Critical Success Factors for Implementing Smart IoT based Decision Framework in Water Industry

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Abstract— **The decentralized nature of information and the widespread use of mobile devices for accessing content makes the water sector an excellent platform for using the Internet of Things (IoT) paradigm to streamline procedures, benchmark standards and create a sustainable environment. Smart devices play an essential role in deploying digital solutions through IoT. They help connect the physical world with the digital universe and are regarded as fundamental items within a network integrated through IoT. The study provides a better understanding to assess the critical success factors (CSFs) for smart device implementation in the water sector. The factors are obtained from the literature and shortlisted with the help of experts using the Delphi method. Kappa statistics are used to further validate the conclusions of experts. The significant factors identified were Leadership, Usability, Cost of Implementation, Technology Awareness, Data privacy, Interoperability and Community Partnership. Mental modeler software has been used to construct a fuzzy logic cognitive mapping (FCM) of CSFs to represent causal reasoning in diagraphs. Scenario analysis was conducted for each CSF. The study provides recommendations for policymakers to develop precise strategies for integrating IoT in the water industry.**

Keywords—Water Industry, Fuzzy Logic Cognitive Mapping, Smart Devices, Internet of Things, Decision Making.

I. INTRODUCTION

The term 'Things' in Internet of Things (IoT) refers to objects denoted by various names in literature, like smart devices, smart things, smart gadgets or smart objects. Smart devices can be characterized as electronic devices equipped of communicating and computing that span from small sensor nodes to household appliances, along with real-time access through mobile connectivity. These devices form a typical part of the Internet of Things (IoT) and play a critical role in implementing and developing smart solutions for the IoT network in the water industry.

The regular internet is a global network that establishes communication between computers and devices using a defined protocol. The Internet helps to exchange information among various devices through data exchanges. On the other hand, the IoT is a network that links physical devices such as appliances, equipment, vehicles or wearables. It helps to share information between these gadgets and connect the real world with the digital space. The Internet of Things (IoT) paradigm encapsulates a virtual network of physical objects that enables real-time data collection, data analysis, flexibility, productivity tools and increased security with improved stakeholder communication.

The Internet of Things (IoT) has expanded the idea of smart water for the water industry to encompass more pertinent and connected services, connecting water with other utilities and water equipment. The inclusion of IoT technology in the water utility sector would reduce the per capita cost of the water utility in the long run [1]. The Gartner Hype Cycle report in 2015 looked into the commercial evolution of IoT in the water sector. They predicted that smart water would remain an evolutionary technology for some years [2]. The initial adoption of smart devices in the water industry should be in a phased manner, with smart meters, leakage management devices and smart irrigation gadgets as the initial adoption techniques [3]. Until recently, the world's focus was towards changing customer behavior by encouraging them to consume less water. The industry has now stepped in the direction of optimizing water flow, detecting internal leaks, real-time monitoring and timing the water usage to promote efficient consumption of water and reduced peak demand [4].

The evolution and diffusion of IoT aims to improve water management's social dimensions, i.e., valuing water and the ecosystems it supports, ensuring equitable use and distribution of water resources and the possibility of "water wars." The industry has taken a closer look at smart water solutions due to the challenges of water scarcity, ageing infrastructure, environmental standards, stricter regulations and increased development costs [5]. A smart water grid (an analogy from the smart grid for power) gives agencies the tools they need to serve their customers better while achieving their quality, productivity, and efficiency goals. An integrated system of smart devices, services, solutions and systems can be considered a "smart water network". This is an essential step toward effectively including smart devices and related technologies in the country's water and wastewater sectors. The IoT strategy in the water and wastewater sector encourages academics and software developers to design creative solutions based on mobile content access to boost efficiency and fluid real-time communication around the entire water value chain and among industry players. Implementing such creative solutions necessitates an organized strategy and a competent workforce that could analyze and acquire the skills to successfully implement, operationalize and maintain smart devices in the water network. As a result, the objective of this paper is to:

1. Identify the critical factors for the successful implementation of smart devices in the water and wastewater sectors.

2. Develop and analyze a FCM for the CSFs using scenario analysis.

The following section will discuss smart devices in the water and wastewater industry, followed by the research problem. It will be followed by research methodology including kappa statistics and FCM, scenario analysis and conclusion and recommendation.

