

Towards Sustainability of Urban Water Networks: Addressing Management Issues With Innovative Approaches

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Challenges towards Infrastructural Sustainability of Urban Water Networks

Physical infrastructure assets are essential to provide a specific service, which may change over time, according to service needs, challenges and life style. 40-100 years old water and wastewater pipes were installed to provide a service – conveying water for consumption for the former, carrying away storm and sanitary water for the latter - to a given number of customers under assigned external conditions, and were designed according to technologies and rules existing at the time of installation. As the conditions and the population to serve vary over time and during infrastructure lifetime, performance is likely to suffer as the physical condition of the pipes deteriorates, if timely remedial action is not taken. Talking of performance, what is expected from the pipes may change over time (the loading may increase for instance), and the reliability with which they can perform these functions may decrease.

European utilities, for example, are still able to provide largely adequate water and sanitation service. However, tremendous forces of change are at work. Changing demands, society, regulations, environmental policies, economy, customer expectations are only few of the factors that will influence water and sanitation services in the future.

Climate changes will make it necessary to adjust design and operational procedures to impacts due to climate variation, requiring the water sector to deploy a quick reaction force that can provide immediate water supply and sanitation.

Recently, national reports on state of the urban infrastructures have been produced in several countries (e.g. Canada, USA, Denmark, Norway), evaluating the investment needs to replace aging facilities that are near the end of their useful lives and to comply with existing and future water regulations. In the national reports, the current situation is weighed towards the standard requested by regulations, the customers' expectations and coming challenges. Compared to other infrastructures, water and wastewater networks are among the systems that are most vulnerable due to their intrinsic nature. Thus, the reports emphasize the need for massive investment in urban water and wastewater networks to come up to and keep today's desired service level for the coming decades. The projected shortfall in funding for water and wastewater infrastructure projects in the next five years has been estimated to be \$108.6 billion by the American Society of Civil Engineers [2]. A common problem is that no clear strategy exists on how to make these needed improvements "to achieve today's service level"; neither central authority nor local utility leaders really know how to cope with this situation.

Good decisions must address uncertainty and variability associated with global changes: relevant examples include planning for a reliable water supply, analyzing environmental impacts, or assessing health consequences as described in the Water Safety Plan (WSP) [7].

Uncertainty is an important factor in the decision making process at national and local level. The analysis of the degree of uncertainty and variability of key determinants provides additional information for decision making and a better understanding of how an investment in urban water system works. However, the city utilities need tools to balance the costs of measures against the risks associated with the "do-nothing scenario". Large utilities have the financial resources to hire consultants to develop risk management models, and basic GIS tools are provided to the asset managers by in-house GIS specialists. But medium and small utilities have no access to tools to plan for the future, do not have a key asset management plan, and in some cases do not even use GIS.

There is a need for gradually implementing infrastructure asset management strategies in water utilities of different size, having different problems and technological and organizational levels.

The Approach Must Be Holistic – Predictive – Interdisciplinary and the Solution Sustainable

Strategies and solutions ought to be sustainable – socially, economically and environmentally – in order to be reliable and able to fulfil the desired end-goals consistently. Identifying the needs to overpass global and local challenges and acting to acquire an effective management of water infrastructure systems will support the water utilities in achieving sustainable provision of the service with respect to the three accepted pillars of sustainability – society, environment, and economy (the so called "Triple Bottom Line" or TBL, [8]) - and the technical (infrastructural) and governance aspects, identified as instrumental and essential for the social, environment and economic dimensions and objectives of sustainability.

The economic dimension of the TBL is the easiest to recognise, since it is simple to calculate direct costs associated with replacement of infrastructure and an increased level of asset management. Social and environmental impacts, on the other hand, are slower, more silent and hidden, but once they are perceived, the investments needed to compensate damage brought can be much higher than rehabilitation direct costs.

Increasing the overall performance of urban water infrastructure and the sustainability of the service provided does not only depend on

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tools and technologies, but also relies on specific issues to be addressed at different levels of responsibility as listed below.

Political/Financial level:

- increase the national (political and social) vision in infrastructure needs;
- estimate the future investment needs;
- identify novel solutions with funding, regulation and planning;
- increase interest in innovation and its implementation;
- develop standards to stimulate the small municipalities/water utilities.

