AWARE-P: a system-based software for urban water IAM planning

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Abstract

The AWARE-P IAM planning software offers a non-intrusive, web-based, collaborative integration environment for a wide variety of data and processes that may be relevant to the IAM decision-making process, including maps, GIS shapefiles and geodatabases; inventory records; work orders, maintenance, inspections/CCTV records; network models, performance indicators, asset valuation records, among others. The software provides an organized framework for evaluating and comparing planning alternatives or competing IAM solutions, through selected performance, risk and cost metrics. It comprises a portfolio of system metrics and network analysis tools that may also be used individually for diagnosis and sensitivity gain.

The public beta release in early 2012 garnered significant numbers of users worldwide, and subsequent versions and a growing number of utility deployments and pilots have been steadily confirming the potential of its system-based approach. It is based on the collaborative, web-based and highly modular Baseform platform (www.baseform.org), which runs wherever Java is supported, and materializes as an integrated and expandable suite of plug-in tools, taking advantage of the platform's user management, common data integration services and next-generation 2D/3D visualization capabilities with Google Earth® integration among other features. The paper describes the software's design and main features, and illustrates its main use cases.

Keywords

Urban water services; infrastructure asset management; software; collaborative; integrated; planning.

INTRODUCTION

A large proportion of the world's built urban water infrastructures have, over the past decades, accumulated alarming levels of deferred maintenance and rehabilitation. The combined replacement value of such infrastructures can be overwhelming, demanding efficient planning and the capability to pace spending and maximize its impact over the long-term (Alegre & Coelho, 2012).

From an infrastructure asset management (IAM) viewpoint, the notions of system design, preventive maintenance and system rehabilitation are all part of the same long-term, *balanced design* process. In mature networked infrastructures, all these stages co-exist — designing new or extending, maintaining or rehabilitating old are all part of the same process and pursue the same goals. Essentially, investing in a system over a period of time should always maximize its performance-risk-cost balance.

Most urban water infrastructures are complex, arbitrary networks evolved through fragmented growth over the years, largely responding to urban development and geographical needs. They are always perfectible, and IAM planning should strive to take every opportunity (through capital investment or daily maintenance alike) to evolve the system's configuration towards a better design — that which best serves the long-term strategic objectives defined for the infrastructure, faced with its evolving context.

This broader perspective does not preclude adequately managing each individual asset, making sure that it does not pose an unwanted risk or economic liability, and that it performs at its best as part of the whole system. However, emphasis must be placed on overall system performance, risk and cost (and on metrics that reflect them), as water networks behave not as collections of assets, but rather as systems where the symptoms of problems are often felt at a distinct location from their causes.

SOFTWARE SUPPORT TO IAM PLANNING AND DECISION-MAKING

IAM needs to factor in as much information as possible to support maintenance and capital investment decisions that may impact short- and long-term infrastructural sustainability, on the financial, environmental and quality of service dimensions.

IAM must rely on many inputs from a fragmented landscape of information systems (IS), from utility GIS, maintenance management systems and work order software, enterprise resource planning systems, customer and billing applications, simulation models, and several others. These processes involve a variety of utility personnel, from infrastructure asset managers and maintenance managers, to engineering planners, information system staff and finance managers, further adding to the dispersion of data, processes, objectives and decisions. One of the greatest challenges in achieving efficient IAM is precisely the integration of data, processes, objectives and decisions in aligning strategic, tactical and operational efforts.

THE AWARE-P IAM PLANNING SOFTWARE

The AWARE-P IAM planning software was designed as a non-intrusive, web-based, collaborative environment to integrate data, processes, objectives, metrics and decisions, with the capability to

