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ICT and stakeholder participation for improved urban water management in the cities of the future

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Abstract: Cities are facing a series of challenges: on-going urbanization, resource depletion and emissions, an ageing and deteriorating urban water supply infrastructure and the effects of climate change. To meet these challenges and to be able to drive sustainable economic growth, cities need to become smart and tap their innovation potential through the use of Information and Communication Technologies; this will allow us to create cities with a smaller water footprint overall. This will be achieved by optimizing the operation of water utilities, thus saving water and energy, and minimizing network leakages and non-revenue water. At the water utility level, smart pressure management and optimized operation based on smart algorithms, network intelligence, and the installation of pressure and flow sensors throughout the network can significantly improve operations, save water and energy, and successfully follow the new trends in cities. The use of relevant ICT and social computing can be instrumental in raising awareness of stakeholders on the significance of the water sector in sustainability, and can be used to change behaviors and attitudes among citizens. ICT can help water managers drive aggressive information campaigns and integrate the water sector with other city services, in order to deliver sustainable services and quality in urban life.

Key words: ICT, smart water, pressure management, smart cities, stakeholder participation, social networks.

1. INTRODUCTION

On-going urbanization and technology advances that promote knowledge-intensive economies have increasingly put cities at the core of our economies and societies at large. City populations are expected to increase and have a growing share in resource consumption and emissions. According to the United Nations, city dwellers are expected to double by 2050, with most of this urban growth expected to occur in developing countries. Urgent actions are needed to combat water stress, to remedy the vulnerability of infrastructures, and to modify water use patterns in agricultural, industrial and domestic processes. This is particularly important in Mediterranean countries that face serious water scarcity issues. The need to increase water efficiency and water savings by investing in resource efficiency has been widely acknowledged as one of the top research and policy priorities for the upcoming decades, in view also of the urgency to adapt to climate change. The Organization for Economic Cooperation and Development (OECD), in their Environmental Outlook to 2030 (www.oecd.org), states that water demand is expected to rise globally by 55% between 2000 and 2050; by 2050, up to 3.9 billion people, 40% of the word's population, may be living in water-stressed areas. Cities put more stress on water resources as they create more challenging conditions for water infrastructure, with more people depending on city systems. In addition, they have increased pollution loads when compared to less populated areas and wastewater treatment can require significant investment. Meeting the increased strains to water and wastewater infrastructure will be critical to maintaining a healthy future for the world's rapidly growing population. Undoubtedly, cities need to change and develop to accommodate all that growth, but this change needs to happen in a smart way, making our cities "smart cities." According to the European Innovation Partnership (EIP) for Smart Cities and Communities Strategic Implementation Plan, there is a large untapped innovation potential in the areas of Energy, Transport and Information & Communication Technologies (ICT); these areas, along with the water sector, have the most environmental and societal benefits to gain.

Europe has established a good understanding of needs and concerns of stakeholders at the local regional and river basin level, and efficient management and governance of water-related problems. But water networks, like electricity networks, are the next level of utility networks to be managed. The truth is that despite all technological advancements, there is very little in place today beyond basic central control to manage these networks (e.g., quality of water at different points in the network, outages in the network, consumption measurement, smart metering, etc.). The urban water sector, though highly fragmented, plays a major role in European economies, by providing close to 600,000 jobs for more than 70,000 water service operators (EUREAU 2009). The water infrastructure involves 3.5 million km of drinking water networks, 2.2 million km of wastewater networks and 70,000 wastewater treatment plants. This infrastructure is, however, ageing and deteriorating rapidly, while its huge cost and its long life make innovations difficult to implement. The United Nations Environment Programme (UNEP 2013) estimates that the expected cost for urban water infrastructures over the period 2005 to 2030 are higher than the combined costs for urban energy, road, rail, air- and sea-port infrastructures. ICT offers a big potential for upgrading the water infrastructure in a cost-efficient manner. Water management in a city is critical in the process of making our cities smart and liveable and resilient to future shocks of water scarcity and climate change.

