST’.

Software overview: general outline

The TRUST software is a visual suite of tools for infrastructure AM and planning, supporting the quantifiable impact assessment of AM interventions and promoting the best trade-offs between performance, economics and risk.

It is a non-intrusive, web-based, collaborative environment where objectives and metrics drive IAM planning. It was designed for water supply and sewer systems, and is aimed at industry professionals and managers, as well as at the consultants and technical experts that support them.

Using available data (asset registry, geo-databases, kPIs (Key Performance Indicators), financial, operational), the TRUST software comprises a modular tool portfolio for AM planning, spatial analysis, and asset system diagnosis and prediction. The software has been designed following a modular paradigm in an open arrangement that allows for its usage with multiple workflows. The tools may be used individually or in combination.

PLAN and a number of the current tools are designed to be directly applicable to all of the urban water systems: water supply, wastewater and storm water. These other tools include performance indicators, IVI, financial analysis, or failure analysis.

An important feature of the software and of the IAM approach is its focus on evaluating urban water networks as systems rather than collections of independent components. For this reason, the range of available assessment models and methods draws heavily on the capability to represent and simulate system behavior, whenever possible with support from network simulators. This leads to the capability to produce both component-based metrics and system-wide metrics.

AM planning tools

Infrastructure planning in the short and long terms, and deciding where to act or which projects to prioritize, are the driving forces behind the TRUST IAM methodology. At project, subsystem or entire system level, alignment between strategic, tactical and operational decisions is promoted through a coherent metrics/kPI development process. These make up the assessment system that quantifies the consequence of the prospective decisions on utility objectives in the short, medium and long term – a central framework for the continuous improvement principles of ISO 55000.

The currently available AM planning software tools are:

- PLAN
  Compare & decide. A decision-support environment where planning alternatives or competing projects are measured up, compared and prioritized through objectives-guided metrics

- PI
  Performance Indicators. Quantitative assessment of the efficiency or effectiveness of a system is provided, through the calculation of performance indicators. A tool for selection and calculation of kPI based on organized libraries, including industry standards (IWA) and user-developed libraries.

- FIN
  Financial project. Assess the net present value and the investment return rate of any financial project from a long-term/asset lifecycle perspective.

Spatial and water system tools

Water supply and wastewater systems are spatial infrastructures with a direct connection to geographical data and to network hydraulics behavior. Network analysis, spatial analysis and the ability to express results where they happen on a map are key to understanding a system and how it may evolve as a consequence of infrastructure strategies. The available spatial and water system tools include a pressurized networks modelling tool:
NETW

Epanet Network Modeling. An efficient, Java-implemented Epanet simulation engine and natively integrated MSX library for full-range hydraulic and water quality network simulation, with advanced 2D/3D visualization and Google Earth integration.

Asset system analytics and prediction tools

The biggest challenge in AM is to take advantage of the available data to reach the best tactical and strategic decisions. The assessment criteria agreed among decision-makers should always be the basis for iteratively selecting the metrics to adopt and identifying the data needed to assess them. An ‘ideal’ metric often requires data that are not available. On the other hand, the organization may have data that are potentially useful to assess a given assessment criterion, the value of which has not been used. These may be quantitative or qualitative, direct or indirect. For instance, if reliable flow-metering is not available, information about age, materials, pressure, failure rates, or quality of construction can help identify areas with higher leakage rates, allowing the prioritizing of meter installation, detailed analysis and intervention. The AWARE-P software provides tools to explore existing data, while helping to identify what data and what requirements for data collection are critical, so that better metrics can be used in the future. All tools and required data are well documented, so that users can easily select the most fit for the purpose and apply them correctly. A range of modules that make available to everyday use the most effective methods for diagnosing current status and predicting future behavior are included in this category to complement standard AM software and add even more value to their results. The available asset system analytics and prediction tools comprise the following:

CIMP

Component Importance. Simulate the failure of each individual pipe in a water supply network to measure its hydraulic impact on nodal consumption.

UNMet

Unmet demand. Quantify water supply service interruption risk through the expected reduced service, calculated as the volume of unmet demand over a given period.

PX

Performance Indices. Technical performance metrics based on the values of certain features or state variables of water supply is provided. Simulation-based tool provides detailed technical performance assessment, related to capacity, level-of-service, network effectiveness and efficiency, water quality and energy system behavior.