II. Smart Devices in Water and Wastewater Industry

The role of IoT depends on how smart devices are defined in this study. IoT smart devices have been defined by various names like “smart objects”, “smart mobile devices”, “mobile devices”, “smart metering devices”, and “smart gadgets”, depending on their specific applications. The literature outlines and clusters smart devices based on key attributes: context-awareness, autonomy (and self-reaction), user interaction and connectivity. The study considers the theory of [6], which studies smart devices in the context of objects existent in IoT pervasive networks. IoT helps build a network between devices; most of these devices might never directly interact with the stakeholder [7]. Hence, the ability of a smart device to direct interaction with the stakeholder is not essential. However, context-awareness is a necessary element of a smart device.

A fundamental factor that makes a device smart is its ability to be contextually aware. Context-awareness is the capability of smart devices to sense information gathered from their surroundings using sensors (e.g., RFID, proximity, GPS, heat, camera, microphone). The data collected by sensors can then be used to make autonomous judgments or respond with real-time guidance to the stakeholder. Some examples of context-awareness are the application of smart devices in human voice recognition[8], photography and video recording [9].

Connectivity for a smart device is to connect to a new network or an already established, more extensive network. The central objective might be to share data to multiple devices within the network or to only obtain internet access, or both. Internet access on a smart device could be gaining access to a much more extensive or distant network. Internet use is widespread on smart devices. It implies that connecting to a network is essential for a smart device [10], and devices with IoT technology should possess network capabilities [11].

User-interaction is yet another essential feature of a smart device. Various smart device designs are based on user-interaction with smart devices, such as smartphones, smartwatches and tablets [10]. Various consumer-centric gadgets assist stakeholders in making decentralized decisions about usage, cost savings, context awareness, detecting difficulties in real-time, filing customer complaints, and receiving prompt assistance [12, 13]. Even though there is an array of smart devices designed for human interaction, the IoT paradigm is built on the interaction of devices, which means that any item may be linked and can serve as a hub for gathering or transmitting information to a more extensive network [7]. As a result, smart gadgets do not always necessitate communication with humans.

Other technologies that are associated with smart devices in conjunction with IoT are cloud computing [14], augmented reality [15] and graphical information systems [16]. From an operational point of view, a smart device is a context-aware electronic gadget able to perform autonomous processing and data exchange via wire or wireless connections [17]. This notion implies that any device may be converted into a smart device by including the appropriate technology. Despite an established smart device concept, there is limited research to conceptualize and implement it in the water and wastewater industries.

III. Research Problem

Due to the ever-increasing demand, water security remains a significant and growing concern for many countries, especially developing countries like India. According to a 2019 NITI Aayog report, India has been experiencing its worst water crisis in history, with nearly 600 million people without clean water. India resides roughly 18% of the global population and has only 4% of the water resource worldwide [18]. Most of the water and wastewater infrastructure has been outmoded. Ageing infrastructure has resulted in water loss, pipeline and pump failures, contamination, ineffective maintenance and distribution and insufficient treatment. The water and wastewater value chain infrastructure needs a complete overhaul. Water source contamination and water pollution is a challenge that poses health risks to the general public and disturbs the area’s ecology. Some other problems the water and wastewater industry faces are water conservation, operation and maintenance cost, energy efficiency and financial sustainability.

Although the literature thoroughly explains the challenges in the water and wastewater sector, it fails to provide a research foundation to implement smart devices in the water and wastewater network. In this scenario, there is limited understanding concerning the essential factors for the successful adoption of smart devices by decision-makers in the water and wastewater sector. As a result, establishing a meaningful inter-relationship among the factors leading to the application of smart devices in the sectors brings novelty to this study.

IV. CSFs for a Successful Implementation of Smart Devices in the Water and Wastewater Industry

The following section outlines the seven CSFs for embedding and implementing smart devices in water and wastewater corporations. These CSFs have been extracted from literature and the discussion with the experts. The Delphi method was used to discuss the factors obtained from literature. After a brainstorming session of two hours, seven CSFs were finalized with the help of experts that yielded similar themes during the dialogue. Table I presents the response rate of the experts concerning the CSFs finalized for the study.

