A Study on the Impact of IoT Technology on the Operation Management of the Wastewater Management Sector

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Manuscript received March 1, 2024; revised April 12, 2024; accepted June 23, 2024; published September 14, 2024

***Abstract*—The research aims to analyze the impact of the Internet of Things (IoT) technology on the operation of the wastewater management (WWM) sector. The study results show that IoT technology could enhance operational process innovation in WWM. It is mainly reflected in wastewater pipeline network management, water quality monitoring, risk monitoring, and equipment maintenance. Through field data collection, transmission, fault detection, and decision-making support, it replaces the conventional manual operation, simplifies the workflow, and improves efficiency. In addition, IoT technology not only improves operation quality, and dependability, and reduces costs, but also improves the environment and water hygiene from the social level. In terms of risk management, IoT technology improves the accuracy and timeliness in hazardous sources monitoring, handling, and potential hazards prediction, to improve the risk management capability. Finally, IoT technology can enhance "demand" management by WWM authorities and provide accurate decision support for base capacity setting, also can solve the constraints of WWM system capacity to improve supply capacity.**

***Keywords*—IoT technology, Wastewater management system, Operation management**

I. Introduction

Water is one of the most important resources. Clean water resources are important from the perspective of sustainable development and essential for social well-being. Sewage and industrial wastewater are among the most important sources of water pollution. Many countries and regions have inadequate sewage treatment capacity. It is estimated that more than 1.4 billion people worldwide live in areas of high (1 billion) or very high (489 million) water vulnerability [1]. Inefficient and high-cost of wastewater collection networks decentralized treatment facilities, and the low recycling rate of wastewater are among the long-standing problems. The evolution of IoT technology provides new opportunities to address these problems.

IoT is a network of connected devices, such as computers, processors, machines, or objects, that transport data over a network without object-object, object-system interactions [2]. Ullo and Sinha [3] proposed to apply IoT technologies for smart environmental monitoring. Chen [4] tested a real-time pollution monitoring system by using IoT devices to classify the water pollution status of water bodies. Muñoz [5] further explored the feasibility of using IoT technologies for managing distributed water networks in an agro-industrial environment.

II. The Impact of IoT on Process Design

A. *"Input-Transformation-Output" Model Analysis in WWM*

Sewage is collected from households, factories, and other sources through the pipeline network and transported to a Sewage Treatment Plant (STP) for treatment. The process in STP (Fig. 1) generally includes pre-treatment, primary treatment, secondary treatment, disinfection treatment, sludge treatment, etc. The purified water is discharged for agriculture, natural water recharge, or recycling, and the remaining sludge is dried and dewatered for landfill, etc.

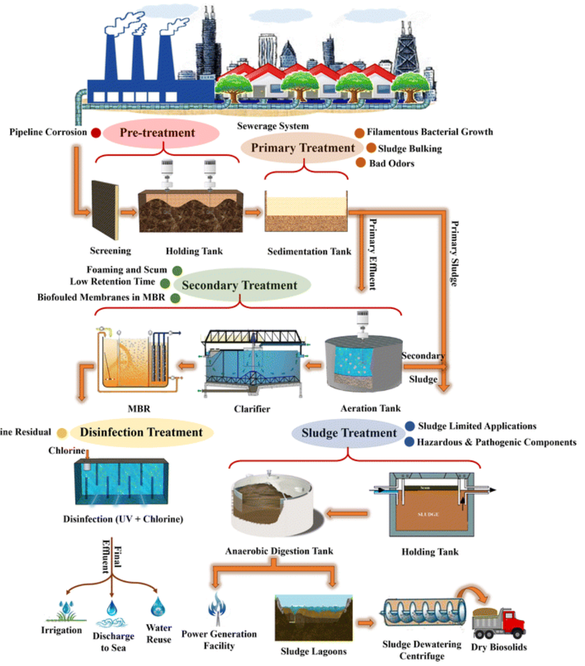

Fig. 1. Steps in a typical wastewater treatment process [6].

From the view of the operations management process, all processes and operations are about transforming input into output [7]. The "Input-transformation-output" model in WWM is shown in the diagram below (Fig. 2).

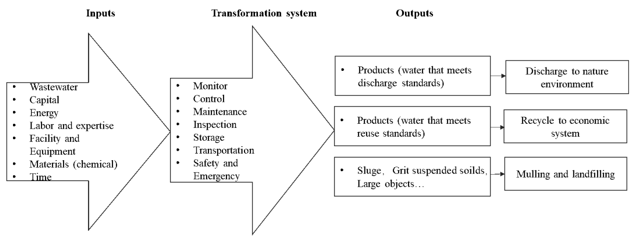

Fig. 2. Input-transfer-output model in WWM.