IVI

Infrastructure Value Index. Analyze the ageing degree of an infrastructure as a ratio between the current and replacement values of its components, and project short- and long-term investment needs.

Support to strategic planning

Strategic planning is developed for the entire organization and aims at establishing global, long-term corporate directions (typically 10–20 years).

The first stage in developing a strategic plan (SP) is the definition by top management of clear strategic objectives. Through the identification of assessment criteria, a range of metrics is selected to assess them, and reference levels are set for each metric, translating a judgment with regard to each metric. Realistic objectives and reference levels require proficient knowledge of the context. If a utility is preparing a SP for the first time, setting up objectives requires taking into account the available context information, even if not yet fully structured and accurate. The metrics selected can assess performance, cost or risk. They can be indicators, indices or qualitative levels. Their number should be kept to the essential: as few as possible to respond to the assessment criteria agreed upon. As a rule of thumb, 10–20 metrics tend to be effective.
The second stage is the diagnosis of both the external and internal contexts, in view of the objectives, reference levels and targets established. This is carried out by assessing the values of all metrics for the status quo situation. The evaluation should be carried out through the planning horizon, using the best available methods. These can issue from the AWARE-P tool kit, from any other external tools, or, if necessary, based on informed guesses or expert opinions (e.g. using the Delphi method). All results are standardized to a 0–3 scale and represented in a traffic-lights colour scheme over time, for simple interpretation and communication. After the diagnosis, which provides a baseline assessment, the organization is in a better position to establish targets over time for each metric.

The third stage is the formulation, comparison and selection of strategies that lead to meeting the targets, given the starting point surveyed at the diagnosis stage. These strategies are at the core of the SP, which is then implemented and regularly monitored and reviewed.

A typical workflow for a strategic planning use case can be summarized through the schematic shown in Figure 3.

**Support to tactical planning**

Tactical planning and decision-making are framed by the SP and guided by the strategic objectives and targets. The aim of a Tactical Plan (TP) is to establish the intervention alternatives, to be implemented in the medium term (typically 3–5 years), that will concur in gradually fulfilling the strategies set in the SP. IAM tactical planning is not restricted to infrastructural solutions, as it should also consider options related to operations and maintenance and to other non-infrastructural solutions. Managing...
the infrastructure has close interdependencies with the management of other assets, such as human resources, information assets, financial assets and intangible assets – overlooking them in the SP and TP potentially leads to lack of alignment and inefficiencies in the use of resources. The IAM plan needs to address the non-infrastructural solutions that are critical for meeting the targets and are related to these other types of assets, e.g., investing in a better work-orders data system, or in the capacitation of human resources and implementation of an adequate human resources policy (Feliciano et al. 2015).

Typical stage-by-stage workflows for a tactical planning use case are summarized in Figure 4.

PLAN: DECISION-MAKING ENVIRONMENT AND PLANNING FRAMEWORK

PLAN is a decision-support environment providing organized assessment and comparison for any number of competing projects, solutions or alternative designs, which can be assessed and pitched against each other numerically as well as visually.

PLAN was designed as the central planning framework of the TRUST IAM methodology, where planning alternatives or competing projects are measured up and compared, through selected performance, risk and cost metrics, through interactive numerical and 2D/3D graphical information display. It may also be used to compare different systems or sub-systems for diagnosis and prioritization. It was created as a technical tool, but just as importantly as a negotiation and communication vehicle. Emphasis is placed on evaluating impacts over the long term and in multiple dimensions (service, economics, social), and on quantifying the impact of those interventions.

PLAN is based on the three main axes that characterize the assessment and comparison process: a time frame, a set of alternatives under comparison, and the chosen metrics (Figure 5). PLAN’s flexible 2D/3D cube display gives the user total control of which dimensions and viewpoints are

Figure 4 | Tactical planning use case with typical software workflows.
required for analysis, providing a global view of the impact of a decision.

The time frame comprehends both a planning horizon (i.e., the time frame of the intervention) and an analysis horizon (the long-term time frame for impact assessment).

