# A Proposed IoT System for Monitoring and Controlling Movable Zamzam Tanks in the Holy Mosque

Taha M. Mohamed
College of Business, University of Jeddah, Jeddah, Saudi Arabia

***Abstract*—Zamzam water is very important for all Muslims worldwide, especially for Pilgrims and Umrah performers who are visiting the two holy mosques in Saudi Arabia. Many movable Zamzam tanks are dispersed in many places of the two holy mosques. These tanks are available for pilgrims and visitors for drinking. When the two holy mosques are crowded, visitors want to know the locations of the nearest filled Zamzam tanks. Administrators and operators also need to monitor tank statuses for performing necessary logistics operations. In this study, we proposed a novel IoT system for automating, monitoring, and controlling water levels in Zamzam tanks in the two holy mosques. The proposed system modifies the existing Zamzam tanks' architecture to be smart tanks. The proposed system is analyzed, modeled, simulated, and discussed. Simulation and discussion show that the system is very useful for administrators, operators, and holy mosque visitors as it saves time, decreases efforts, automates logistics, and increases productivity. The system is very important for stakeholders, especially in crowded seasons. The performance metrics indicate that the proposed system is scalable with minimal delay and higher throughput. Also, the proposed system can participate in the digitalization of the two holy mosques, achieving the Saudi Vision 2030.**

***Keywords*—Zamzam tanks monitoring; IoT smart systems; automatic monitoring and control; Logistics 5.0**

## I. Introduction

The two holy mosques in Saudi Arabia are in Makkah and Madina. The grand holy mosque, Masjid al-Haram, has a capacity of about 2 million people when fully packed indoors and outdoors [1]. The area for each person is only about 0.25 square meters in regular seasons. In peak seasons, each square meter is available for twenty people in the Hajj season [1]. The government of Saudi Arabia targets 30 million Umrah performers and pilgrims per year, according to Saudi Vision 2030. The sacred Zamzam well springs from the grand holy mosque. Zamzam water is rich in many minerals and has useful components for all pilgrims, Umrah performers, and visitors of the two holy mosques. Muslims consider Zamzam water blessed (Mubarak) due to its greater benefits. Recent medical research indicates the great benefits of drinking Zamzam water. Zamzam water contains many essential minerals that are useful for drinking. Also, Zamzam water has a large pH that has antioxidant properties. So, Zamzam water raises body immunity [2], [3]. For medical and religious purposes, Zamzam water has been drunk for more than 4000 years [3]. Moreover, millions of pilgrims and visitors carry some of the Zamzam water to their families in their original countries for drinking.

Fig. 1. Example of five movable Zamzam tanks.

Zamzam water is distributed by many methods, such as bottles, movable tanks, and fixed tanks. For example, about 40 million Zamzam bottles were distributed daily to pilgrims during Hajj 2024. Additionally, the supply of Zamzam water can reach 1.6 million liters daily in peak seasons. Movable Zamzam tanks are approximately equal to 25,000 tanks in the holy mosque. They are refilled at least five times daily. Each tank can contain about 40 liters. These tanks are placed and dispersed around the mosque. Fig. 1 shows an example of five movable Zamzam tanks in the holy mosque. Despite the regular filling of these movable tanks by operators, however, there is no automated method exists for filling these tanks based on accurate readings. Also, there is no automated method for monitoring the statuses of these tanks. This issue represents a problem for both administrators, mosque visitors, and Zamzam operators. For administrators, they want to know the current filling statuses of all movable tanks in the holy mosque. So, if some tanks are empty or semi-empty, the administration can give commands to Zamzam operators for filling empty tanks instead of just filling these tanks at regular intervals. The automated system will achieve operational efficiency, save costs, and optimize resources, including human resources. Also, administrators need to predict the future demand for Zamzam water in certain locations of the holy mosque. Data analytics and predictions are also required by administrators. For mosque visitors and pilgrims, a map of the nearby filled Zamzam tank is required. This is important, especially in crowded seasons, where the movement inside the holy mosque is very tedious [4]. So, automation of knowing filled Zamzam tanks can save visitors time and effort. For operators, they need to know the locations of the empty Zamzam tanks instead of the current periodic routine checking of all movable Zamzam tanks. If empty tanks are identified automatically, then the operators can refill only those tanks, saving their time and effort.