It is estimated that distribution systems lose on average 20% of the transported water in Europe with great variability between settings (Figure 1). ICT tools for early leakage detection and smart metering may lead to substantial reductions in water resource losses. Water utilities/suppliers and city/regional authorities who manage urban water networks, and typically administer wastewater treatment and water competence centers, now see the need to enhance collaboration and exchange innovative promising practices, jointly with the industry, research establishments and laboratories, in order to ensure efficient water resources management for the upcoming decades that risk to be dramatically affected by climate change and water scarcity.

ICT is the indispensable enabler to achieve the necessary level of control and management of water networks. Just like telecom networks, water provision is a trans-national issue (e.g., rivers running over several countries) and development and deployment of solutions make sense only at the European level. What is impressive, however, is that there is no standard for data management, and no standard for interoperability of systems across European providers; practically, everything needs to be built. This will require a massive research effort from the ICT industry to adapt solutions to the water sector, develop adequate standards and interoperability, but also presents massive market opportunities for the combined sector. ICT-enabled solutions offer the potential to realize an integrated water resources management (IWRM) framework, in line with the vision established by the Water Supply and Sanitation Technology Platform –WssTP.

One of the biggest drivers for change to smart water networks is leakage and conservation, especially in countries facing serious water scarcity issues. In 60% of European cities with population greater than 100,000 people, groundwater is being used faster than it can be replenished, exerting stress to fresh water aquifers that are negatively impacted by over-pumping, salt-water intrusion, water-level decline and even ground subsidence. Given the latter, in some areas, even seismic activity has been linked to groundwater over-exploitation. Reducing leakage conserves water resources and also the financial and energy investment made in those resources. Leak detection is one of the most active areas of smart networking. Network monitoring, combined with analytics software, are helping to reduce the impact of leaks and identify areas in need of repair before a burst becomes visible and/or is reported. According to a survey conducted by the Israeli company TaKaDu, absolute network efficiency appears to be the "Holy Grail" of water utilities (2014 SWAN Global Utility Survey Report, available at www.swan-forum.com); when asked about their key goal within the utility for the coming year, 72% of survey respondents cited network operational efficiency issues, with 32% referring to "reduced real water losses."

