SMART WATER METERING AND AI FOR UTILITY OPERATIONS AND CUSTOMER ENGAGEMENT: DISRUPTION OR INCREMENTAL INNOVATION?

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Digital technologies are disrupting several economic sectors and creating new business opportunities. As part of this transformation, the utility sector is also becoming more digital. However, water businesses have been slow to change paradigm and so far adopted digital technologies with incremental steps, often acting reactively to water scarcity conditions. Technologies such as smart water metering and Artificial Intelligence now offer water businesses the opportunity to focus on customer centric solutions to reap both operational and customer satisfaction benefits.

Digital sensors and communication technologies have rapidly gained momentum with the transformation of our urban centers into smart cities. New digital products and data communications have revolutionized several urban services and enabled new economic models, as demonstrated, for instance, by the gig economy subverting the consolidated paradigm of the highly regulated taxi industry. Comparably, technological development coupled with existing demographic, economic, and climate challenges is giving traction to the utility sector to transition to the digital age. Both smart water metering and the associated data processing techniques, including advanced analytics and Artificial Intelligence (AI), are often mentioned as key transformative digital technologies of the utility sector [1]. However, we acknowledge that the uptake of digital technologies has been more gradual in the water sector, compared, for instance, to the energy sector. Smart water meter development and experimental trials started more than 20 years ago. Yet, large-scale smart water meter rollouts, as well as commercial applications of AI technologies coupled with smart water meters, are still limited.

Here, we analyze the role of smart water metering and AI in water business applications, and ultimately inquire: are they disruptive or incremental innovations for the digital transformation of water businesses? In this paper, we first investigate and provide examples on how smart meters and AI have been so far applied to support utility operations and customer engagement. We then formulate motivations and identify the benefits for using smart water meters in customer applications. Finally, we propose a pathway to best practice for water businesses to assess the maturity stage of their metering technologies and their capacity to innovate.

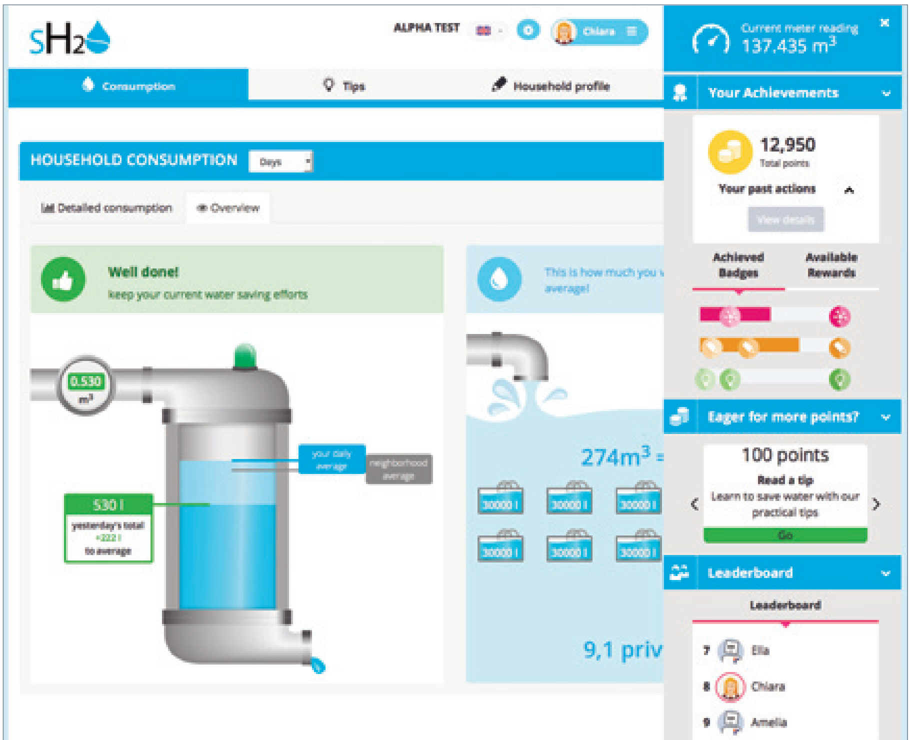

Figure 1. User interface of the SmartH2O platform with household consumption goal setting mechanisms [4].