B. *IoT Impact on WWM Operation Process Design*

The typical impact of IoT technology on process design is

doi: 10.18178/ijimt.2024.15.3.965

reflected in the ability to monitor the operational status of decentralized, complex, partially underground space-based equipment, facilities, water sampling, and testing, and potential risks in real-time, changing the working model that relies on manual monitoring and operation as well as the reporting and decision-making process of information collection, analysis, and reporting.

IoT technology can drive development and progress in the WWM in the following ways (Fig. 3).

The impact of IoT on the workflow of water leakage detection, water quality monitoring, equipment maintenance, and small-scale facility management is analyzed in Table 1.

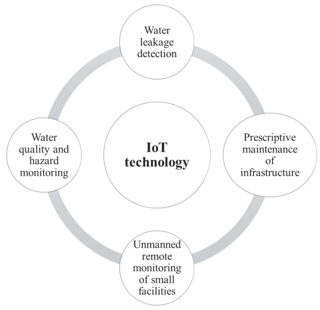

Fig. 3. IoT impact processes design in 4 aspects in WWM.

Table 1. IoT technology changes operation process design in WWM

Application of IoT in the process	Traditional operation process	IoT solves the following process challenges	Impact on objectives
Water leakage detection	Manual on-site inspection	· Scattered locations and time-consuming manual inspections · High labor cost · Untimely detection of problems and environmental pollution due to sewage overflow in case of pipe network leakage · Difficulty in tracing the source of illegal discharge of sewage	Cost, Dependability, Environment
Water quality monitoring and control	The water quality lab technician takes daily water samples and tests in the laboratory, including COD, BOD, TP, TN, fecal coliform bacteria, and other pollutant indicators. Based on the raw data from the tests, calculations, and analyses are carried out, and report abnormalities	· Manual errors in the sampling and testing process · Time consuming · Miscalculation	Quality
Prescriptive maintenance of infrastructure	Operators refer to equipment manuals for routine inspection, maintenance, and repair	· The incapacity to perform preventive maintenance on equipment, which reduces its lifespan · Equipment failure brought on by delayed problem diagnosis that interferes with production · Manual inspection, high workload, and high labor cost	Dependability
Remote management of small rural or community sewage treatment facilities	Personnel on-site or by one person who manages several small-scale treatment facilities and conducts daily inspections	· High labor cost	Cost

C. The Basic Process of IoT Technology-Based WWM Operation System

Lee [8] suggested that "IoT technology has created a new paradigm in which a network of machines and devices capable of communicating and collaborating is driving new process innovations in enterprises".

Generally, IoT technology-based operation systems include three parts: sensor layer, network layer, and application layer.

- In the sensor layer, such as monitoring equipment, and smart meters are installed to collect data from the site, including energy consumption, pollutant content, water discharge, pipe network data, etc.
- In the network layer, the data collected by the sensors is transmitted and stored via 5G, wireless networks, and digital cloud technology.
- In the application layer, data is quickly and systematically analyzed and displayed to enable dynamic monitoring and real-time control.

III. The Impact of IoT on Operations Performance Objectives

A. Social Objective

WWM is an essential process in society, which is closely linked to society, the environment, and human well-being. From a social level, the application of IoT technology in WWM contributes to improving WWM efficiency and water safety and reducing the health risks of the population caused by water shortage and water pollution, thus promoting the sustainable development of society.

Furthermore, from the operation view, IoT technology has a significant impact on operation quality, dependability, and cost (Fig. 4).

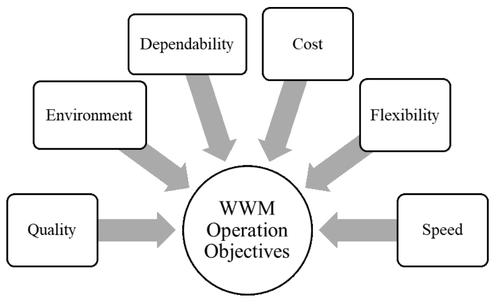

Fig. 4. Operation performance objectives in the WWM system.

B. Improve Operation Quality

Standards and requirements related to WWM are regulated by most governments; one example is China's Environmental Quality Standards for Surface Water (GB3838-2002). For wastewater treatment plants to comply with sludge and effluent discharge regulations set by the government, quality control must be maintained on an ongoing basis.