A. Leadership

The administration and governance are critical in devotedly aligning the decision-makers with the corporation’s endeavors. Organizations that demonstrate leadership capability receive support from the top management to deploy innovative technological solutions [19]. The implementation success is significantly influenced by attitudes toward change and leadership encouraging transformation. According to [20], leaders that exhibit transformative and practical leadership traits improve the favorable environment for implementation and sustainability. Empirical research has also demonstrated the need for leadership for the success of implementation decisions [20, 21].

Convincing the organization's decision-makers about the benefits of technology implementation is one of the most critical stages of executing smart devices in the water and wastewater sector. To capture the value of the upgraded system, leaders must invest in new technology, upskill their workforce, increase connectivity and information sharing, and streamline organizational boundaries [22]. The bottlenecks of the existing water value chain can be well understood by executives managing daily operations. Therefore, executive-level decisions at each level are also essential for implementing the novel technology [23].

B. Technology Awareness

The degree to which industry professionals perceive technology status is referred to as their level of technology awareness. Being aware necessitates continuous information-gathering due to technology's ever-evolving nature [24]. There are different age groups of professionals within an organization who understand and embrace technology and its use at different levels. Some groups are resilient to change. Therefore, it is necessary to continuously educate professionals on innovative and upcoming technologies to avoid resistance to their implementation [25]. The industry would more readily accept the technology if it adopted a common mindset regarding the advantages of smart devices. Administrative procedures generally obstruct and slow innovation attempts [19]. Greater use of new technologies can result from an entrepreneurial culture emphasising employee flexibility and accountability. The awareness of the organization's workforce is closely related to its culture.

The government has the power to develop regulations that can enable this in the water and wastewater sector. To increase knowledge and utilization of smart device technology, educational institutions and professional organizations could offer programs like workshops, webinars, seminars, and continual professional development courses [26].

C. Usability

Usability refers to the effectiveness of a system's interaction and user experience [27]. The user's sentiments are a part of usability. An essential component of a user's ability for decision-making is emotion [28]. The smart devices for the entire water value chain should be user-friendly, and the communication with professionals should facilitate wider adoption of such solutions.

The applicability of smart devices in the water industry depends on various factors. The criteria for the water sector vary significantly and are extremely specific. Before implementing a technology-based solution, the adoption of smart devices should consider the conditions of the water network and any changes that may be required. Positive usability must make anything simple to utilize. The execution of an optimal user experience necessitates understanding and anticipating the network situations, such as network infrastructure and installation location, which may impact the use of smart devices.

TABLE I. RESPONSE RATE OF CSFs OBTAINED FROM EXPERTS

CSF	Response Rate (% from 11 experts)
Leadership	100
Technology Awareness	81.81
Usability	81.81
Cost of Implementation	100
Interoperability	90.90
Data Privacy	72.72
Community Partnership	81.81

D. Cost of Implementation

A key aspect to take into account for a successful installation of smart devices is the cost of the suggested solution. The organization's capacity to adopt new technology is influenced by the size of the water and wastewater network. Developed countries can more easily incorporate innovative technology-based solutions since they have higher resources than developing countries [29]. Densely populated areas have a denser water and wastewater network, which increases the likelihood that smart device deployment may be necessary for efficient coordination [30]. A denser network ultimately increases the overall cost of the network. Eventually, the decision-making process is heavily influenced by the implementation cost.

The diffusion of technology is reliant on a cost-benefit analysis of the suggested solution. The use of smart devices initially entails higher costs for the decision-makers. By demonstrating the possible advantages to be attained and how these benefits can be deciphered to earnings, positive cost-benefit analysis could promote the use of smart devices [1]. It is unlikely that the cost-benefit analysis will be put into practice if it does not result in either cost or time savings [31]. Due to the scale of water and wastewater network, communication improvements typically result in cost and time savings. Real-time information sharing within the management staff is the primary driver for integrating smart devices [4]. This would help to make the water and wastewater network cost as well as time efficient.

E. Interoperability

According to [32], interoperability is a term used to define the capacity of equipment to integrate and share data. Because information systems are not interoperable, organizations must spend a lot of time as well as funds switching between and within projects. Therefore, it is vital for the systems to be interoperable [33].