Advent and future of smart water meters

Smart water metering technologies have been developed since the late 90s, allowing for gathering of water consumption data with high spatial and temporal resolution. Pioneering studies to advance smart meter technologies and run smart meter trials emerged primarily in Australia and the United States, fostered by prolonged drought conditions requiring campaigns and incentives to promote water conservation [2]. As reported in a recent review paper on the benefits and challenges of using smart meters for residential water demand modelling and management [3], different smart water meter technologies have been developed since the first prototypes. Along with their technological development, several modelling applications have been implemented, closing the loop between water consumption data gathering and water demand management. Smart water meters have been used to promote short-term water conservation, simply by enabling water consumers to gain more information and control over their water consumption and water bill. Moreover, the usage of smart meters to retrieve end use level information, characterize water consumption profiles of individual households, and monitor changes in water consumption has fostered the development of tools to analyze the different water consumption behaviors of individual customers, obtain insights on water consumption and conservation drivers, and ultimately design customized water demand management programs. Interactive web portals and customer engagement tools have been implemented as part of new customized demand management programs to enable data visualization and facilitate the two-way communication between water consumers and utilities (see, for example, the user interface of the SmartH2O platform in Figure 1 [4]).

Overall, several studies and applications analyzed the information content of smart meter data to characterize and model water consumers' behaviors. However, uncertainties related to return of investments, meter battery life, data management, data privacy, product availability, and the long-term persistence of conservation behaviors have so far slowed a complete rollout of smart metering technologies [5]. This does not mean that smart water meters are not revolutionizing the water utility sector, but rather that their benefits and business cases for water utility applications are becoming evident only gradually. Water businesses are beginning to view smart water metering as a valuable technology for them to manage water demand, reduce infrastructure costs and streamline operational functions.

The global smart water meter market is expected to grow in the next years, reaching a value of more than 10 billion USD before 2030.[1] As smart water meters are now being considered "smart" not only because of their possibility to enable remote data reading, but also because of the wealth of applications enabled by their associated informatics, water businesses are adapting and starting to acquire new skill sets for their employees. A best-practice smart metering system goes beyond automated meter reading and rudimentary presentation of hourly consumption data to provide deeper insights on customers' usage of water and the associated costs [6]. IT, data science, and analytics skills are needed to fully exploit smart meters coupled with advanced analytics and AI to support utility operations and customer engagement.

Smart water meters coupled with AI to support utility operations

AI-based models have been used already to support utility operations independently from the development of smart meter data. Typical applications regard metamodeling of water distribution networks with black-box models, such as Artificial Neural Networks (ANNs), or urban water demand prediction. Accurate predictions of urban water demand are key inputs for designing optimal planning and management decisions. Several techniques have been used in the literature to identify and infer existing relationships between water demand and sets of heterogeneous variables representing potential water demand determinants. Among these, the last two decades have seen a rapid increase in the usage of ANN-based methods. The success of such methods is primarily due to their flexibility of use, their ability to capture unknown nonlinear relationships between the predictand, i.e., water demand, and its potential determinants, and their predictive capabilities demonstrated by benchmarking with alternative methods.

The availability of smart water meter data is facilitating the full potential of such data-driven methods, especially for applications related to high-resolution descriptive and predictive modelling of water demand. For instance, Bennet et al. [7] demonstrated the suitability of ANN-based methods to forecast water demand at the household level for a sample of over 200 households in Australia. Besides the usage of ANN to forecast water demand, other advanced Data Analytics (DA) techniques have been adopted to create value from smart meter information. Data-driven customer segmentation enabled by data dimensionality reduction, clustering techniques, and pattern analysis, has been developed to support water businesses obtaining detailed insights about the heterogeneous behaviors of their water consumers, along with their socio-demographic drivers and, thus, to better design demand management interventions.