Traditional operations rely on manual operations, including maintenance of the pipeline network system, sewage sampling and testing, equipment maintenance and adjustment of the processing system, etc. This is time-consuming and may lead to errors due to personnel skills, experience, and responsibility, affecting the quality of system operation. IoT technology contributes to scientific decision-making and reduces human errors, thus, improving the quality of system operation.

C. Improve Operation Dependability

In WWM, pipeline networks, pumping stations, and sewage treatment facilities are widely distributed geographically, the traditional way of operation relies on the worker to inspect regularly and solve the problem, which often takes a long time, resulting in a high risk of system operation. With the application of IoT technology, when real-time monitoring data anomalies, the system will be the first to alert and provide solutions, enhancing the speed and efficiency of problem-solving at the decision-making level as well as the operational level.

Besides, IoT technology creates a collection platform to collect operational data from the whole process of the entire system, solving the problem of data silos, achieving holistic analysis and display of the entire WWM, improving the predictive capability of the system's operation, allowing preventive measures to enhance the reliability of the system's operation. For example, pipe network monitoring data can be used to predict the incoming water quality into the wastewater treatment facility, the Water quality and quantity entering the wastewater treatment facility can be predicted through the pipe network monitoring data to improve the impact resistance of the WWM system.

D. Cost Efficiency

The deployment of IoT technology necessitates large financial outlays, which will raise WWM investors' capital expenditure.

However, from the perspective of facility operations, the application of IoT technology will change the traditional operation and management methods which rely on manual on-site operations and require companies to bear high labor costs, especially in many developed countries, labor costs are particularly costly.

On the other hand, IoT technology can detect issues more quickly and precisely, allowing engineers to locate issues promptly and fix them. This lowers the likelihood of accidents and prevents losses from accidents.

E. Flexibility and Speed

The use of IoT can increase the flexibility of the system to cope with dynamic external environments through remote control and remote diagnosis of the WWM and improve the speed of the WWM system in responding to emergencies.

IV. The Impact of IoT on Operational Risk Management

A. Risk Management Process in WWM

Risk is the potential for unwanted negative consequences from events. To manage risk, potential sources of risk should be identified first. WWM is regarded as a crucial component of vital infrastructure. If their operations are interrupted, effluent that hasn't been properly treated may be released into the environment. As a result, there may be health issues, and soil, groundwater, and surface water contamination, etc.

Based on ISO 31000 and research, The diagram Fig. 5 below shows the basic procedure applied to perform a risk assessment of a WWM system [8].

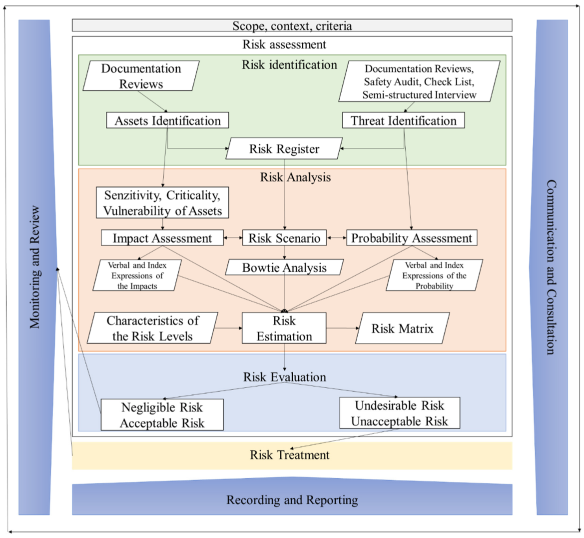

Fig. 5. Basic procedure applied to perform a risk assessment of a WWM system.

B. Potential Risk Identify in WWM

According to [9], Potential sources of risk to the wastewater management industry are identified, including supply, human, facility, and environmental risks.

1) Supply risks: Unidentified pollutants or sewage containing high concentrations of contaminants entering the sewerage system and flowing into the treatment facility, may cause an impact on the activated sludge system of the treatment facility and may lead to a functional failure.

2) Human risks: Risks arising from operational errors caused by inadequate skills and experience of the personnel. This includes the management of the electrical system, the operation of the sewage treatment process system, the operation of specialist equipment, the operation of chemicals, etc.

