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Recommended Citation
Sancho, David; Rodríguez, Alvaro; Sánchez-Diezma, Rafael; Llort, Xavier; Anzaldi, Gabriel; Rubión, Edgar; Corchero, Aitor; and Rodríguez, Albert, "UrbanWater And WatERP: Decision Support Systems For Efficient And Integrated Water Resources Management" (2014). CUNY Academic Works.
http://academicworks.cuny.edu/cc_conf_hic/361

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URBANWATER AND WATERP: DECISION SUPPORT SYSTEMS FOR EFFICIENT AND INTEGRATED WATER RESOURCES MANAGEMENT

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In this work we present UrbanWater and WatERP, two EU-FP7 projects with the common objective of designing and developing innovative ICT solutions to integrate real-time knowledge on demand and supply across water sources. Although both projects aim at developing an open platform solution with a decision support system as the knowledge deducting element, the approach used by each of them is different.

INTRODUCTION

Water management enabled by ICT is a new and promising area with the objective to integrate real-time knowledge on demand and supply across water distribution networks and water sources (European Commission [1]). With this lead-in, the European Commission stimulated the creation and development of ICT-enabled solutions for Integrated Water Resources Management [IWRM], involving as key building blocks innovative demand management systems, decision support systems and data management technologies under FP7-ICT-2011-8 call. The proposed ICT solutions had to involve robust and proven technologies permitting a holistic approach towards IWRM, and possibly include new data management technologies with a real-time predictive capability demand forecasting, advanced metering, real-time communication of consumption patterns, adaptive pricing, and/or combined energy and water management schemes.

On this paper we present two projects that were born in this context, offering different but complementary approaches. On one hand, WatERP (Water Enhanced Resource Planning “Where water supply meets demand”) proposed to develop an intelligent open platform that integrates real-time knowledge regarding available water supply and demand, from water sources to users and across geographic and organizational scales. The information from each step of the process can be exchanged and accessed so that the entire water distribution network can be viewed, understood and improved in an integrated and collaborative manner.

On the other hand, UrbanWater (Intelligent Urban Water Management System) proposed to develop, demonstrate and build an innovative ICT-based platform for efficient and integrated
management of urban water resources, incorporating weather prediction and surface water reserves data, household consumption data, water distribution data (including pressure and leakages), and statistics coming from other sources.

GENERAL OBJECTIVES OF EACH PROJECT
In recent years, water shortage has become an increasing concern, with a growing imbalance between water demand and availability reaching critical levels due to the growth of cities. This imbalance has put more pressure in water reserves management where effective decisions are becoming essential (Brandes [2] and European Commission [3]). Therefore, in order to secure water supplies into the future, there is an urgent need to transition towards a more water-smart society and develop water-wise solutions to improve water and energy efficiency, reduce water consumption and preserve water resources (European Commission [3]).

In the WatERP project, an open platform covers the previous needs. Such platform allows integrating information from multiple decisional tools and systems to enhance and support water manager’s decisions by improving water resource management and energy efficiency. Therefore, the open platform integrates near real-time knowledge in a framework where the water domain ontology, the decisional systems (Demand Management System [DMS] and Decision Support System [DSS]) and the data warehouse system interoperate under Service Oriented Architecture – Multi-Agent System [SOA-MAS] architecture to create an intelligent and interoperable environment where multiple systems interact autonomously and provide information at different time and geographic scales through the Open Management Platform [OMP]. The DSS supports the decision-making process in the water supply and distribution chain by (i) prioritizing water uses; (ii) improving distribution efficiency, and (iii) producing water energy and cost savings.

The overall objective of UrbanWater is to provide an intelligent water management platform to efficiently manage water supply in urban areas. Specifically, the main sub-objectives are to (i) develop a multi-technology gateway prototype according to most efficient current standards, combining wired and wireless technology, ensuring maximum geographic coverage, cost-efficient performance and power savings, as well as data integrity and customers’ privacy; (ii) deploy data management tools including security frameworks to guarantee rapid and efficient management of smart water meter data; (iii) develop a set of novel prediction and monitoring systems based on real-time information, statistics data and forecasting models for determining the urban water demand, the water resources’ availability and for detecting leakages in water supply networks; (iv) develop an set-up a Spatial Decision Support System [SDSS] based on information coming from the set of prediction and monitoring systems; (v) deploy an automatic billing system based on a novel real-time adaptive pricing model; (vi) deploy an on-line platform to communicate European utilities and customers; and (vii) integrate all components to build the UrbanWater platform and validate it during at least three months in two differentiated urban environments.