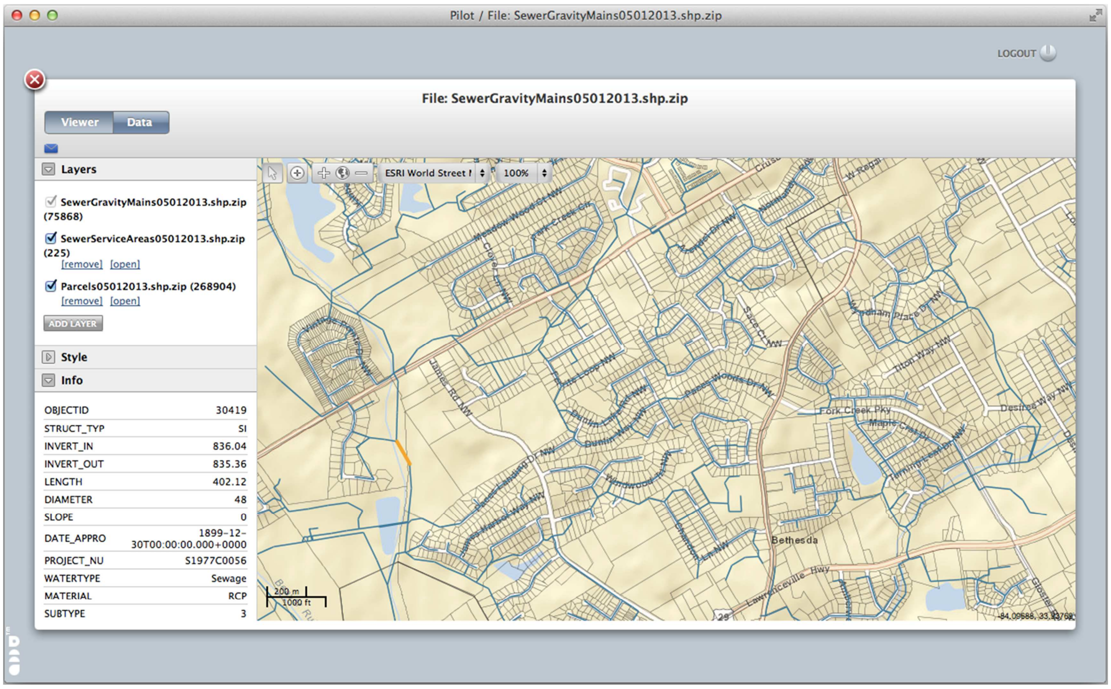

Figure 1. The AWARE-P GIS viewer and geodata browser

assess and account for individual as well as system behavior. It offers the ability to collect available data and information from a large variety of sources and processes that may be relevant to the IAM decision-making process, including maps, GIS layers (shapefiles) and geodatabases; inventory records; work orders, maintenance, inspections/CCTV records; network models, performance indicators, asset valuation records, among others (Figure 1).

The software provides an objective- and metric-driven organized framework for evaluating and comparing planning alternatives or competing IAM solutions, through performance, risk and cost assessment metrics. It comprises a growing, modular portfolio of system metrics and network analysis tools that may equally be used individually for diagnosis and sensitivity gain. The approach corresponds to a vision of IAM that seeks to align and integrate all efforts that may reflect on the infrastructure itself and on the data and information available about it, striving for measurable long-term infrastructural sustainability — be it on the financial, environmental or quality of service dimensions.

Background

The AWARE-P project (www.aware-p.org) aimed at providing water and wastewater utilities with the know-how and tools needed for efficient urban water services IAM decision-making. It inherited from previous R&D efforts, such as the CARE-W and CARE-S projects (Sægrov, 2005 and 2006), as well as professional best practice (e.g., Sneesby, 2010; ISO, 2012a,b,c). The IAM approach developed is a management process that addresses the need for a plan-do-check-act cycle at a utility's strategic, tactical and operational decisional levels, aiming at alignment of objectives, metrics and targets, as well as effective feedback across levels (Alegre *et al.*, 2013, 2011).

The AWARE-P IAM software system materialized several years of utility-driven R&D in a structure developed in order to host the range of tools identified as central to the analyses and decision support involved in the IAM planning process. The public beta release in early 2012 garnered significant numbers of users worldwide. Subsequent versions and a growing number of utility deployments and pilots (USA, Norway, Spain and Portugal, among others) have been steadily confirming the potential of its system-based approach.