In fact, automated methods of logistics management use Industry 4.0. Industry 4.0 [5], [6] integrates advanced digital technologies in manufacturing and industrial processes. Part of Industry 4.0 is called logistics 4.0, which adopts advanced technologies in supply chains. Logistics 4.0 can create intelligence for the devices connected in the whole supply chain to optimize storage and movement of products. The logistics of Zamzam tanks in the holy mosque can be enhanced using logistics 4.0 technologies. Such technologies may include IoT, data analytics, artificial intelligence, and cloud computing. These technologies efficiently enhance the logistics operations [7].

The Internet of Things (IoT) refers to the connectivity of things to the Internet to be smart. There is an increasing number of IoT applications in various fields such as transportation, engineering, and many other fields [8]. IoT can be used for automatic monitoring and control of movable Zamzam tanks in the holy mosque. IoT can use sensors, embedded systems, communication, and cloud technologies to monitor and control water levels in movable Zamzam tanks in real time [9], [10]. This real-time monitoring helps in making real-time decisions. Moreover, using IoT solutions assists in keeping an accurate record of water levels in movable Zamzam tanks in the holy mosque. The sensors can detect the water level in each tank. Communication technologies can send water level information to the cloud. The cloud can analyze sensor readings and make appropriate decisions, including triggering and notifying operators to fill empty tanks. On the other side, the absence of an automated system for monitoring movable Zamzam tanks makes great challenges to pilgrims, Umrah performers, and visitors of the two holy mosques, especially in crowded seasons such as Hajj and Ramadan. There are many losses that occurred due to the absence of the automated system, including high efforts, increased operational costs, and more time overhead. So, in this study, we propose a novel IoT system for monitoring and controlling movable Zamzam tanks in the holy mosque. The proposed system has some subsystems that use logistics 4.0 technologies, aiming to automate monitoring and controlling processes. The proposed system can decrease operational costs and improve overall system efficiency. Also, the proposed system decreases the efforts of administrators, visitors, and operators. The proposed system is modeled and simulated. The simulation results show the importance of the system for resource optimization and cost reduction.

The rest of this study is organized as follows: Section II presents the necessary background of IoT technologies. Section III presents the previous work. Section IV shows the proposed system components. Section V analyzes the proposed model, simulations, and discusses some of the performance criteria. The study is concluded in Section VI.

## II. IoT Technologies

IoT technologies could be adopted in monitoring and controlling the logistics of movable Zamzam tanks. The proposed system for automating monitoring and controlling movable Zamzam tanks relies on IoT. An IoT system can consist of the following components [11], [12]: sensors, actuators, communication, cloud, and software for monitoring and control [9]. In this section, we will evaluate different technologies related to movable Zamzam tanks automation. We will show the merits and drawbacks of each technology used.

### *A. Sensors*

The sensors' subsystem is considered as the data acquisition layer at the tank site [13]. Each tank is provided by a sensor to measure water level in this tank. Selecting the right sensor to detect water level in the tank depends on several factors. The first factor is the type of tank monitored, where it is open or closed. The required accuracy is another factor. Also, the type of sensor used where its readings may be continuous or discrete time. From contact point of view, there are two types of sensors: contact and non-contact sensors. In our case of movable Zamzam tanks, the tanks are closed. Also, continuous monitoring of the water level in each tank could be achieved using discrete time intervals (e.g. every minute). In this case, a tradeoff is achieved between fast decision making and continuous monitoring. This avoids network congestion. The contact sensors touch water inside the tank. This is not practical as the water inside the tank is prepared for drinking. Also, contact sensors may be harmed if they touch the water inside the tank. Additionally, contact sensors are not convenient for Zamzam operators during tank filling process. So, the practical approach is to use contactless sensors outside the tank for monitoring water level in the tank. This achieves isolation between the tank itself and the sensing subsystem increasing convenience and reliability.