DESIGNED SOLUTION APPROACH
WatERP’s ICT architecture (Anzaldi et al. [4]), which is based on SOA-MAS architecture, is focused on providing intelligent and near real-time linkage between manifold resources (e.g. source data, management tools and systems, etc.) such as decision support tools, demand management tools, hydrological forecasts, or management platforms (like the OMP). This architecture provides flexibility and scalability to the platform, and facilitates the integration
with third parties (tools and data) thanks to the use of OGC standards on the communication interfaces (OGC’s SOS and OGC’s WPS) and the data exchange formats (WaterML2).

The solution designed in WatERP (Figure 1) integrates the following modules: (i) Multi-Agent System [MAS], that orchestrates the tools and data; (ii) Water Management Ontology [WMO], that provides a common vocabulary to enable access to and sharing of information during the decision-making process; (iii) Water Data Warehouse [WDW], that collects and processes raw data and makes it available to the platform; and (iv) OMP, that integrates the outcomes of all modules and presents them in a graphical interface that empowers local and global management.

UrbanWater’s ICT platform offers a set of SaaS (Software as a Service) to water utilities. The architecture, which was designed with the aim of simplifying the connection and interaction between the different services as well as facilitating the development of potential new services, is divided into several layers (see Figure 2): (i) user layer, who represents the users or actors of the platform; (ii) presentation layer, who offers a common Graphical User Interface [GUI] providing a single user experience for all services (including outsourced services); (iii) service layer, where all services offered in the platform (e.g. SDSS, billing, demand prediction, leakage detection, etc.) are located; (iv) integration layer, which is used by all services to access UrbanWater platform’s resources; and (v) data layer, which is the single access point to all information resources provided to the services.

Figure 1. WatERP platform architecture.

Figure 2. UrbanWater layer-based architecture.
Additionally, there are two vertical layers providing management and monitoring capabilities to the IT department of the water utility (green boxes in Figure 2).

**DECISION SUPPORT SYSTEM DEVELOPMENT**

Implementations of DSS focused on decision-making related to water resources management can be found in the research publications and in a number of case studies. A close involvement of models (e.g. hydrological, groundwater, hydraulic, or quality models), included into the DSS or as an external support, has been a common pattern in many DSSs in water supply. In this context, DSS approaches can be classified in DSSs oriented to planning activities and DSSs oriented to operational activities.

DSS oriented to planning activities usually are data-driven DSSs that support the activities for the planning and development of a water supply system. DSS oriented to operational activities are focused on providing real-time information and decision support to the operation of the water supply system. Many of these DSSs are based on a data-driven or model-driven approach, building the DSS capacities in the ability to inspect and analyze data from the supply system or from specific model outputs. There are three noteworthy sub-categories in the operational-oriented group: (i) DSSs that aim at optimizing part of the water supply system (e.g. water allocation or the water distribution network) by finding the optimal solution to a specific problem; (ii) DSSs including spatial capabilities, usually related to the implementation of GIS modules; and (iii) Knowledge-driven DSSs, which are based on the idea that current practices representing a heuristic knowledge of the system can be encoded into a structured reasoning process that could mimic the human thinking process. The main advantage of knowledge-driven DSSs in the context of water supply is that they can provide a holistic approach, integrating expertise or knowledge from the different parts of the system without neglecting the use of additional supporting elements (as models or optimization processes).

Although both projects opted to use a knowledge-driven DSS with spatial capabilities in their platforms, the resultant solutions have different points of view.