The convenience of integrating with existing technologies is a crucial consideration when adopting new technology that might be connected to smart devices and the IoT [34]. Existing assets may be converted into a smart device or gadget, including sensors and internet connectivity. Installing new technology can be made smoother through interoperability and easy integration [35]. The concept behind the IoT is that every component of a water and wastewater network may be linked to a system of devices that collects data from every aspect of the network [36]. Corporations must consider the compatibility between new and old devices to successfully migrate from a traditional network to a new network paradigm that adopts IoT technology.

F. Data Privacy

However, a discussion regarding citizen data privacy difficulties has become popular in the past few years [37]. Big data has emerged, and its value chain appears to handle large data volumes. As a result of the immense volume of sensitive and personal data that Internet of Things (IoT) devices may gather, analyze, and communicate, data privacy is a crucial problem in the IoT environment. To safeguard people's rights and stop information from being misused, it is crucial to secure data privacy as IoT devices continue to expand in many facets of our lives [38]. A smart device enabled network has benefited from big data because sensors generate enormous amounts of data that call for management and analysis. Benchmarking, Quality of Service, connection, real-time analytics, and storage are additional crucial requirements to improve IoT water network services using big data analytics [39]. Big Data may be both a problem and a research opportunity for identifying and assessing security vulnerabilities [40].

Due to the many communication stacks and standards used in an IoT-enabled network, traditional security services in the water and wastewater network would be ineffective. Flexible security solutions must be created to address malware attacks and security concerns in a dynamic IoT ecosystem in order to produce a safe network [35, 41]. Public water and wastewater data breaches can be detrimental to society and can be used for mala-fide intentions or terror attacks. It is a challenge for professionals to design and monitor access control, authorization, bootstrapping, and authentication to ensure data privacy and security. The increased complexity and data gathered through an integrated strategy will present specific obstacles to handling and maintaining such large amounts of data. In order to give information outputs based on externally assumed assumptions, it would be challenging to manage and protect the data in a way that best reflects actual demands.

G. *Community Partnership*

The water and wastewater network is an essential utility service for the community. The smart devices installed in the network and consumer IoT designed for the public must be developed keeping in mind the community's sentiments availing the services. Consumers are reluctant to use smart devices due to data breach issues and the extra money they must bear for their use, maintenance and repair. Long-term per capita water utility costs would decrease with the use of IoT technology [1]. One of the fundamental difficulties facing resource managers and utilities may be the ability and desire of consumers to pay for water and wastewater services. Full cost recovery is still an anomaly universally. There is a significant difference between the current capital investment levels of the corporations and what may be needed to successfully install smart devices in the water and wastewater network [42]. Public awareness and participation would be key to effectively implementing smart devices in the water and wastewater network.

V. RESEARCH METHODOLOGY

The CSFs are finalized with the help of experts. The Delphi methodology was used to collect the responses from water industry experts regarding the critical factors for a successful implementation of smart devices. Thirty-five experts were contacted, out of which eleven experts (Table II) agreed to participate in the study [43]. The necessary questions were asked about smart device utilization in the water industry and CSFs to implement smart devices effectively. After the discussion and brainstorming sessions, seven CSFs were finalized for smart device implementation. The 11 experts assisted in developing the FCM of the 7 CSFs using mental modeler software. Scenario analysis of the FCM was also conducted with the help of the experts.

TABLE II. DETAILS OF THE EXPERTS INTERVIEWED

Expert No.	Organization	Designation	Experience
Expert 1	Smart water solutions	CEO	20 years
Expert 2	Smart water solutions	Water technology advisor	14 years
Expert 3	National Water Mission	Director	18 years
Expert 4	National Water Mission	Ass. Section Officer	10 years
Expert 5	Ministry of Jal Shakti	RD head	12 years
Expert 6	Municipal Water	Executive Engineer	12 years
Expert 7	Municipal Water	Executive Engineer	12 years
Expert 8	Municipal Water	Executive Engineer	10 years
Expert 9	Municipal Water	Assistant Engineer	7 years
Expert 10	Municipal Water	Assistant Engineer	5 years
Expert 11	Municipal Water	Junior Engineer	4 years

A. *Kappa statistics*

The opinion of the experts was further validated using kappa statistics. The statistics are used to measure the inter-rater reliability and consistency of the responses. Kappa statistics is a widely used method in research to validate agreement among the decision makers [44].