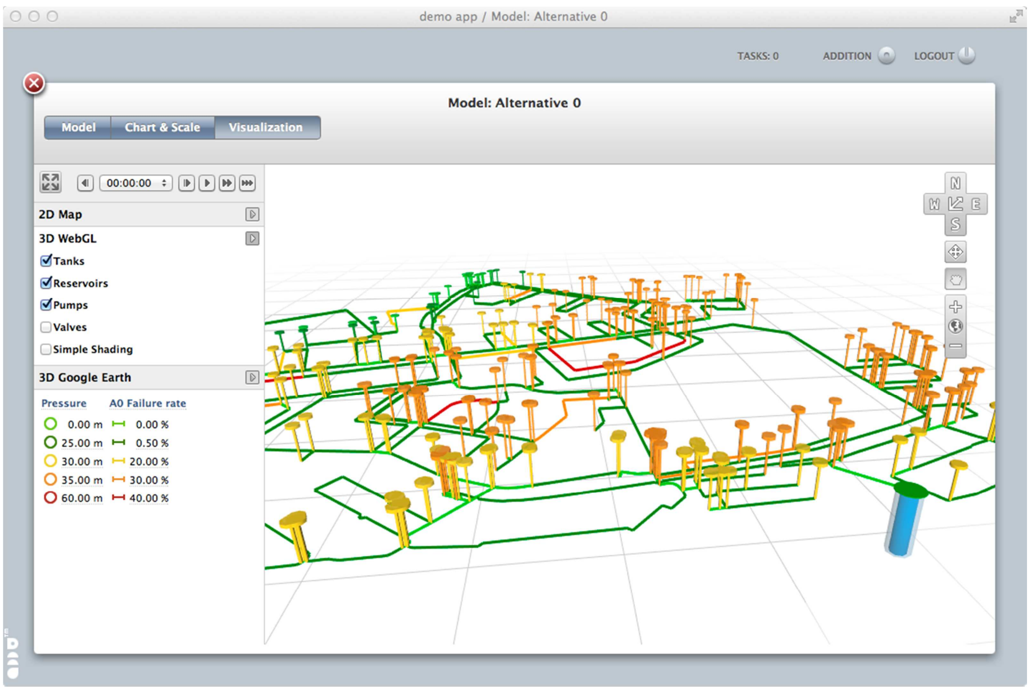

Figure 2. The AWARE-P software's 3D network visualization

The software system has since expanded to incorporate a growing family of modules, tools and capabilities, as the Baseform (Baseform, 2013) development and deployment platform that hosts it harbors new R&D projects (TRUST, 2013; WERF, 2013) and utility-sponsored development efforts.

Maturity has been steadily achieved through industry roll-out efforts such as the collaborative *National Initiative for Infrastructure Asset Management* (Leitao *et al*, 2013; iGPI, 2013). The software's continued development is today backed not only by an ecosystem of research organizations but is also present on the market through at least one provider of professional services.

Software overview

AWARE-P brings to a single environment a large variety of IAM-decision making data, and offers the ability to take advantage of them around two main usage modes:

- as a portfolio of assessment-oriented models and analysis tools, used individually or in combination for diagnosis and sensitivity gain to a system; or
- following the AWARE-P IAM planning procedure, oriented to the definition of a planning framework (time horizon, metrics, alternatives) and to feeding the PLAN tool with metrics issued from the tools available or sourced externally.

The software is thus built around the PLAN decision-making environment (Figure 3) and the NETWORK network-level integrated environment (Figure 2).

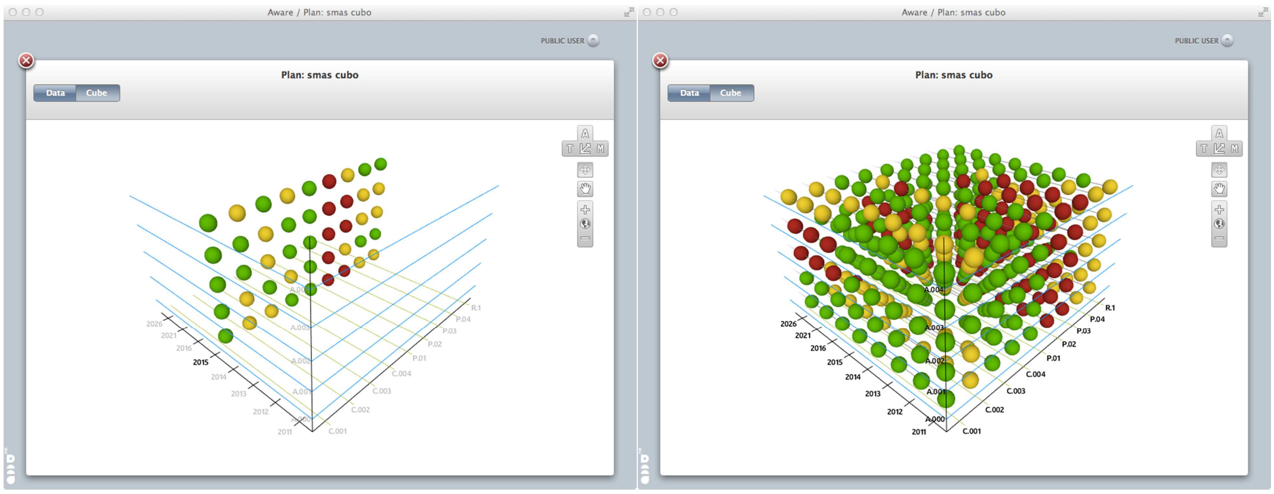

Figure 3. The PLAN decision-making environment: (left) a single planning time frame; (right) the 3D decisional space with metrics, time, and solutions along the X,Y,Z axes