The most two popular non-contact sensors are ultrasonic sensors and pressure (submersible) sensors [14]. Ultrasonic sensors are mounted on the top of tanks. These sensors measure the time the ultrasonic signal takes to the surface of the water. However, these sensors cannot be used for monitoring Zamzam tanks. They may be damaged by continuous handling of Zamzam tanks by operators during filling processes. The second type of non-contact sensors is pressure sensors. These sensors measure the pressure resulting from the column of water in the tank. The idea of these sensors is like a digital balance. As water level in the tank increases, the weight of the tank also increases. Eq. (1) describes the computation of water level height in the tank:

$$h = \frac{p}{\rho \; x \; g} \tag{1}$$

where, h the height of the water level inside the tank, p is the pressure of water, ρ is the water density, and g represents gravitational acceleration. However, pressure sensors are also impractical in determining the quantity of Zamzam water in the tank when being mounted on the bottom of the tank because cleaning and handling issues can harm the sensors. Alternatively, in the proposed system, we use pressure sensors after modifying the way that the sensors are mounted. We isolate the sensors from the tank itself. The sensors are mounted externally in the base of the tank, outside it. So, we avoid the problems resulting from tanks handling processes by operators.

### B. Microcontrollers and Communication

Microcontrollers collect data from sensors. They are also used for secure transmission of data. Examples of microcontrollers include Arduino, Raspberry Pi, and ESP32 [8]. Microcontrollers can send sensor readings at every certain time interval. In the proposed system, we propose sending sensor data to the cloud every minute. This satisfies the tradeoff between minimizing the amount of data transmitted and satisfying semi-continuous monitoring of the water levels in the tanks. The data transmitted every minute is very small, about only five bytes representing the tank identifier and the water level in the tank. The microcontroller is often equipped with a network connection module, such as a SIM module or any other wireless module. Occasionally, any small capability microcontroller can achieve the required transmission of a small amount of data. The microcontroller sends sensor data through the communication network to the processing servers. The main wireless technologies used for data transmission are Wi-Fi, Long Range Wide Area Network (LoRaWan), and cellular networks [15]. There are many considerations that affect the chosen technology from them. Wi-Fi networks can serve devices within the range of wireless access points. Wi-Fi is suitable for indoor locations like smart homes and smart buildings. The devices consume low power when connected to Wi-Fi. There are no fees to connect to these networks; that is, the operational cost is low. However, congestion and interference can affect the performance of Wi-Fi networks due to the unlicensed spectrum, which includes other technologies such as microwave ovens and Bluetooth devices. Although the merits of Wi-Fi connections, they are not suitable for Zamzam tank monitoring as these tanks are dispersed along a large area of the holy mosque. Also, some of these tanks are already located outside the holy mosque. LoRaWan is another technology that consumes low power. This communication technology is suitable for small and infrequent data transmission. It supports transmission for long distances with minimal power, which saves battery life. A LoRa module could be connected to the microcontroller supporting LoRaWan transmission. However, access to a LoRaWan gateway is required. LoRaWan is ideal for smart cities, smart agriculture, and asset tracking. The main disadvantage of using LoRaWan technology is the requirement of a gateway to act as a bridge between IoT devices and clouds. Gateways require additional settings and infrastructure expenditures [15]. If this technology is used in Zamzam tank monitoring, then gateways must be established first. Compared to Wi-Fi, LoRaWan is better than Wi-Fi in monitoring Zamzam tanks. The third option is the cellular networks that connect devices to the server and cloud. Cellular networks could be accessed anywhere and do not need any additional infrastructure. These networks can connect sensors embedded in Zamzam tanks regardless of the location of the tank, either indoors or outdoors. While cellular-connected devices consume more power than Wi-Fi connected devices, there are some cellular technologies, such as NB-IoT, that are optimized for infrequent data transmission. Also, cellular networks need a monthly fee for transmission. However, power consumption is slightly higher than both LoRaWan and Wi-Fi. The main advantage of using cellular networks is the greater availability and the ease of tanks movement inside and outside the holy mosque and in far places from the holy mosque. Also, cellular networks are more stable and secure than Wi-Fi. For cellular networks, IoT-specific plans are often cheap due to sending only a few bytes of sensor readings. Interestingly, using either 4G or 5G networks is sufficient for the proposed system as the sent information is almost few bytes representing tank identifier and a discrete sensor code represents a quantized version of the sensor readings. The transmission occurs at a discrete interval (every minute) to decrease the required bandwidth and network congestion. Cellular networks are more stable and reliable than the other two previously mentioned networks as they use licensed spectrum managed by the carrier [15].