Water utility level:

- set clear strategic and tactical goals to be used for driving decisions and setting directions;
- choose technologies properly integrated with social, economic and organisational measures;
- estimate the present condition and remaining life of core public infrastructure, improving the reliability of current deterioration prediction models;
- evaluate the risks to public safety and health associated with the deficiencies in the assets and services, in a context of climate change and emerging environmental concerns;
- assess if the current practices (technology, service delivery mechanisms, financing, management, decision-making, etc.) are the most appropriate;

Educational level (i.e. Civil/Environmental Engineering studies):

- review and update educational programs to develop required new competences;
- find ways to increase personnel skills in water utilities, often less attractive to young engineers when compared with private consulting companies;
- evaluate if the current knowledge and achievements in research are applied; if not, identify the reasons.

The challenge is therefore to work, at different levels, to contribute to the perception of the problem and allow decision-makers, owners and operators, to move towards solving it, starting from actions to assess the current state of infrastructure, report on its performance, predict future demands, requirements, conditions and corresponding level of performance, and to improve the management of infrastructure assets in a holistic way. Owing to the complexity of these issues and to the importance of a reliable assessment of the state, performance and management of the infrastructure asset to achieve infrastructural sustainability, it is essential to establish an approach that integrates all key elements of assets and services across multiple sectors.

Infrastructure Asset Management – Top Down Approach

Infrastructure Asset Management (IAM hereafter in the text) is a systematic process of planning, operating, maintaining, upgrading and replacing assets cost-effectively with minimum risk, ensuring that they

provide the expected levels of service all through their respective life-cycles [5]. Management of water and wastewater systems in general – irrespective of their degree of complexity and the level of economic development of the cities which they serve – entails three distinct hierarchical layers. There is the macro-view at the strategic level, an intermediate one at the tactical level in between, and a detailed view at the operational level at the bottom of the hierarchy [1]. The strategic level defines the direction which the organization seeks in the longer-term, with respect to the management of the assets. The tactical level defines the path to be trodden upon, in the medium-term, establishing priorities for intervention and possible solutions. The operational level encompasses the day-to-day implementation of measures – the short-term in other words.

IAM can follow either a top-down (strategic to operational) or a bottom-up (operational to strategic) approach. When a top-down approach is followed, an overview of the system is first formulated, specifying but not detailing any first-level sub-systems. Each subsystem is then refined in further detail, sometimes adding many additional sub-system levels, until the entire specification is reduced to base elements. In a bottom-up approach, the individual base elements of the system are first specified. These elements are then linked together to form larger subsystems, which then in turn are linked, sometimes over many levels, until a complete top-level system is formed.

With greater and more diverse demands on system performance these days, advanced methodologies like risk management, reliability analysis, residual life estimation and life cycle thinking have been incorporated into IAM, adapting it to changing times. In fact, while the engineering approach to analyze system performance and compute costs is quite well established in the water utilities, a gap is evident in the lack of use of risk and sustainability analysis to cope with increasing demands and challenges (climate changes, population growth, deterioration of infrastructure, environmental protections) of today's integrated water systems.

The consumers of the 21st century are demanding better and more reliable services, while utilities are hard pressed to fulfil their responsibilities towards the environment. IAM in the water industry has as an overarching goal the task of determining actual needs of capital and operational investment to deliver adequate levels of service to customers, at an acceptable level of risk, balanced against wider stakeholder expectations. Table 1 lists the various facets of IAM with respect to the three levels of analysis.

The list of Table 1 seems to be a task-focused one, and is often interpreted as a mere application of tools. However, IAM is not as simple as that. The development and embedding in standard procedures of a formalized approach to IAM facilitates decision-making, ensuring a better knowledge and comprehension of assets. It allows to manage the relationships between cost, performance and risk and to achieve the best results using the available resources. Making IAM a reality requires new information and analytical tools, new technologies or implementation of existing ones scarcely employed, novel approaches to organizational communication and innovative management practices.