The PLAN decision-making environment

PLAN (Figure 3) embodies the central planning framework, where planning alternatives or competing solutions are measured up and compared through selected performance, risk and cost metrics, through interactive numerical 2D/3D graphical information display. The tool is based on the three main axes that characterize the assessment and comparison exercise: a set of alternatives, a set of standardized metrics and a given time frame. The latter comprehends a number of user-specified time steps and may include both a planning horizon (i.e., the time frame of the intervention) and an analysis horizon (a longer time frame for impact assessment).

The metrics selected by the user, which may come from the performance, risk and cost assessment tools present in the AWARE-P portfolio or from external evaluations as selected by the user, are standardized as numerical indices and then categorized as color-coded levels, with an emphasis on coherent definition by the user of the target category values.

The NETWORK network-level integrated environment

NETWORK (Figure 2) is the other integration environment present in the software, and operates at the network level. A physical description of the infrastructure is provided along with 2D and 3D visualization, based on either a network model or layered geodatabase / GIS maps (Figure 1). NETWORK allows for expression of component-based analysis results such as failure analysis, component importance, performance indices or hydraulic simulation to be concurrently expressed on the same 2D/3D visualization, with Google Earth integration available.

The portfolio of analysis tools

The software makes available a coherent set of user-configurable assessment algorithms or models related to performance, cost and risk, which are used to evaluate user-defined alternative system configurations or planning solutions, following the AWARE-P methodology. Based on given planning objectives and measuring criteria, the user selects a set of metrics from the software's available metrics portfolio and proceeds to evaluate each planning alternative at the selected time frames within the planning and analysis horizons, feeding a cubic space of planning results.

The software's tools are also ready to be used in stand-alone, direct assessment mode for the fastest possible path to results (or in the context of general-purpose sensitivity gain and system diagnosis). Examples of such uses may be a PI calculation, an analysis of failures rates (Poisson and LEYP models are available), or an investigation of network component importance (as a measure of consequence of failure). The tools have been specifically developed to make the available methods and analysis algorithms accessible for effective industry usage, striving to retain a maximum of simplicity in delivering useable results. The tools plug into the integrated environment, with the current range comprising:

PI – An objective-driven environment for selection and calculation of performance indicators (PI), a quantitative assessment of the efficiency or effectiveness of a system, based on standardized, reference PI libraries as well as user-developed or customized ones. Available libraries include the IWA water supply and wastewater PI libraries.

PX* – Performance Indices, technical performance metrics based on the values of certain features or state variables of water supply and waste/stormwater networks. The indices measure performance concepts related to level-of-service, network effectiveness and efficiency.

FAIL – Using statistical models such as Poisson and LEYP, the failure analysis tool predicts future pipe/sewer failures for a given network, e.g. in the context of estimating risk or cost metrics. The analysis requires a failure data file, containing a historical record of pipe failure events (e.g., from work orders) and the corresponding complete inventory of pipes.

CIMP* – The component importance tool calculates the importance of each individual pipe in a network by comparing the total demand that the network is hydraulically capable of satisfying when that pipe is down (reduced service), with the total demand that the intact network is able to supply. The analysis requires a working network model.

UNMET* –The Unmet Demand tool calculates a service interruption risk metric, expressed as the expected volume of demand that the system will be unable to satisfy over a period of one year, caused by the failure of each individual pipe. A total expected value for the network is equally computed. The calculation is based on the predicted failure rate for each pipe, the component importance of each pipe, and an average downtime per pipe outage. The tool combines the results of the Failure Analysis and the Component Importance tools.

IVI – Infrastructure Value Index, representing the ageing degree of an infrastructure, calculated through the ratio between the current value and the replacement value of the infrastructure.

FIN – Financial project planning tool with the capability to project investments, costs and revenues over a user-defined period of time and calculate NPV and IRR.