Moreover, some studies primarily conducted in drought-prone areas exploited advanced analytics and smart meter data to monitor behavioral responses to demand management interventions, pinpointing water use shifts correlated with climate-related mass media and policy events, and identify rebound effects (e.g., [8]).

Finally, pattern analysis of smart meter data allows better identification of anomalous consumption levels and more accurate billing. Utility operations can even take advantage of smart meter applications that are apparently only customer oriented. For instance, the practice of service recovery leading to compensatory refunds for concealed leaks continues to cost water businesses as do disputes over accounts and compensation paid for water damage from network leaks and bursts.[2] This is particularly the case in complex, multi-metered properties such as high-rise and multi-unit communities where both individual unit and communal consumption occurs.

All the above examples illustrate a range of operational cases where water businesses benefit from advanced analytics coupled with high-resolution smart meter data. As a result of such coupling, water businesses can better inform their water demand and supply strategies, and therefore increase the efficiency of their operations. However, differently from other sensors distributed in the water distribution network (e.g., pressure sensors), smart water meters inherently record information on individual customer behaviors and consumption habits. This provides water businesses with further opportunities to exploit such information to develop customer engagement programs that include water consumers in their efficiency loop more transparently and proactively.

> ***"Digital transformation in the water sector will be incremental, but successful citywide rollouts will accelerate change through pressuring adjoining water businesses to step-up and provide similar solutions and efficiencies."***

Water businesses must engage customers better

Digital disruption has already revolutionized many industries and allowed much better engagement with customers through web and phone interfaces. Travel, banking and finance, education, retail, food, etc. are all industries that have used digital technologies and DA to capture and push useful information to customers and engage them better. However, the urban water sector is still largely engaging with customers in the same way that they have over the last few decades, where a single water usage data point is collected by human meter readers on a quarterly basis and paper bills are distributed to customers with limited useful information. Water bills are paid and engagement rarely occurs, and when it does, it is often to discuss high water usage from months past that may be due to a range of reasons such as an unknown leak, high usage, meter or reader error, meter read estimations, to name a few. Sadly, due to the present limited information collected on water

1) https://www.reportsanddata.com/report-detail/smart-water-meters-market

2) https://energycentral.com/c/iu/advances-artificial-intelligence-ai-and-machine-learning-coupled-smart-water

usage in most jurisdictions, it is not possible to meaningfully engage with customers on high water usage, hidden leakage events, incentives to reduce total and peak period demand, water affordability, custom conservation opportunities, etc.

Given that water businesses are often government-owned water service provider monopolies having no direct competition that can provide a superior customer experience, they often forget about the customer and the opportunities and benefits of smart water metering for them. However, modern business survival is often premised on their ability to engage with customers and provide them a fulfilling experience with the product or service provided. A recent paper by Monks et al. [9], identified a total of 75 benefits from smart water metering. These benefits help either the water businesses, or customers, or are shared by both water business and customer. Many benefits had not previously been revealed in the literature. Of the reported benefits, 40 benefits directly impact customers and of these, 18 are considered exclusively benefits to customers, such as the reduction in costs to customers due to leak alerting or the availability of customized product offers, and the other 22 as benefits delivering to both customer and the water business, such as reduced customer billing complaints, enhanced communications, and improved meter failure analytics (shared benefits). Monks et al. [10] examined the extent to which smart metering would improve levels of customer satisfaction.

Most operational smart water metering benefits can be quantified in monetary terms. Customer Satisfaction (CS) related business impacts are more easily distinguished in a comparable privately operated telecommunications business due to lost customers when service is comparably lower than competitors. These impacts are not directly discernable in a monopoly water business market arrangement where customers are not lost due to poor CS. However, in such market arrangements, while customers and revenue may not be lost in the short term, customer trust and relationships are being eroded over time, and dissatisfaction may culminate in pricing caps, government penalties, political backlash, and a lack of community cooperation. Not sufficiently engaging with customers and not providing them with a comparable level of service to other best-practice water businesses presents an unpalatable long-term risk to contemporary water businesses.