Kappa Statistics was developed by [45] to evaluate the inter-rater reliability and consistency of various decision-makers. The difference between observed theoretical agreement and chance agreement divided by the probability of beyond-chance agreement is what is referred to as the Kappa coefficient [46]. The strength of the agreement may be measured using the Kappa index calculated from equation (1) using the Kappa measurement scale (Table III) provided by [47].

The values of i, j, and E in this investigation are 7, 5, and 11, respectively. A total of 11 decision-makers have been considered to examine 7 CSFs on a 5-point Likert scale. The kappa index of 0.371 shows fair consensus (Table III). The steps are as follows:

$$\aleph = \frac{P_0 - P_e}{1 - P_e} \quad (1)$$

Where, P_e is the chance agreement and P_o is the proportion of observed theoretical agreement. Further, P_e and P_o can be calculated as:

$$P_e = \frac{1}{y}\sum_{j=1}^{y} P_j^2 \quad (2)$$

$$P_o = \frac{1}{x}\sum_{i=1}^{x} P_i \quad (3)$$

Where, y is the number of categories and x is the number of variables. Then, the percentage of alignment (Pj) and percentage of involvement (Pi) can be calculated as:

TABLE III. KAPPA STATISTICS SCALE

Kappa statistics value	< 0	0.10 – 0.20	0.21 – 0.40	0.41 – 0.60	0.61 – 0.80	0.81 – 1
Corresponding Interpretation	Insignificant Consensus	Slight Consensus	Fair Consensus	Reasonable Consensus	Significant Consensus	Perfect Consensus

$$P_j = \sum_{i=1}^{x} e_{ij} \Big/ \sum_{j=1}^{y} \left(\sum_{i=1}^{x} e_{ij} \right) \qquad (4)$$

$$P_i = \frac{1}{E(E-1)} \sum_{j=1}^{y} \left(e_{ij}^2 - e_{ij} \right) \qquad (5)$$

Where, E denotes the total number of decision-makers and eij denotes evaluation of ith variable w.r.t. jth category.

B. Fuzzy Logic Cognitive Mapping (FCM)

FCM was initially developed by [48] as a technique to organize expert knowledge using a "fuzzy" soft systems programming methodology that is claimed to be analogous to how the human mind makes decisions [48]. A parameterized version of concept mapping called FCM allows you to create qualitative static models that are converted into semi-quantitative dynamic models. The computational dynamics of FCM are established by analyzing the construction and use of concept maps utilizing graph theory-based studies of pairwise structural interactions between the ideas included in a model [49]. Models such as these can be employed to investigate how people perceive a social or environmental issue or to simulate a complicated system when uncertainties are substantial and there is a dearth of empirical evidence. Building FCM becomes a simple and straightforward task by employing the Mental Modeler software. After creating models, one may investigate various scenario changes by raising or lowering the model's component count [50]. FCM has been applied in various scientific fields, including political science, economics, and ecology, because of their versatility and adaptability.

The FCM developed for this study is shown in Fig. 1. The CSFs' centrality explains the model's most relevant factor. Ordinary factors with lower centrality act like a bridge between the driver and receiver. Table IV shows the centrality along with the type of CSF.

C. Scenario Analysis

It has been observed from Table IV that the model has only one driver, i.e., leadership and community partnership is the receiver CSF. The water industry is primarily a public sector focused on efficiently delivering community services. The other CSFs are ordinary and support the physical service system built with the help of streamlining smart devices and IoT in the network. Leadership plays a crucial role in