EPANETJAVA* – an efficient, Java-implemented Epanet simulation engine and natively integrated MSX library, for full-range water supply network simulation (Figure 2), available in the NETWORK environment and taking advantage of its 2D / 3D network and results visualization.

The asterisk (*) denotes the tools developed for water supply networks in the initial portfolio of AWARE-P. The remaining tools are equally applicable to wastewater/stormwater and water supply infrastructures. Current development aims at increasing the offer for wastewater/stormwater, as explained further along.

An important feature of the software and of the AWARE-P IAM approach is its focus on evaluating the water networks as systems rather than as collections of independent assets. For this reason, the range of assessment models and methods available 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.

Further open-source capabilities have been added to the portfolio and are the subject of continued development, such as the ability to read GIS shapefiles and use them as another means of representing the network and perform topological, connectivity and geodata analyses. This is

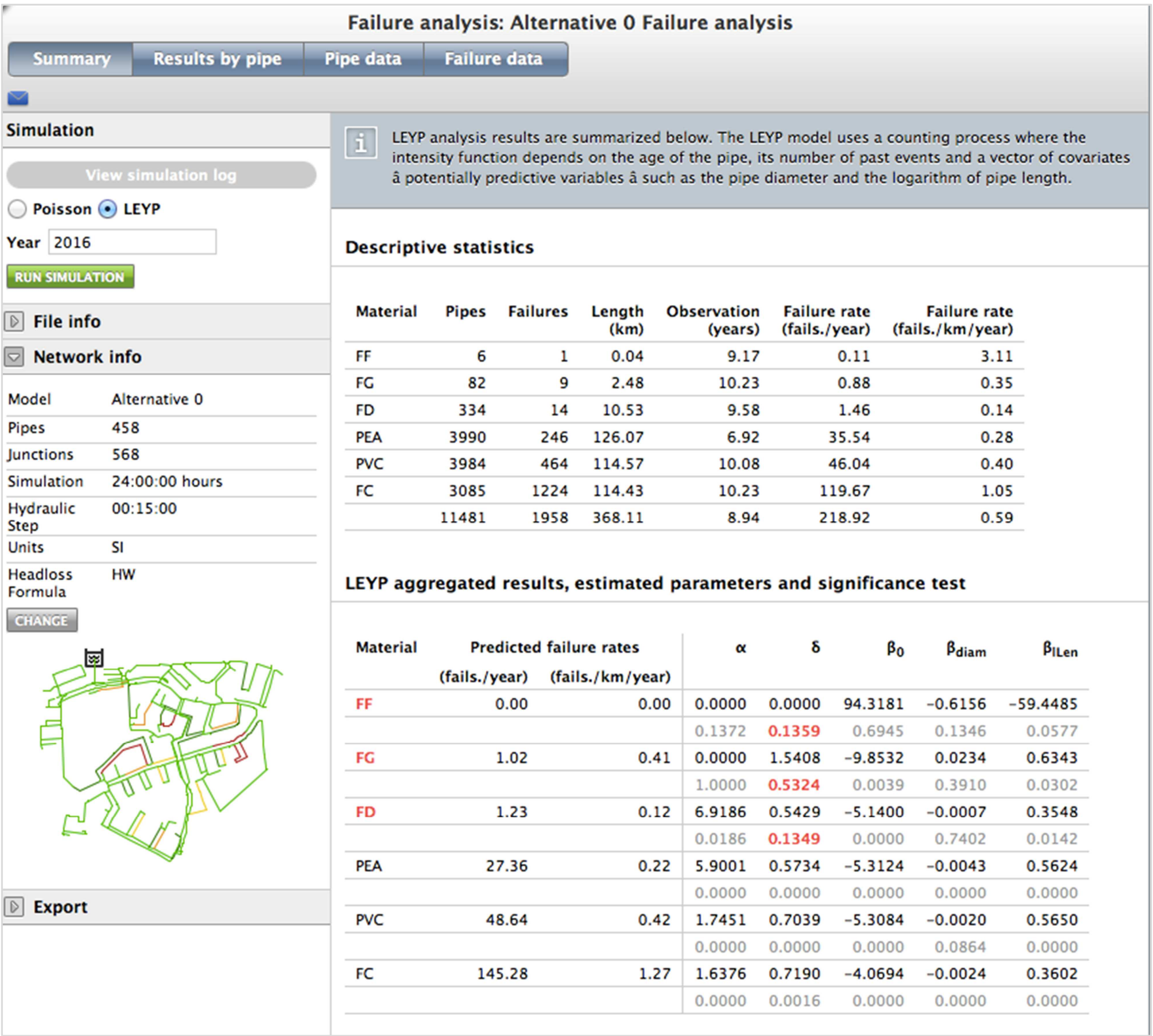

Figure 4. LEYP estimated failure rates and probabilities

particularly useful in the case of sewer systems, where network models often represent a morose and much heavier investment than for water supply systems. The current portfolio in AWARE-P includes water supply simulation capabilities, but not yet a network model for sewer systems.

Upcoming modules

The AWARE-P approach is equally applicable to water supply, wastewater or stormwater infrastructures. While the software is designed with that purpose in mind, the initial portfolio was evidently more complete as regards the needs of water supply systems than for wastewater or stormwater systems. A roadmap is in place to redress that balance, with important contributions from R&D funded by the EU's FP7 program (TRUST, 2013) and by WERF (2013).

A key goal is to bring the level of the analysis and assessment tools available for wastewater/stormwater drainage systems on a par with the tools already available for water supply. Among those, some of the most needed methods concern the capability to produce risk metrics in wastewater/stormwater systems, through the combination of failure estimates and component importance evaluation. Two new modules are therefore in the works to become the wastewater/stormwater counterparts of FAIL and CIMP.