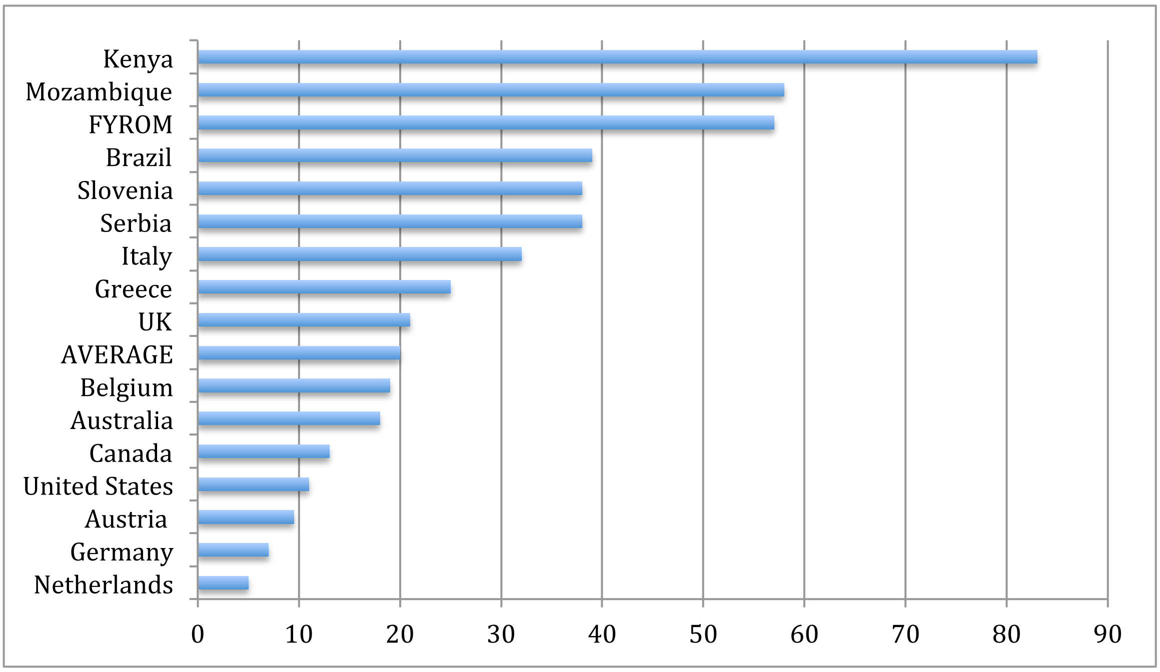

Figure 1. Leakage rate in water distribution networks world-wide. Average based on country-level leakage percentage estimates weighted by water operational expenses spending by country (data from Global Water Intelligence, 2008; available on-line at www.globalwaterintel.com)

2. MATERIALS AND METHODS

2.1 Network Pressure Management

There are many challenges to the efficient and effective operation of the water supply network, especially since leakage levels often remain high, leaking not only water but revenue at the same time, since water distribution is an energy-intensive business, with water being pumped. With an ageing infrastructure, burst rates are rising, while replacing affected network sections requires large capital investments. Given the fact that most networks are still controlled manually, the operational costs of managing these challenges are also rising. Pressure management is really a central issue in tackling the challenges of leakage, bursts and high operational costs. The dilemma faced here is: on the one hand pressure needs to be consistently high enough to satisfy customer needs providing water in adequate pressure, while on the other hand, excessive pressure drives up leakage, burst frequency, energy consumption and operational costs, while decreasing the lifespan of network assets. So, the goal of pressure management is pressure optimization, which usually follows a successful network simulation.

Techniques for water network simulation are nothing new, as they are well developed and widely implemented. Software tools, such as EPANET (Rossman 2000), are commonly used for the simulation of flow and pressure distribution on a network of known design (e.g., pipe topology and size) and known operation (e.g., valve settings and pump schedules). In order to successfully manage pressure in a network, simulation needs to be followed by a network optimization algorithm that will ensure that the best decision is made regarding network design or operation. Nicolini and Zovatto (2009) couple one optimization approach, a meta-heuristic, to the hydraulic simulator EPANET, in order to optimize pressure and flow in the network. Meta-heuristics have been used extensively to optimize water systems; a major advantage is that the optimization technique is independent of the hydraulic simulator. A disadvantage of these heuristic approaches is that the solution identified by the algorithm is the best one found, but is not necessarily mathematically optimal. Mathematical optimization approaches, on the other hand, although much more complex than meta-heuristics, use the hydraulic equations in the problem formulation and guarantee that the solution found is locally or globally optimal.

At the bottom of this simulation/optimization procedure lays the fact that pressure varies differently and continuously across the network following the constantly changing demand patterns, weather conditions and other outside events. So, even before simulating and optimizing flow and pressure, a good grasp on forecasting demand is of critical importance. Several stochastic models have been used in water demand time series modelling, such as the white noise model, the autoregressive (AR), the moving average (MA), the autoregressive moving average (ARMA), the autoregressive integrated MA (ARIMA) and seasonal ARIMA (SARIMA) (Billings and Jones 2008; Donkor and Mazzuchi 2012). Many of these methods have achieved really good predictabilities of water demand with ARIMA doing a great job in capturing the seasonality of data, whenever it exists (Kofinas et al. 2014). These methods have been proved effective even when the utilities are not "smart" and only have a limited water demand data set.

Kofinas et al. (2014) have also applied an artificial neural network methodology on urban water demand data and obtained really good results, with forecast values being able to capture both data seasonality and yearly trends. A neural network model is a massively parallel-distributed processor that has a natural propensity for storing experiential knowledge and making it available for later use (Allende et al. 2002). Researches find similarities of this type of model to the human brain, because: it recognizes trends and patterns and learns from their interactions with the environment; furthermore, information transfers from earlier layers to consecutive layers, conducting a nonlinear functional mapping from past observations to future values. What is important with neural networks is that it improves its forecast capability with "training"; the more training the model has, the better predictions it can produce. Smart networks with ICT infrastructure have the capability of producing large amounts of data that will enable adequate training for the neural network to become a powerful tool in predicting water demand.