From the previous comparison, we choose cellular networks for sending tanks information to the cloud. That is because these tanks are remote, movable, and may be moved to locations where they are not being covered by other networks. This is due to the large area of the holy mosque. Also, cellular networks do not need any special infrastructure or handling. They could be used as plug and play networks for network users. Due to the large number of movable Zamzam tanks in the holy mosque (around 25000), it is impractical to use other networks which need additional settings, manipulation, and infrastructure. Regarding power consumption, sensors and microcontrollers can use low-power technologies which save battery life. Additionally, the batteries could be also charged continuously by using solar panels or any continuous electrical sources.

### C. Cloud Computing

Cloud is a technology that can receive and store data readings from sensors. Also, the cloud can perform many other beneficial tasks, such as performing data analytics and machine learning tasks. The output of data analytics is interpreted as commands sent to the actuators. It can cover the journey of IoT data from sensors to actuators, including storage, processing, and visualization. Also, the cloud can handle millions of devices simultaneously. It is often provided by a time series database, which is suitable for the storage and manipulation of sensor data that arrives according to predetermined time slots. Also, the cloud could compress the data received if large amounts of data arrived, making it a good option for future data analytics and data mining. In the proposed system, the received sensor readings are time series data for each tank. This is very helpful in data analytics and prediction. For IoT, the most used cloud providers include Amazon Web Services (AWS), Google Cloud Platform (GCP), and Microsoft Azure [16]. IoT services of AWS can provide massive scalability and a deep service ecosystem. Microsoft Azure has great integration with Microsoft products and tools like Power BI that offer data analytics and visualization. Also, Google Cloud has powerful machine learning and artificial intelligence tools and provides advanced data analytics tools, including BigQuery.

All three clouds have data analytics capabilities and integration with machine learning. In the proposed system, the services offered by any one of the three cloud providers are sufficient. The choice between them depends on the actual cloud used in the site. The main advantage of using existing cloud infrastructure is to reduce the costs of adding a new investment in cloud technologies. Interestingly, the data volume and velocity of the proposed system are not large. This is because a small number of bytes are transmitted each minute, representing the tank identifier and the quantized sensor reading. Even with the large number of devices used in the IoT, the overall data sent is very small. The huge capability of the cloud can handle the data sent without any delay.

## III. Related Work

In this section, we will overview the related work regarding smart logistics and automation, as Zamzam tank monitoring is an example of smart logistics automation. In [5], the authors review a lot of Industry 4.0 technologies concentrating on the applications in the supply chain management field. In the following subsections, we will review the related work.