**WatERP DSS**

The main aim of WatERP’s DSS architecture (see Figure 3) is to provide the needed evaluations (solid arrows in the figure) and simulations (dotted arrows in the figure) in order to offer recommendations and alerts to the water managers to be applied into the whole water resource management chain. Hence, the designed architecture is made up of different sub-systems such as (i) “DSS Core” that aims at managing the DSS components towards decision-making; (ii) “Knowledge Acquisition System” that is in charge of transforming incoming information into formats suitable for the DSS; and (iii) “Inference Engine” that uses artificial intelligence techniques in order to exploit collected information and produce proper knowledge to help in the water decisional-making process. Moreover, the required information as well as the recommendations and alerts generated are managed by the MAS, which is the responsible of orchestrating, providing information and integrating all WatERP decisional elements. Therefore, the connection of the DSS with external systems is done through the SOA-MAS architecture, which acts as a bridge between the different decisional elements integrated into the WatERP architecture.

The DSS acts when the water manager requests some evaluation and simulation procedures through the OMP. At this moment, the MAS is in charge of running the DSS process and providing the required data (e.g. scenario information, demand forecast, weather information, etc.). These data are transferred to the “Knowledge Acquisition System” (via “DSS
Core”) in order to perform the needed internal transformations. Once the information is ready, the “DSS-Core” configures and executes the “Inference Engine” suitable for the information gathered and the water manager’s objectives. Thereby, the “Inference Engine” is divided into the “Rule-based inference engine” (RBR) and the “Case-Based inference engine” (CBR). The decision of using one, the other, or both is made taking into account the complexity of the scenario. On the one hand, RBR is a forward chaining rule system (Giaratano and Riley [5]) implemented in Drools framework that models the water manager’s expertise in form of rules. As a result, this intelligent system generates a set of alerts and recommendations by applying a set of rules based on the information from the scenario (facts) until no more knowledge can be obtained. Hence, this inference engine permits to (i) avoid conflicts in water resource management by the application of water resources formulas, water policies and operational priorities; (ii) quantitative accounting of all demands based on established purposes and system operational rules; and (iii) comprehensive water resource management by achieving a consensus between the operational rules and water resources management formulas and rules.

On the other hand, the CBR is a cognitive learning technique that gathers knowledge from the past experience, stores it in a case database, and applies this newly learnt knowledge into current situations. Then, when a new situation (case) occurs, the CBR selects the most appropriated past situation by applying a machine learning process (e.g. KNN or similar techniques). The past situation is adapted to the new one by interpolating the data before selecting the case from the database, which returns a set of recommendations. Therefore, this kind of reasoning permits (i) a highly dynamic modeling of the water distribution system, and (ii) the resolution of non-linear hard problems without having to identify the whole domain’s knowledge.

Finally, the “Inference Engine” results are provided to the “DSS Core” that returns the results to the WatERP module that originated the request through the MAS.

![Diagram of WatERP's DSS](image-url)

Figure 3. Detailed architecture of WatERP’s DSS. Solid arrows represent evaluation petitions and requests while dotted arrows represent simulation petitions and requests. The rectangle delimits the components that belong to the DSS.
UrbanWater SDSS

The design of the UrbanWater SDSS (Spatial Decision Support System) focuses on taking advantage of the knowledge from experts’ current practices (often based on their experience operating the site), providing a framework to structure such existing knowledge. The SDSS allows top cover of the full extent of parts/elements that integrate the water supply system, as well as to extend the reasoning process with new knowledge or decisions making the most of the already structured process in order to provide a rich content where integrated decisions can be performed. Moreover, it allows the integration of additional supporting tools (e.g. water availability, water demand, water leakage, etc.) to enhance the reasoning process.

This module also provides a GUI including the spatial representation of the information (e.g. location and shape of a basin/reservoir) using GIS modules that provide OGS’s WMS and OGC’s WFS features, as well as the graphical representation of the evolution of the dynamic information (e.g. evolution of the water flow of a river).

The design of the SDSS is based on the sense that it will act as an expert system providing support to the decision-making process regarding the operation of the elements present in the supply and distribution network. Saying “the operation of the elements” leads to the basic components of the SDSS structure: elements and rules.

The element component literally represents an element of the real water supply and distribution network (e.g. reservoir, borehole, water treatment plant, etc.). An element is made up of parameters, which embody the static information related to its structural characteristics (e.g. maximum volume of a tank or a reservoir, minimum outflow, etc.), the static information related to its spatial characteristics (e.g. coordinates of the location, description of the shape, etc.), and variables, which contain the information related to measurable data (e.g. current volume of the water stored in a tank or a reservoir, current outflow, etc.). The UrbanWater SDSS will be released with a set of predefined elements suitable to build the logical model potentially for any water supply and distribution network. Those elements together with the representation of the water flow through them will constitute the logical model diagram.