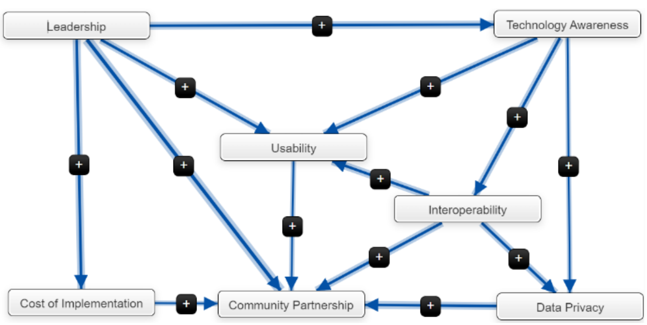

Fig 1. *Fuzzy-logic Cognitive Mapping based model for the critical success factors.*

TABLE IV. CENTRALITY OF CSFs IN THE MODEL

CSFs	Centrality	Type
Leadership	2.64	Driver
Community Partnership	2.68	Receiver
Interoperability	2.26	Ordinary
Data Privacy	1.62	Ordinary
Cost of Implementation	1.1	Ordinary
Usability	2.18	Ordinary
Technology Awareness	2.2	Ordinary

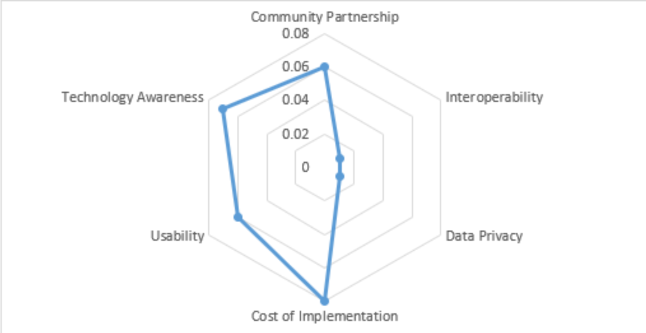

Fig 2. *Scenario analysis of the critical success factors*

implementing smart devices in the water industry. It is the primary driver that should support reformation as well as attitudes toward the development of the sector. It has an immense influence on the success of smart device implementation in the water and wastewater network. The climate conducive to implementation and sustainability is improved by leaders who demonstrate specific transformative and practical leadership attributes. These leadership traits have a domino effect on the other CSFs leading to transformative changes and increasing the efficacy of the entire water and wastewater network.

The variation in the energy of the driver influences the impact strength of other CSFs for smart device implementation. Fig. 2 shows the variation observed in other CSFs when the energy of leadership is changed to 1.

VI. CONCLUSION AND RECOMMENDATION

The water industry is critical for humanity's continual existence and well-being. Thus, incorporating contemporary technologies like IoT offers the industry more efficiency and a more centralized information flow between stakeholders. The literature established several advantages for using smart devices and the IoT framework in the water sector, including more efficient water distribution and management along with reduced risks, efficient recovery and reuse of wastewater (Owen David A. Lloyd 2018).

The study identified the critical success factors for implementing smart devices in the water industry. The study derives the CSFs from literature and in consultation with the experts using the Delphi methodology. Kappa statistics were further used to validate the output. The CSFs identified were Leadership, Usability, Cost of Implementation, Technology Awareness, Data privacy, Interoperability and Community Partnership. A brainstorming session was conducted to develop a FCM using mental modeler software. Scenario analysis was conducted by varying the energy of the driver. Its effect on the other CSFs was observed.

The study serves as a springboard for creating awareness of the significance of integrating smart devices in the water industry. This research adds to the increasing body of knowledge since there is a dearth of empirical literature on using the IoT paradigm in the water industry in general. It highlights the benefits of using smart devices in the water industry and refers to the effective distribution, recovery, reuse and management of a water and wastewater network. Highlighting the advantages of using smart devices can help critical decision-makers in the sector make better decisions.

Different stakeholders in the water sector can have multiple associations with the CSFs identified in the study. In order to generate the appropriate regulations for the industry, the government must establish guidelines and examples of a region that presents a quantifiable result for the effectiveness of the use of the IoT in water projects. Then, it might be desirable to create appropriate regulations that support the appropriate implementation of IoT in the water industry. Government regulations are essential in encouraging or mandating corporations adopt an improved technology ecosystem with extensive IoT deployment. Government policy can initially inspire both the public and private sectors to adopt smart devices in the water sector. When creating and enforcing an implementation strategy, policymakers should also consider factors like data privacy, usability, implementation cost, and interoperability because these factors are crucial to the effective adoption of smart devices.

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