Technology

From a technology viewpoint, the software is deployed as a web-based application that may be run from public or private servers, as well as on an individual machine as a stand-alone deployment. It materializes as an integrated and expandable suite of plug-in tools made available on the highly modular Baseform™ development platform (baseform.org), taking advantage of its user management, common data integration services, GIS information management and advanced 2D/3D visualization capabilities (Figure 2). It is open-source, Java-based and runs on all operating systems that support Java, such as Windows, Mac OS X or Linux, as well as on mobile systems such as iOS or Android.

APPLYING THE AWARE-P SOFTWARE IN PRACTICE: USE CASES

The software has been designed in an open and flexible arrangement that allows for its usage with multiple workflows, both structured and unstructured. The tools may be used individually or in combination; when supporting IAM planning, the most frequent use cases are variations of two basic modes: support to strategic planning, and support to tactical planning. Leitão *et al.* (2013) describe a range of applications in strategic and tactical planning that largely fall into either category. Both types of use cases are illustrated below.

Support to strategic planning

Strategic planning is developed for the entire organization and aims at establishing the global, long-term corporate directions, typically 10-20 years (Alegre *et al.*, 2013). The first stage is the definition by top management of clear objectives, assessment criteria, metrics to assess them, and finally, targets for every metric. Realistic objectives and targets require proficient knowledge of the context. If a utility is preparing a strategic plan for the first time, setting up objectives requires taking into account the available context information, even if not structured and accurate.

The second stage is a diagnosis based on the analysis of both the external and internal contexts, and anchored in the objectives and targets established. The evaluation should be carried out through to the planning horizon. The third stage is the formulation, comparison and selection of strategies that lead to meeting the targets, given the starting point surveyed in the diagnosis. These strategies will make up the core of the strategic plan. A typical workflow for a strategic planning use case can be summarized through the schematic shown in Figure 5.