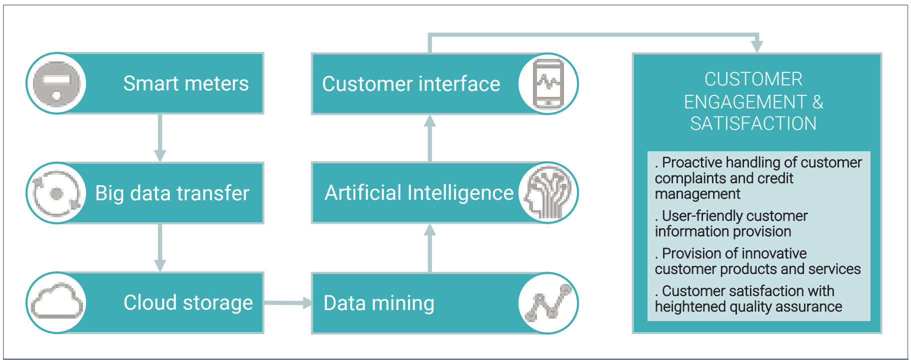

Figure 2. Pathway to harness customer engagement and satisfaction from smart metering.

The advent of smart metering technologies and near real-time communications of high-resolution data has enabled many leading water businesses to provide to their customers superior levels of service that are best practice. Deeper insights from smart meter collected big data, supplemented with other internal and external datasets, can only be realized through the development and deployment of advanced data mining methods and AI techniques. Figure 2 outlines a pathway to harness customer engagement and satisfaction benefits from smart metering.

> *"Water businesses that can effectively harness digital technologies like smart meters and AI techniques, will reap both operational and customer satisfaction benefits"*

Artificial Intelligence to facilitate customer data interpretation

Understanding and interpreting customer data requires the development of AI through a range of DA and Machine Learning (ML) techniques. Smart water meters are now affordably deployable to provide the necessary data to interpret and report individual customer data in a proactive and meaningful way. Near real-time personalized water usage information and feedback has the potential to increase CS substantially [10]. Various AI approaches are being investigated to deeply analyze customer data, and they can be considered within the following four categories: Neural Network (NN) methods, regression methods, stochastic methods, and hybrid methods [6].

The dominance of NN-based methods is notable in customer data interpretation because of the large volume of smart metering data. Various researchers have employed a range of ANNs in their proposed methods, including more advanced deep learning (DL) NNs. Regression-based methods are also commonly used. Regression-based approaches are good for identifying key factors contributing to customer water consumption. Some regression-based methods include Support Vector Regression (SVR), Support Vector Machine (SVM)-based regression, Multivariate Adaptive Regression Splines (MARS), and Projection Pursuit Regression (PPR). There is a growing use of sophisticated stochastic-based techniques such as Hidden Markov Models (HMM) to forecast customer water usage information. Recently reported methods are hybrids, i.e., they employ more than one technique and are often required for complex customer interpretation and reporting requirements. Some hybrid methods already adopted by water researchers and industry professionals for customer water usage profiling include General Regression NN (GRNN), Extreme Learning Machine (ELM) integrated with Variational Model Decomposition (VMD), Singular Spectrum Analysis (SSA) coupled with linear autoregressive models, spatiotemporal Gaussian process models, Gaussian mixture models and K-means clustering Generalized Additive Models (GAM), hybrid Particle Swarm Optimisation–ANN (PSO-ANN), Bayesian Additive Regression Trees (BART), Gradient Boosting Machines (GBM), to name a few examples. Each of these techniques fosters the creation of sufficient AI to feedback customized information to customers, such as their quasi real-time water consumption, time-of-use or exceedance of high demand thresholds, and leak alerts.

Smart meter and AI customer applications and benefits

Smart meters and AI will enhance existing customer engagement activities and provide a whole new range of applications [10]. These applications will provide various benefits for both customers and their service providers. The key applications and benefits are discussed below.