### A. Smart Logistics

In [7], the authors show the performance enhancements of logistics by using Logistics 4.0 technologies. The authors in [17] analyze the relationship between Industry 4.0 and Logistics 4.0 and discuss future trends, including operations such as predictive analytics and sustainable practices. The authors in [18] show the concept of Logistics 5.0, which is the recent generation of intelligent logistics. They suggest human-oriented operating systems to provide intelligent logistics solutions. Moreover, the authors in [19] show some of the possible new technologies of Logistics 5.0, including adopting robotics, edge computing, Internet of Things, and artificial intelligence into manufacturing and production processes. Also, they conducted a survey on the importance of edge computing in logistics. A large component of Logistics 5.0 is the IoT systems.

### B. IoT Recent Technologies

The authors in [8] compare the performance of different hardware platforms of IoT, including Arduino and Raspberry Pi. The comparison includes programming capabilities, hardware specifications, and some other factors. In [15], the authors compare some different communication technologies used in IoT systems, including LoRaWAN, Wi-Fi, and cellular networks [15]. Additionally, the authors, in [16], analyze the three popular cloud platforms: Google Cloud Platform, Microsoft Azure, and Amazon Web Services using five different benchmarks. The authors review some of the cloud features, such as pricing and services. They state some considerations in choosing the appropriate cloud model for organizations.

### C. Related IoT Systems

In fact, IoT may be used in different relative fields such as smart irrigation. In [11], the authors propose a smart, low-budget, IoT irrigation system using an Arduino Uno microcontroller and a Node-Microcontroller ESP8266. They claim that their system reduces water wastage than the traditional process. Cloud and mobile applications are used to notify farmers. The communication is carried out through a Wi-Fi module [11]. Also, the authors in [12] present an IoT-based system for smart irrigation. Four sensors are used to determine soil status. Sensor readings are sent to a central control system to control pumps. The system is supported by a mobile application to notify farmers remotely [12]. Regarding monitoring water level in tanks, the authors in [20] propose a smart water management system to manage water stored in large tanks in Makkah, Saudi Arabia, in residential buildings. The data is transmitted via cellular networks to the cloud for remote monitoring. Also, the authors in [13] monitor and control water level using an IoT system in Saudi Arabia. The system can monitor leakage. The system uses an Arduino Uno board connected by an ultrasonic sensor. Data transmission is performed using a GSM/GPRS module. The system controls motors based on the actual water level thresholds [13]. The authors in [14] use optical fibre sensors for real-time pipe monitoring to detect leakage. The detection can be deployed without pipeline bonding [14]. In [21], the authors propose an IoT model to monitor and manage water levels in tanks. The model uses ultrasonic sensors that send water levels to a microcontroller. The system could be manually controlled by users or automatically controlled through a mobile application [21].

The authors in [22] propose an IoT system using an ultrasonic sensor that is designed to monitor water level in tanks, either in farms or homes. The valves are controlled automatically by the cloud. Water is substituted automatically if it goes below some predetermined level. Also, a notification is sent in case of empty, full, or failure tank status. Manual control is also possible by the user. The authors in [23] propose an IoT system that uses four sensors in a cistern. Some of these sensors are assigned to measure water level in the cistern, whereas the other sensors measure water quality. The system is controlled using online dashboards. The cistern is automatically filled when it becomes empty. The authors in [24] introduce an IoT system that uses an ESP32 microcontroller connected by an ultrasonic sensor to monitor water level in a tank. The authors emphasize the importance of monitoring and controlling water in tanks for efficient management of resources and minimizing waste [24].

From the previous survey and discussion, we can conclude that different technologies could be used in IoT systems, including different types of sensors, microcontrollers, communication technologies, and cloud services. The choice of suitable IoT technologies depends on the intended application. Although IoT technologies are adopted in many related fields, such as smart irrigation and tank monitor and control, however, IoT systems are not yet adopted in the monitoring and control of movable Zamzam tanks in the holy mosque, despite the large number of tanks. Automation of Zamzam tanks monitoring is very essential as the number of beneficiaries is millions of people who visit the holy mosque for Hajj, Umarah, and visit.