The main steps in the planning process are the following:

- Begin by setting **Objectives** and the **Assessment criteria** (e.g., objective: service sustainability; assessment criteria: infrastructural sustainability).
- Define the time steps: the planning horizon and the analysis horizon.
- If required, define **Scenarios**, to translate potential external contexts that may impact the system or alternatives under consideration.
- Choose the **Metrics** (e.g., Infrastructure Value Index), to quantify the degree of achievement of a given objective, and define its reference values (e.g., 0.4–0.6: green; <0.3 red; remaining: yellow).
- Describe the **Alternatives** under assessment (e.g., replacement asbestos cement pipe in subsystems C and D according to the redesign specifications).
- Introduce data related to all the metrics in each of the alternatives, over time.
- Once the problem is formulated, PLAN compares and ranks the different alternatives.

Particular care has been given to the process for selection of metrics and their reference values and targets. Stating objectives up front, and understanding which criteria to use for their assessment, is a crucial step in developing effective metrics. Standardized metrics reflect the impact of the alternatives on the set objectives in performance, risk or economics terms. Reference values are consensual values aimed at judging results in absolute terms (e.g., a leakage value of 300 l/connection/day is poor, regardless of a specific target). Targets depend on the base situation and on the resources that can be mobilized. They tend to evolve over time (e.g., if the baseline is 450 l/connection/day of real losses, a medium-term target might well be 300 l/connection/day). In general, targets are established or adjusted post-diagnosis.

The diagnosis stage should be carried out based on the metrics selected, for the base situation and through the planning horizon. There is often the need to adopt a progressive system-based screening process, aimed at prioritizing system sectors, using the set of metrics selected. The most problematic sectors are homed in on and analyzed in more detail. For those that do not display significant overall problems, there is the need to confirm that they do not have relevant localized problems. If they do, these localized areas need to be equally retained for detailed analysis.

The metrics development procedure in PLAN is a powerful means for understanding the impact of the measured criterion on the overall decision. PLAN uses a standardization of the real-world values of the chosen metric into a 0–3 continuous scale. This scale has an explicit qualification into good (green, ≥2), fair (yellow, ≥1, <2) or poor (red, <1) levels (Figure 6).
In essence, the metric reflects the deviation from the reference value of the good performance (green zone), which translates the set objective. In other words, it reflects the consequence or impact of adopting the alternative under evaluation (if used to compare competing solutions) or the shortcoming of the object under evaluation (if used to diagnose and prioritize subsystems or sets of assets).

A simple weight system provides a mechanism to balance off the different metrics selected for the assessment process. The system can be sophisticated through time-dependent weights or an exclusion criterion. This screening process leads to the identification of priority areas of intervention. For these, the diagnosis needs to be more detailed, so that the causes of the problems are fully understood. Feasible intervention alternatives are compared and ranked in PLAN. For each subsystem, the intervention alternatives that best balance the set of metrics for the chosen objectives (evaluated via a ranking procedure), over the long term, will be selected. In the example of Figure 7, alternative 1 is globally the best, for the metrics and reference values pre-established, particularly due to long-term effects.

**CONCLUSION**

The TRUST approach and tools to support water professionals and decision-makers have already proved to be a success story in terms of innovation. A symbiotic effort between pre-existing knowledge, and running in parallel with an eco-system of other R&D projects, TRUST has produced very sound results: a number of TRUST cities across Europe have been trained; 30 Portuguese utilities developed and are now implementing their strategic and tactical IAM plans (www.iniciativaGPI.org); 17 utilities finalized in February 2015 their integrated plans for Water and Energy Losses Management, also based on the same principles and tools (www.iPERDAS.org); 27 utilities joined the second edition of the national IAM initiatives (2015). Prior to AWARE-P, a specific term for IAM did not even exist in the Portuguese language lexicon. ‘Gestão Patrimonial de Infraestruturas’ and its acronym GPI have since entered the common technical jargon and been incorporated in the strategies of PENSAR 2020, the National SP for Water and Wastewater Services. Also outside Europe the impact is relevant: the
public online trial version of the AWARE-P software garnered more than 1,200 registered users on all continents between 2012 and 2014, and its public-access Community Edition was downloaded over 300 times in the first 6 months after its release in September 2014; a leading-edge utility in the USA successfully applied the approach and implemented many of the tools, with partial pilots in Australia and Spain; training courses on demand were carried out in Brazil (four editions) and Mozambique, with further courses in Uganda and Jordan already slated for the near future.

The results achieved and summarized in this paper have only been possible with cross-organization teams working together from the outset, including utility professionals, researchers and academics, software developers and consultants. They represent a very important step in what is effectively a long road. This joint effort will continue in order to contribute to paving the way for more sustainable urban water services.

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