2.2 ICT and Stakeholder Participation

Social innovation platforms can be very beneficial for the urban water sector. Concepts, such as the Internet of Things (IoT—the networked connection between everyday objects, now including smart phones and tablets, social media, fast broadband and real-time instrumentation) make a powerful tool that enables managers to collect and exploit all data from the environment and deliver smart cities. A smart city comprises a step-change in both intensity and extent of connection; in other words, almost all aspects of infrastructure—from transit networks to energy, waste and water—can wirelessly broadcast their state and activity in real-time through the use of robust, cheap and discreet sensors. According to the IoT concept, almost every object can become aware to some degree; this way, smart urban infrastructure can tirelessly and continuously watch and monitor its own operation, predicting faults before they occur and optimizing delivery of resources or services to match demand. This can be multiplied by the intense interest of citizens to use social networks—facebook, twitter, linkedin—logging their descriptive data about their lives and activities. This way, through social innovation, societies can use the ICT sector to get all citizens involved and to support informed and sustainability-aware decisions, based on an extended awareness of the environment and of the consequences of our actions.

In the context of improving urban water management, citizens and relevant stakeholders can get involved in prompting behavioral change through various paths. First of all, creating *collective intelligence* can make very good use of the network effect. Collective intelligence, through the use of new communication technologies, now allows a large number of people all over the planet to work together in new ways, bringing experts together with citizens, forming a common view on environmental issues and setting urban sustainability as a goal. Additionally, *self-regulation* can be based on *collective situational awareness.* Similar self-regulation schemes have been observed successfully in the past: for example, making people aware that smoking is harmful for one's health has led to the formation of an overall conscience that smoking is bad, thus bringing a general drop in smoking rates overall (self-regulation). In a similar way, it is possible to create *conscience* among citizens and stakeholders regarding water use and people's perception of water, thus leading everybody to value and respect it as a valuable and scarce good.

3. RESULTS AND DISCUSSION

3.1 Smart Pressure Management

Smart water supply network management has at its core smart and accurate pressure management. The precision with which it is possible to control pressure is really important. Weak network pressure control means that higher pressures will have to be targeted to take account of excessive fluctuations, in order to ensure adequate pressure and good service for customers. Leakage rates are usually directly proportional to average pressures. If there is a slight fracture and a pipe burst is expected, even small changes in maximum pressure can cause a burst to happen; therefore, effective pressure management is of critical importance. A powerful tool for minimizing network leaks through optimal and precise network pressure management is realized through the following: (i) smart ICT solutions with flow and pressure sensors in the network providing online visibility and network intelligence, and (ii) remote control of valves based on automatic pressure optimization algorithms.

Depending on the infrastructure that every municipality and water utility company has at its disposal, smart pressure management implementation may start at different levels. The foundation of this process is the establishment of Pressure Management Areas with pressures at their inlet being regulated by Pressure Reducing Valves (PRVs), or variable speed pumps. These Areas are usually also District Metered Areas (DMAs) and are equipped with bulk meters to provide the potential and benefit of leakage and demand monitoring. Once these basic Areas and divisions are established, the water company, depending on its objectives, its assets and its soft and hard infrastructure, can move from a basic pressure management scheme to a fully automated optimized pressure solution. This process can be roughly organized in four levels, according to the suggested schemes of i2O, a leading company in the implementation of smart pressure management solutions worldwide (www.i2owater.com).