- **Proactive handling of customer complaints and credit management:** in addition to the elimination of reading errors, estimated reads, self-reads and meter-reader access, customers will have access to web portals and phone applications that provide detailed information on their water usage and alert them of high water usage and bills well before payments are required, thereby allowing customers to reduce consumption to fit within their monthly available budget.

  Benefits of this enhanced customer engagement application include**:** reduced customer billing complaints; reduced external and internal costs of ombudsman referred complaints and legal costs; improved outcomes from billing disputes; and reduced requirement for customers to contact bill relief agents.

- **User-friendly customer information provision:** information is power, and when customers have tailored water usage information for them, they are able to make better decisions and more timely actions [11].

  Benefits of this application include: reduced leaks and associated costs at properties; water usage awareness and education; greater water efficiency and reduced bills; choice of billing frequency (e.g., monthly, quarterly, etc.); information on appliance efficiency; increased goodwill from information sharing with their customers; and the ability to be notified of internal leaks that may cause building damage and insurance claims.

- **Provision of innovative customer products and services:** big data from smart meters opens opportunities for water service providers to offer a range of new products and services to their customers. These products and services may generate new or improved revenue streams or be used to increase levels of CS such as billing day flexibility. For example, through under-standing water usage within a customer's premises, providers may be able to refer required services (e.g., plumbers to fix identified leaks, efficient appliances where high water use, etc.). Water service providers may also seek to offer complete water monitoring solutions where they sub-meter their larger water usage customers or the provision of algorithms to provide end-use data (e.g., shower, tap, etc.) on residential properties [12]. Other services could include tailored benchmarking, increased security through monitoring of water usage, to name a few.

  Customer benefits of this application include: billing day flexibility; provision of complete customer end-use data logging and analytics services; new suites of online products and services; and increased goodwill from new products and services provision.

- **Customer satisfaction with heightened quality assurance:** current urban water management approaches adopted by industry professionals are reliant on many assumptions (e.g., water bill estimates) and are subject to error. Customers expect others to pay their fair share through accurate metering. This relatively low level of quality assurance due to decision making based on incomplete information has been accepted by captive customers for some time. However, smart metering and big data analytics provides an opportunity to signifi-cantly enhance the level of quality assurance related to water usage, which will generate goodwill with customers.

  Customer benefits of this application include: the ability of large smart meter datasets to help detect faulty meters and improve meter sizing for non-residential customers; water theft; automated regulation compliance monitoring; improvement in value of goodwill customer recognition of better capital management and operational efficiency.

A pathway to best practice

We suggest that there is a "best practice" that water businesses might strive for that maximises the return on investment on smart water metering. The collected meter readings need to be assembled into a data repository along with other sensor and operational data, and complemented with external weather, demographic, property, and various other data sources. Digital twinning of physical and virtual city infrastructure is already driving the push for an open source Common Data Environment (CDE) for all static and 'live' data sources.

The level of business transformation based around the metering technology might be recognised through a capability model. The Intelligent Metering Maturity Model is suggested and a prototype is illustrated in Figure 3. Capability models have provided observers with a method of comparing businesses against each other and best practice, and they have provided a roadmap to improvement.

At the lowest level, water businesses would score zero with 100% manual metering and no digital metering, or incomplete metering (e.g., it is estimated that only 50% of the domestic properties in the UK were metered in 2015; differently, in Australia almost all properties in urban areas are metered, but the penetration rate of digital metering is roughly 10%). The score rises to 1 when digital metering is raised to 100% replacing all manual metering, but without any in-depth exploitation of the data other than automated billing, as is the current situation with metering of high-rise buildings in many utilities. Applying basic DA and AI approaches for leveraging of the data for