3) Facility risks: From the pipe network facility side, the water leakage from cracks and joints in a manhole overflows which may cause traffic and human casualties [10]. Besides, many of the pipe networks, equipment, and facilities are in underground spaces. There are extremely high risks when working in underground spaces, such as hydrogen sulfide gas poisoning. In addition, warehouses, where hydrochloric acid and sodium chlorate disinfectants are stored, can also cause toxic gases to accumulate if the ventilation equipment is operating abnormally.

4) Environmental risks: Environmental risks are mainly external risks such as floods, windstorms, earthquakes, epidemics, and power supply disruptions.

C. IoT Implementation in WWM Risk Management

The application of IoT technology to risk management in wastewater management is mainly reflected in three aspects, firstly, the real-time monitoring of risk sources, followed by the alarm of abnormal situations to accelerate the speed of emergency disposal. In addition, through systematic data collection and historical data analysis, IoT technology can enhance the ability to predict risks and take measures in advance to reduce the chances of accidents.

For example, IoT technology and big data technology in the WWM be used to monitor and report operation data in real-time through a combination of sensors and hardware such as smart water meters, which can alert the WWM authority when there is a problem to avoid the expansion of accidents. On the other hand, it can be implemented to monitor the status of infrastructure, and prescriptive maintenance on equipment and facilities can reduce the breakdown risk to ensure the stability of the WWS system.

D. New Risk of Cybersecurity

IoT also brings with it new potential impacts to WWM operation. The main potential is cyber threats and attacks, which have caused incalculable damage to individual users and business organizations worldwide, and have become one of the most important areas of the IoT [11].

V. The Impact of IoT on Capacity Management

Capacity management is the process of addressing inconsistencies between the nature of an operation's demands and the organization's ability to deliver goods and services while also maintaining efficiency by managing the expenses of excess capacity [12].

A. Operation Capacity in WMM

The capacity of WWM facilities is important in deciding when and how to add new plants to meet the growing demand for wastewater treatment needs for authority, the capacity is usually influenced by the tank volumes, equipment capacities, influent characteristics, operational factors, and license constraints [13]. Along with the growth of population and the accelerated urbanization process, the demand management of the capacity of WWM systems has become more complex and variable, resulting in overflow, which is functionally unable to meet the demands of sewage treatment, in addition, some WWM facilities have the problem of low-capacity utilization rate, resulting in overcapacity.

In addition, inefficient operation within the system can also affect the capacity. for example, blockage and leakage problems in the pipeline network, affecting the flow of water delivered to the wastewater treatment facilities; manual operation errors, equipment failure, and other accidents or unscheduled downtime, or annual planned maintenance, all from different degrees to shorten the system operation time, affecting the operational capacity. For scattered rural areas as well as communities, small-scale, individual sewage treatment facilities are operated, which are often neglected due to their scattered location, small- scale and low economic efficiency.

B. IoT Improves Operation Capacity in WWM

1) Precisely demand management

IoT technology can more finely manage the expanding pipe network system due to the expanding population, economy, and geographical scale, and improve the efficiency and scale of the WWM system.

In addition, government authorities can also use the data collected from the water supply system through IoT technology to make more accurate decisions during the capacity planning phase.

2) Improve sewage collection rate

By systematically supervising the pipe networks distributed throughout the city, the efficiency of pipe network maintenance can be improved. Real-time monitoring data can provide precise feedback on the locations where problems such as leaks and blockages occur, helping engineers resolve faults quickly to resolve faults in a short period and promoting an increase in the wastewater collection rate, thereby reducing capacity loss.

3) Improve the capacity utilization rate

WWM system requires regular shutdowns to inspect and repair submerged equipment such as pumps, aeration devices, etc. The application of IoT technology provides a more accurate understanding of the operational status of this equipment, improving the efficiency of maintenance, and shortening the downtime for maintenance, thereby Increasing capacity.

4) Rapid cloning to enlarge the capacity

WWM system is a high volume and low variability system. IoT technology-based operation systems with high scalability that can be applied to small-scale rural wastewater treatment facilities unmanned operation management, can achieve rapid cloning, without increasing the number of personnel to enlarge the capacity.

VI. Conclusion

This study focuses on the application of IoT technology in the WWM sector and analyses their impact on the process design, objectives, risks, and capacity of the operation and management of WWM. The study results show that IoT technology has significant advantages in achieving efficient, low-cost, and safe wastewater management. It is an effective technique to improve the efficiency of global WWM to solve the water pollution problem. This report implies that IoT technology in WWM has high application value and wide development potential in the future, but there is still room for further research on how to effectively use IoT technology while avoiding technical risks.

Conflict of Interest

The author declares no conflict of interest.

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