Both parameters and variables are expressed as key-value pairs (value can be either a number or a string), but as opposite to variables, which are linked to a physical measured variable in the cloud database or to the output of any platform module (see Figure 4), parameters are defined when creating an instance of the element and will not be modified during the execution of the SDSS.

The rule component, which represents the business rules describing how the elements of the water supply and distribution network are operated, must be transformed into knowledge that the SDSS is able to understand in the form of “if/then” statements.

The essential components described are stored in a local database conveniently structured. Then, the rule-based inference engine (Drools in this case) executes the defined rules with the specified information gathered from the cloud database (read from a sensor or originated by other modules), modifying the value of the elements’ parameters. The modified elements are stored again in the database and made available to the rest of modules.
Figure 4. The SDSS module plays an important role in the UrbanWater platform centralising all decision-making activities. Any module processing information that could help the water utility to make decisions can be connected to the SDSS module and contribute with new information, combine it with the existing data from the cloud database or other modules, and generate new knowledge.

The presented design achieves the goal of building a highly flexible SDSS capable of connecting manifold data sources and data processing modules that enables to (i) effectively estimate water demand in urban water areas to manage water supply chains in an efficient way; (ii) reduce waste of water and economic losses associated to leakages in the urban water distribution network; (iii) smoothen daily water demand peaks in order to allow distributors to save costs related to the urban water distribution networks’ management; and (iv) provide an off-line and on-line operation framework that allows define/test scenarios of availability and demand, testing specific strategies for the operation of the water system.

The main differences between both approaches rely on the management and ICT perspective. From the management perspective, WatERP aims to cover the whole water supply and distribution chain by making recommendations and alerts related to water resources allocation and water distribution pumping schedules, while UrbanWater aims at offering recommendations beyond water allocation taking into account other factors like water losses (leakages) or smart metering data to adapt the price for the customers.

From the ICT perspective, the most remarkable differences are related to data gathering and reasoning process (inference engines). Regarding data gathering, WatERP retrieves the information from the sites using OCG standards (SOS-WaterML2), stores it in the data warehouse/water domain ontology and then the MAS orchestrates this information making it accessible to the integrated software elements that require it. Instead, UrbanWater retrieves the information from the sites using a tailored legacy data parser and stores it in the cloud database. The SDSS or any other module can then request this information, which will be served in a
standardized format through the UrbanWater platform. Finally, WatERP’s DSS uses a combination of rule-based and cased-based inference engines depending on the part of the water supply chain (lower or upper part), while UrbanWater’s SDSS relies on a rule-based in order to give support to the operators in the decision-making process.

In spite of the differences between both projects, UrbanWater and WatERP could complement each other. They are focused on solving different issues of the same problem, and both approaches are based on open platforms to maximize its flexibility. Therefore, it is not difficult to imagine that the modules belonging to one platform could relatively easily be adapted to be integrated in the other platform.

EXPECTED IMPACT

With the presented solution, WatERP expects to (i) achieve water savings of up to 8% in water-scarce areas where water distribution is already efficient but where further savings could be achieved by improving coordination among operators in the upper part of the distribution chain; (ii) energy savings up to 5% in areas where water is abundant and water distribution is already efficient but where energy savings could help to reduce costs; and (iii) additional water, energy and costs savings from increased user awareness and behavioral change.

From the other side, UrbanWater expects to (i) reduce water use due to leakage by 30%; (ii) reduce water use by 10% through price incentives; (iii) reduce water use by 15% through behavioral change; (iv) reduce energy use at national level by 1% (representing 16M tones of CO₂ per year); and (v) save €15 billion due to environmental costs of water extraction. If the previous goals are met, the total water saving can be up to 56M m³ per day in Europe.

In order to test and validate the proposed platforms, WatERP is implementing its solution in Spain and Germany while UrbanWater is implementing its platform in Portugal and United Kingdom.

ACKNOWLEDGEMENTS

This work is being carried out in the framework of the EU FP7-Projects UrbanWater (grant: 318602) and WatERP (grant: 318603).

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