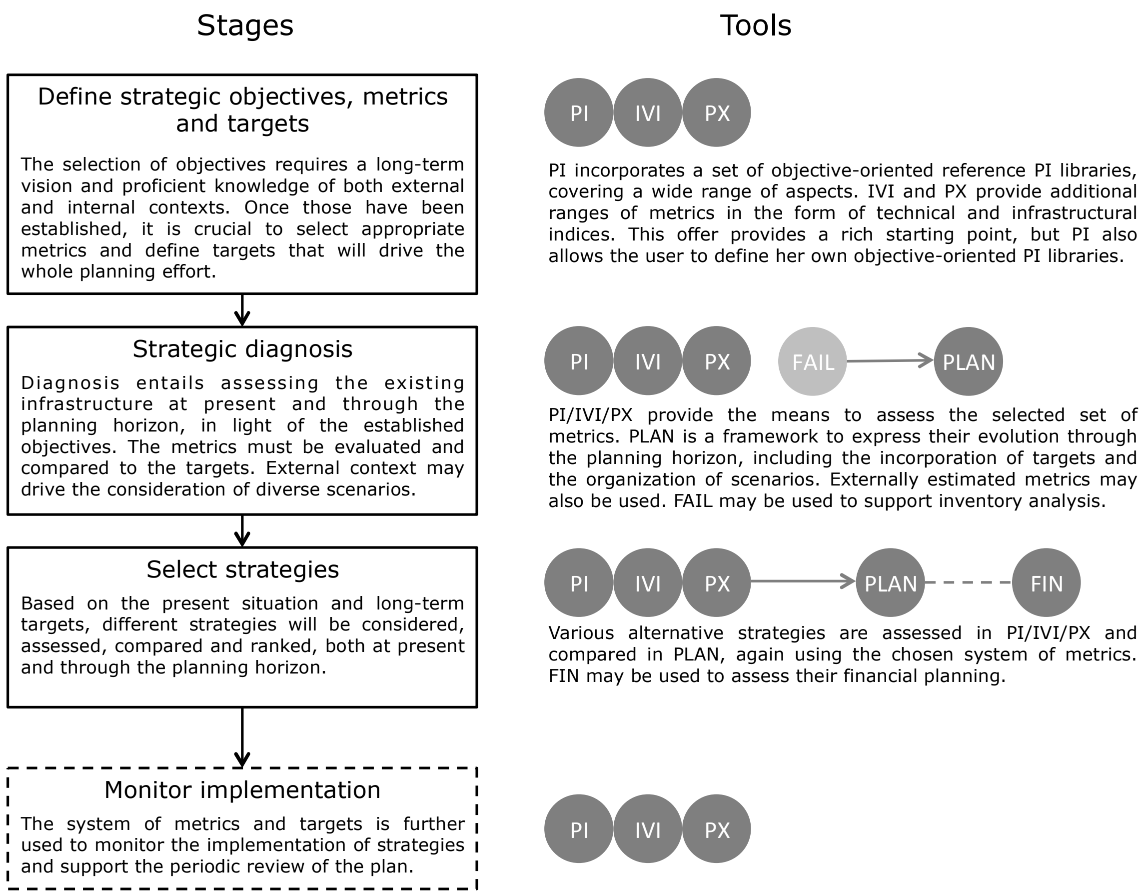

Figure 5. Strategic planning use case and typical workflows

Support to tactical planning

Tactical planning and decision-making are framed by the strategic plan and guided by the strategic objectives and targets. The aim of tactical planning is to establish the intervention alternatives to be implemented in the medium-term (typically 3-5 years). 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, intangible assets. The IAM plan needs to address the non-infrastructural solutions that are critical for meeting the targets and are related to these other types on assets, e.g., investing in a better work orders data system.

Typical stage-by-stage workflows for a tactical planning use case are summarized in Figure 6 (refer to Figure 5 for the explanation of tool roles at the corresponding stages in the two workflows). The key stages of tactical planning are similar to those described for strategic planning. The objectives, metrics and targets need to be coherent and aligned with the strategic plan. Metrics should typically address all three dimensions of performance, risk and cost, and enable a more detailed assessment in spatial terms, down to the subsystem.

The diagnosis stage should be carried out based on the metrics selected, for the present situation and through the planning horizon. There is often the need to adopt a progressive system-based screening progress, aimed at prioritizing system sectors, using the set of metrics selected. The most problematic sectors are focused 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 retained as well for detailed analysis. This