At a first level, data on pressure and flow are being collected from the network in order to gain some insight on the conditions at which it operates. For this purpose, sensors and data loggers are implemented in the network. At level 2, network monitoring is achieved through visibility and intelligence. This means that data read from data loggers and telemetry systems are displayed in an online platform that is usually GIS-based. The dashboard of information provides a plethora of data that is also spatially distributed throughout the network to the operator. Various alarms are also potentially issued here, as well as graphs and trends that facilitate timely and accurate decision-making for network management. Level 3 enables basic pressure management, by implementing remote control of network assets, such as PRVs and pumps. Having used level-2 network intelligence helps staff identify areas of the network that would benefit from pressure management. With PRVs and remotely-controlled pumps, water company staff can decide on and implement pressure management regimes from a control room and without the need of site visits. Even within the "remote control" pressure management category, three levels of control are possible: basic, timed and flow-modulated control. Basic control involves having the user modify outlet pressures on the PRV depending on network needs; timed control involves using a pre-set schedule of pressure changes (ideal for not-metered areas); flow-modulated control builds on timed control and enables the PRV outlet pressure to vary as a function of flow rate. The final and most advanced level involves a fully automatic pressure optimizations. All previous levels rely on human decisions, on engineering expertise and experience. This most advanced level relies on optimization algorithms being employed, so that all adjustments in the system take effect automatically and in an optimized manner. This level ensures that networks constantly changing over time remain effectively managed and optimized (Mizuki et al. 2012).

3.2 Stakeholder Involvement: the Value of Social Networks and Gaming

Building on the need to address urban water use and the potential of a smart infrastructure for engagement and management, a basic premise is that people make bad decisions due to poor information, and that with better information, behavioral change would follow. The question that remains to be answered is, whether people will make good decisions when they have good information at hand. Behavioral psychology research supports this premise by indicating two key drivers of behavioral change: *active learning* and *social proof*, i.e., trying something out and also seeing others doing it. ICT can enable both these processes through transmitting information (active learning) and establishing social proof by reinforcing broader social patterns through social media. A precedent of this type of behavioral change in terms of water use can be found in Australia, where a combination of regulation and information (often indicating a household’s performance against targets set for the city) resulted in a household water use diminishing by 7%, despite an increase in population during this period (ABS, 2006). It seems that the possibility of sustainability-related behavioral change among citizens is something that the cities of the future will have to rely on increasingly. In Helsinki, the Low2No project (http://www.low2no.org/) states that 50% of a citizen’s carbon footprint concerns lifestyle choices and, accordingly, has launched an informatics-enabled behavioral change campaign.

The City of Dubuque in Iowa, USA, has implemented, in collaboration with IBM, a citizen defined sustainability model into practice that regulated urban water use. They implemented a pilot program for three months that involved more than 300 Dubuque households with information, analysis, insights and social computing around their water consumption to test the hypothesis that informed citizens would be able to conserve water more efficiently. Data involved were smart meter readings and information including water, demographics and household characteristics. A portal was created by IBM to allow volunteer households to understand their water consumption in real-time, be alerted about potential anomalies and leaks, get a better understanding of their consumption patterns, compare and contrast it with others in the community, participate in games and competitions aimed at promoting sustainable behavior, and therefore, get fully engaged and informed about their consumption and the impact of the changes they made to it (IBM, 2011).

The value of social gaming was also assessed in the IBM-Dubuque pilot. The question to be answered was whether a large-scale behavioral change that would result in the reduction of water use across households could be achieved via social networking and social games. Team-based weekly games were introduced to provoke users to reduce water consumption by participating in contests, while social computing was used to enable people to share best practices, post messages and communicate with the city. Results show that households that participated in the portal and used all social computing tools reduced water consumption by 10%, a percentage higher than that of the other water users with no portal access. According to portal participants, 48% stated it helped them conserve water, while 61% reported making a change in the ways they used water. Based on this limited data, results suggest that social computing and well-designed and targeted social campaigns can be a powerful tool in changing people’s behavior on urban water use patterns.

4. CONCLUSIONS

An analysis is presented in this article, emphasizing on the potential of improving urban water supply and use in the cities of the future. Our cities are faced with various challenges, such as intense overpopulation, water scarcity, ageing infrastructure and water supply networks that lose through leakage an average of 20% of water. Since, the quantity leaking through the networks is Non-Revenue Water and is also water that has been treated to potable quality, it means that such leakage is also loss of revenue, energy and chemicals used. ICT presents significant potential in improving the operation of water supply networks and reducing operational expenses, by managing their pressure, optimizing their operation and potentially making them fully automatic. On top of that, ICT, through social media and gaming, can influence human behavior, alter social patterns and inform a wide audience about the significance of water in the cities of the future, thus, helping citizens and stakeholders to develop sustainable habits regarding urban water use.

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