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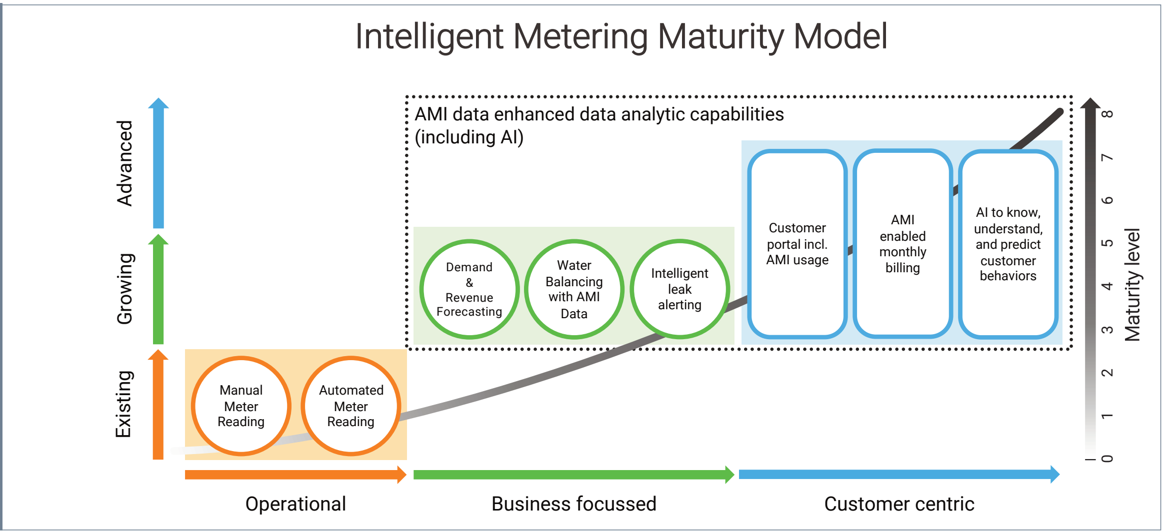
Figure 3. Suggested capability model and pathway to best practice.



processes that are essentially operational (e.g., network leak detection, planning and peak demand analytics, meter sizing and meter failure analytics) raises the score. Higher scores are achieved by providing leak alerting and a customer portal for accessing their data and offering frequent (e.g., monthly) billing. The highest scores can only be achieved when water businesses introduce sufficient predictive AI to accurately understand and predict network and customer functions without manual human data manipulation and interpretation.

Disruptive or incremental innovation?

Two technologies are under consideration here: smart water meters and AI. At times both would be considered disruptive in their own right and have improved CS. A demonstrative case study is given by a smart meter installation rolled out in Kansas City, Missouri in the United States, along with an extensive process re-engineering undertaken to leverage the technology [13]. The published customer satisfaction level reported over the following four years from 2013 show an uplift of the percentage of customers satisfied from the high sixties to the mid-nineties. Another case study in Newmarket (UK) reports 8% water savings achieved by combining a smart metering program with data and behavioral science.[3] Townsville (Australia) avoided a costly engineering solution saving USD 4M when they used sensors and data analytics across their network to identify the true cause of low-pressure supply issue and resolved the issue through better valve operation. Longer term water savings of 6.8% were achieved in Sydney (Australia) when smart meter data is presented back to the customer via in house displays [14]. To realise the CS improvements the technology needs to be enabled, first.

Most of the 75 benefits identified from smart water metering in reference [9] rely on the use of data analytics to mine the data for insights. Indeed, one of the pre-conditions is the resourcing of a data analytics capability, whether through deploying in-house expertise or by out-sourcing to their digital metering supplier or to consultants. An example of best practice in this regard is the recent smart meter rollout of the city of Gandía (Spain), where the joint effort of the local utility, city council, and a telecommunications company is leading to the collection of hourly water consumption data from over 40,000 smart meters and this data is standardized in a Big Data platform.[4]

The willingness of a water business to enable the benefits would depend on their appetite and capacity for change and, in some cases, may require change approval by their regulator. Where metered billing is not the social norm, water businesses might still move to smart metering (or data logging) having recognized the potential to deliver the detailed data needed to overcome operational and water quality issues, and assist water conservation efforts. Indications from past and recent surveys of water businesses, and inclusions in recent pricing submissions to regulators, show that the larger water businesses are actively considering a move to digital metering. Many smaller regional water businesses with less capital and capacity for risk, are waiting to see the direction taken by larger utilities. However, there are some smaller agile water businesses that are better able to exploit the benefits of digital technologies, and they are technologically leapfrogging the larger metropolitan water service providers in their country.