## IV. Proposed IoT System

In this section, we will review the detailed description of the proposed IoT system for monitoring and controlling movable Zamzam water tanks in the two holy mosques. The key components of the system are discussed. These components include sensing subsystem, microcontroller subsystem, communication subsystem, cloud subsystem, and actuators subsystem. The whole system is depicted in Fig. 2.

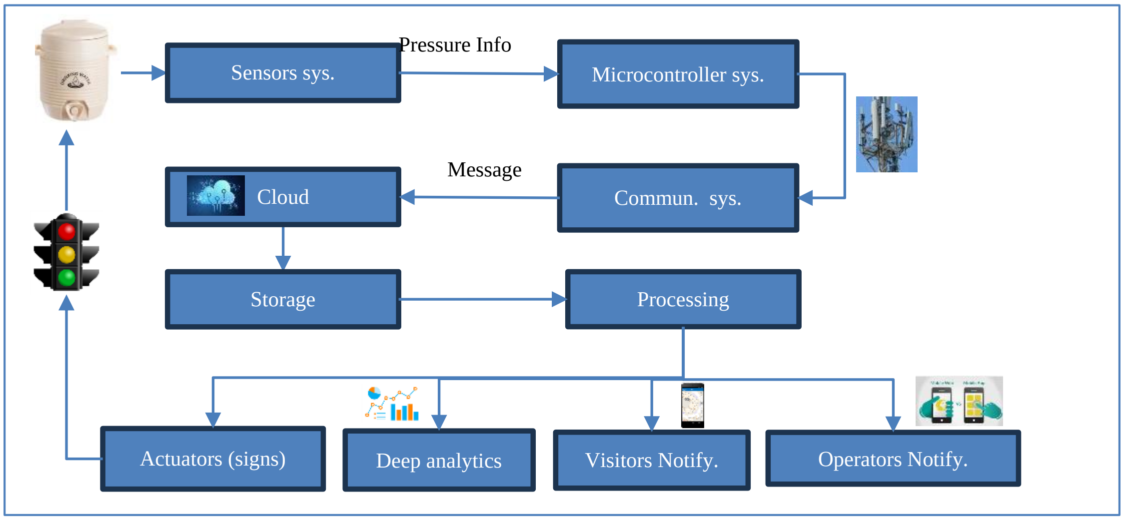


Fig. 2. The proposed system architecture.

The first component of the proposed system is the sensors subsystem, which measures water level in movable Zamzam tanks. In the proposed system, we decided to use non-contact pressure gauge strain sensors, like a digital balance, for mechanical and environmental protection. The main advantage of using this type of sensor is the isolation of the sensor's circuitry from the water itself and from the tank itself. The isolation is also convenient for Zamzam operators who handle and fill the tanks a lot of times daily. Also, non-contact sensors are protected against humidity, dust, heat, and other environmental effects.

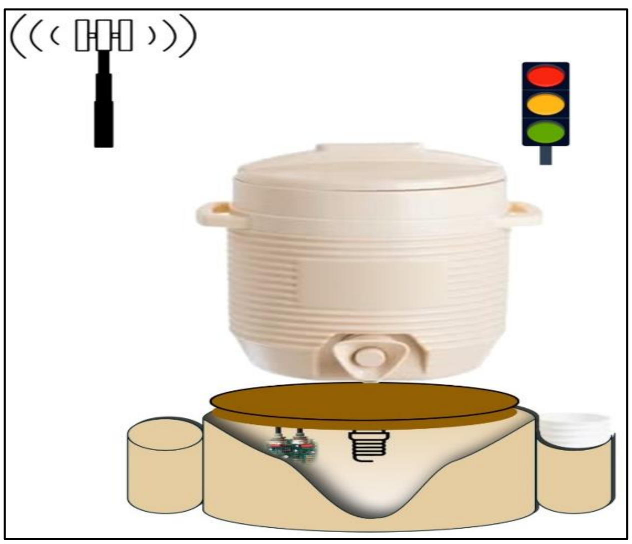

Fig. 3. The proposed modified sensor's subsystem.