Life Cycle Assessment (LCA), Material Flow/Energy Analyses (MFA/EA), Input/Output Analysis (IOA) are interesting top-down approaches to be implemented on the IAM set of strategies to guide

• What are the objectives (at strategic/tactical/operational level)?
• What are the assets owned by the utility contributing to the achievement of the objective?
• What are the services delivered currently?
• What services will be expected from the assets in the future?
• What are the risks to these services?
• What is the residual life of the assets?
• What are the life-cycle costs (LCC) and assessment (LCA) of these assets?
• When will the assets need to be replaced or repaired and how?
• What may need to be done differently in the future?
✓ Identifying, cataloguing and assessing the condition of its assets
✓ Defining and monitoring service levels and key performance indicators (current and future)
✓ Understanding the deterioration of asset condition and performance
✓ Risk assessment and management
✓ Whole life costing incorporating cost benefit analysis

Table 1: Questions to be addressed in IAM at strategic, tactical and operational level.

the selection of sustainable management solutions. Based on the engineering theory of ‘doing more with less’, Sahely et al. [3] devised a general framework describing a sustainable infrastructure, to help define the interaction of an infrastructure with environmental, economic and social systems. The model reflects the notion of infrastructure providing services (socio-economic demand), whilst drawing upon resources.

There are many excellent recent and ongoing research initiatives that address this issue, but results have been put in practice only to a very limited degree. One reason for this may be the absence of a practical cost/benefit context that fits with the utility planners’ perception of their situation and opportunities. Pros and cons of the application of sustainability analysis into IAM have to be investigated to determine whether it would really be worthwhile to invest time and money into the cumbersome and lengthy exercise of data collection [6]. One primary issue is a need to combine the technological outcome of research programs with financial and economic management and principles of leadership. Another common limitation is related to the lack of complete datasets to run reliable performance and condition analysis; a typical experience is that without a patient pre-work on data collection the outcome of the projects is not satisfying, and the ultimate result is the reduced interest of water utility to implement new approaches. An improvement in the degree of accuracy of the results would entail adjusting / defining the scope of the analyses (of the different tools) to the available data. In [4] the authors have stressed the indispensability of a robust data collection and retrieval system with well-structured and integrated information for pipeline asset management at Oslo VAV (the city water company). In conclusion, it is important to understand what data are really supporting decisions and when data are good enough to achieve reliable results.

Despite these limitations, the use of top down IAM can contribute significantly to sustainability analysis by using different time and spatial boundaries in system analysis, needed in the bottom up approach. By considering the whole system, one can decipher integrated solutions that may not be visible when looking at smaller sub-systems.

Similarly, a uni-dimensional optimization – say only the environmental aspect – may sub-optimize another dimension. For instance, it may affect the affordability. The costs may have to be passed on to the consumers; and thus the social aspect will also take a beating. Moreover, it may be expected that the result of this type of

analysis coordinated with IAM computations, will uncover efficient infrastructure patterns and solutions in the future. The physical infrastructure will be closely matched to service demands, with a good degree of integration among different infrastructure assets wherever possible. Introducing multi-functionality will enable more cost-effective solutions.

Conclusions

Urban water networks of the 21st century are subject to ever increasing requests in terms of customer demands and environmental and regulatory compliance, while being forced to adapt to the consequences of climate change. A change of paradigm coupled with innovative approaches is needed towards sustainable management of water and wastewater networks. Infrastructure Asset Management is an integrated, flexible and robust framework to deal with issues of sustainability in a changing society under a variety of pressures.

Effective Infrastructure Asset Management ensures that capital investments and maintenance expenditures are appropriately estimated in the decisions at all levels (strategic, tactical and operational), based on a variety of criteria (functional, technical, social-economic-environmental and governmental). Decisions are complicated by the fact that most of the network assets are buried infrastructures, and thus require indirect diagnostic and decision support methods.

‘Long term perspective’, ‘whole life costs’, ‘risk management’ are key words in the context of water infrastructure management.

The way IAM is implemented and used differs in relation to the phase of development of the water sector and utilities in a specific country or region.

IAM models use information about the system performance, changing structural conditions, maintenance practices to guide and modify responses, routine activities, procedures and capital investments to try to prevent and predict the occurrence of problems. Modelling performance generally requires data and understanding of the mechanisms contributing to the decline of performance over time. Collecting performance data and developing reliable performance models remains one of the primary areas requiring research aimed at making AM applicable.

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