Hence, can we ultimately say whether smart water meters and AI are disrupting or incrementally innovating the water sector?

Generally, water businesses do not compete against each other by virtue of their exclusive rights of service and natural monopoly status, being government-owned or tightly regulated, and sometimes having common owners, making their relationship more collegiate than competitive. Knowledge and experience are shared through formal and informal channels. However, a technological laggard will eventually be found out by their customers as they become aware of superior services offered by adjoining water businesses, through various channels such as media, government reports, discussions with friends and family, moving to a new address, to name a few. Water businesses that are slow to embrace change, are merely widening the technological gap that will need to be addressed at some point in the future.

Examining the theory of disruptive innovation [15], a gap has been identified with mission driven institutions that have a higher calling, among which water services might consider themselves. While both the take-up of smart water metering and AI within water businesses may be slowly growing after a stuttering and fragmented start, we feel they should now be considered embedded technologies among progressive companies. Following a long gestation period, smart water meters and AI should now be treated as mature Business As Usual (BAU) tools, rather than as must-use disrupting technologies. In the absence of data warehouses being utilised by utilities [6], smart

3) https://www.advizzo.com/portfolio/anglian-water-case-study/

4) https://www.idrica.com/blog/gandia-smart-water-city-2/

water meter technology vendors or private software companies are providing cloud-based data repositories, customer portals, and offering to fill utilities' AI gaps as an add-on service. In this regard, the development of smart metering and AI can be considered disruptive, as it created opportunities for new economic models, tech actors, and investors previously not attracted by the water sector. The next significant innovation and business step will be materialized when synergies between the water sector and other utility sectors (e.g., electricity, gas, telecommunications) will be exploited in a cost-effective manner to realize the vision of a digital multi-utility service provider [16]. Exploiting multi-sectoral synergies will reduce asset and operational costs by collecting concurrent water-energy data efficiently, implementing flexible and data agnostic processing techniques, and ultimately designing integrated tailor-made services to customers. ■

"At a minimum, water service providers must embrace incremental digital transformation, or government sanctioned alternative retail models offered by innovative private technology providers will be pushed upon them and strip back their function to heavily constrained water asset operators."

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Unaccounted for Water (UW), and d) Discolouration Risk Increase (DRI). It can be noticed that even though CML, AMLP and UW are reduced when compared to the 'no response' scenario, the 'new methodology response' offers further improvements over the 'current practice response'. Indeed, the 'new methodology response' further reduced all impact indicators except AMLP that remained the same. The 'new methodology response' also suggested a smaller number of interventions to implement as evidenced by the significant improvement in DRI and cost. In light of the above, it can be concluded that through interaction with the IRPT operators could have identified a more effective response solution. Hence, this case study shows the potential of the IRPT to be beneficially used by United Utilities to make better and more informed decisions.

Summary

This paper describes an AI-based approach for managing events in WDSs such as pipe bursts/leaks and equipment failure. The key pieces of new technology are comprised of a series of ML and other advanced analytics methods that are used to detect and locate these events and then identify an optimal response strategy, all in (semi) automated fashion and in near real-time. This new technology, developed in collaboration with two leading UK universities in water engineering, works by extracting useful information form pressure and flow sensors and other data sources available.

The new technology enables United Utilities to manage the above events much more pro-actively than before by reducing the time of awareness to these events but also, in some cases, preventing events from taking place altogether. This combination has resulted in a range of benefits achieved, from major operational cost savings to reduced interruptions to supply and hence improved service to over 7 million people and 200,000 businesses in the north west of England. As the new technology has also demonstrated the potential to more efficiently guide United Utilities' personnel to the problem areas and to support the ICC operators to make better and more informed decisions when tasked with the identification of a suitable strategy to respond to those events, further benefits arising from the pursued fully managed life-cycle of events approach are expected. ■

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