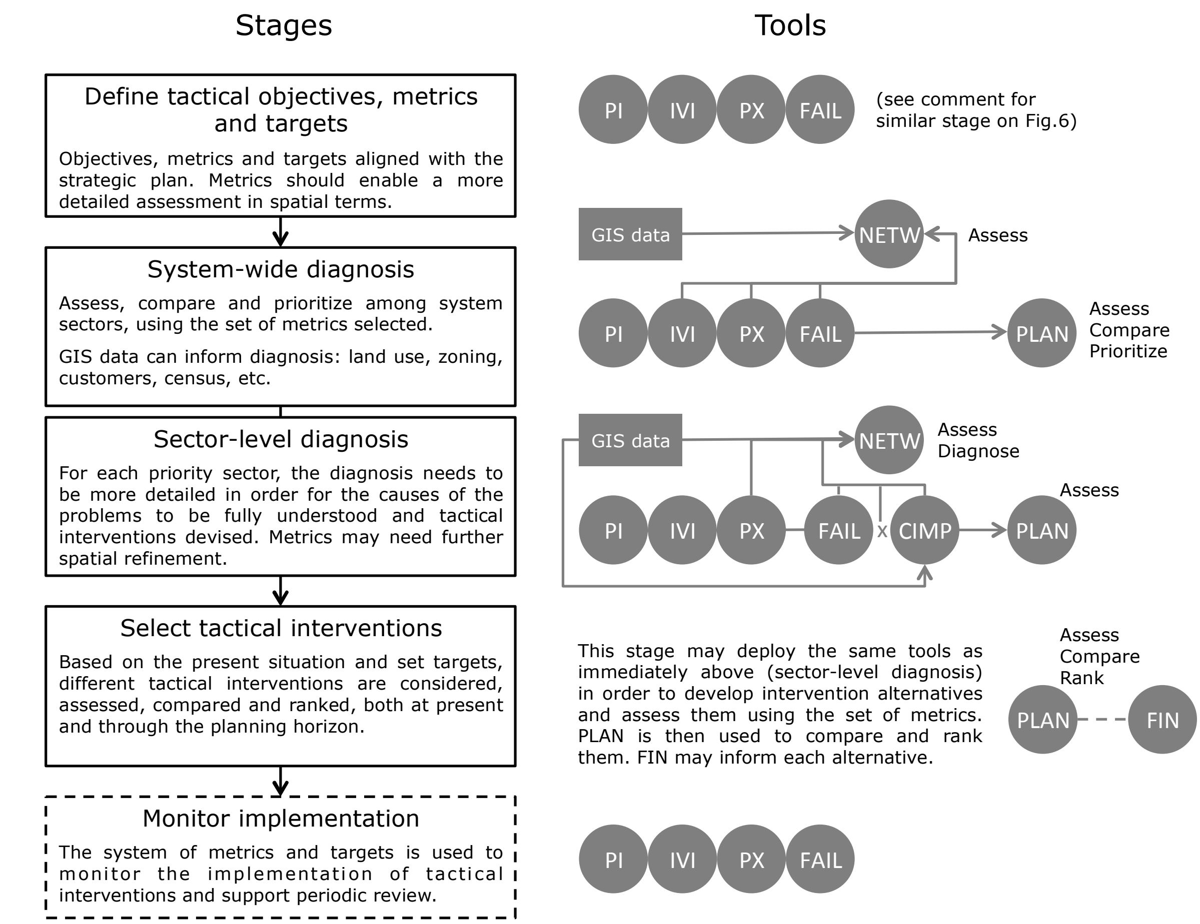

Figure 6. Tactical planning use case and typical workflows

screening process leads to the identification of priority areas of intervention. For these, the diagnosis needs to be more detailed in order for the causes of the problems to be fully understood.

The plan-producing stage encompasses the demanding engineering processes involved in identifying and developing feasible intervention alternatives for each of the priority subsystems, and the assessment of their responses over the analysis horizon for the metrics selected. For each subsystem, the intervention alternatives need to be compared, and that which best balances the set of metrics for the chosen objectives, over the long-term, will be selected.

Both the detail diagnosis and the design and analysis of infrastructural and operational intervention alternatives often benefit from the use of sophisticated analysis and modeling tools, as permitted by the data available.

CONCLUSIONS

IAM planning is a multi-objective, multi-stakeholder activity that must take advantage of a wide range of information sources and systems in order to maximize benefit to the infrastructure over the long-term. It benefits from the best possible alignment and feedback among decision levels — strategic, tactical and operational —and it is severely challenged by the fragmentation and lack of integration of data, processes, objectives and decisions in the organization.

The AWARE-P IAM software system materialized several years of utility-driven R&D in a structure developed in order to host the range of tools identified as central to the analyses and decision support involved in the IAM planning process. The software system has expanded to incorporate a growing family of modules and capabilities, as the development and deployment platform that hosts it harbors new R&D projects and utility-sponsored development efforts.

The AWARE-P IAM planning software is a non-intrusive, web-based, collaborative environment to integrate data, processes, objectives, metrics and decisions, with the capability to assess and account for individual as well as system behavior. It offers the ability to collect available data and information from a large variety of sources and processes that may be relevant to the IAM decision-making process, including maps, GIS layers (shapefiles) and geodatabases; inventory records; work orders, maintenance, inspections/CCTV records; network models, performance indicators, asset valuation records, among others (Figure 1).

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