So, we redesigned the external base of the Zamzam tank to contain the sensor and its microcontroller circuit. This is used to avoid contact with the tank itself. So, the proposed new design of the tank's base is to add a strain gauge sensor in the base of the tank. This sensor is covered by a metallic cover to carry the tank itself and to protect the sensor's circuit. The sensor is connected by a microcontroller and a communication module for cellular transmission. The modified tank's base is shown in Fig. 3. From Fig. 3, it is shown that the sensor reads the weight of the tank, including water and empty tank weights. When the tank is put on the modified base, the sensor's readings indicate the quantity of water in the tank. If the weight of the tank in the empty state is known, then the weight of the inside water could be inducted. This weight is interpreted as the water quantity in the tank. For example, if the tank is filled with Zamzam water (i.e., 40 liters, approximately), then the tank's weight will be about 50 kilograms, including the weight of the empty tank.

The second subsystem is the microcontroller unit. This unit is the brain of the IoT system. Microcontroller sends sensor readings to the cloud after performing some preprocessing. The most used microcontrollers in IoT applications are Arduino, ESP32, and Raspberry Pi. We decided to use an Arduino Uno unit due to its cheap price, convenient settings, low power consumption, and reliability. Weight data is obtained by the microcontroller every minute. The choice of this interval achieves the tradeoffs between continuous tank monitoring and avoiding network congestion. In fact, accurate continuous weight information is not important in this application, as the stakeholders want to know only discrete statuses of the water level in the tank. So, in the proposed system, the weight information is sent to the communication system as a discrete integer value representing one of five tank statuses. These statuses are: Fully Filled, Semi-Filled, Moderate, Semi-Empty, and Empty. These statuses are represented by numbers from 5 to 1, respectively. This number could be represented by only three bits, saving bandwidth. The discrete statuses are more useful for stakeholders than the continuous-value weight information. These statuses are explained by rules shown in Algorithm 1. In fact, discrete statuses are sufficient to determine filling status of each tank. For visitors and operators, the status is more useful than the actual, continuous-value, water level. The transmission of status code is less than one byte. Besides the status code information, additional two bytes are also sent to the cloud representing the tank identifier. So, the overall bytes sent are less than three bytes. Sending this information every one minute converts the continuous transmission of information into discrete transmission which decreases the amount of data transmitted. This interval is flexible and could be decreased or increased based on administrative decisions considering the tradeoffs between continuous tank monitoring and network traffic. Considering that, the number of tanks is very large (about 25000 tanks). So, performing this preprocessing at the microcontroller side decreases the traffic sent to the network.

Algorithm 1: Tank status submission

```
If Weight >= 40 Then
Tank Status = Fully Filled
Return 5
Else If Weight >= 30 Then
Tank Status = Semi-Filled
Return 4
Else If Weight >= 20 Then
Tank Status = Moderate
Return 3
Else If Weight >= 10 Then
Tank Status = Semi-Empty
Return 2
Else
Tank Status = Empty
Return 1
End If
```

Often, the power source for microcontrollers is a battery. This battery may be connected to a solar panel for automatic charging. Using solar panels is very efficient due to the low power requirements of the circuitry. Also, the sun rises in Makkah for a lot of hours daily, and the weather is almost hot throughout the year in these locations. The microcontroller is also equipped with a SIM, or other wireless module, for connecting to cellular networks.

For the communication subsystem, we decided to use cellular networks as communication technology. That is because cellular networks have easier settings, suitable for long and dispersed places, and reliable for a large number of movable tanks. Besides, cellular connections do not need a large amount of power due to the small amount of data sent to the cloud, representing tank filling status and tank identifier. The tank identifier used is the SIM card number of the SIM module embedded in each tank. This number is used as a part of transmission. Also, each tank receives a control message through the SIM card, acting as an actuator. There are three cellular networks operating in Saudi Arabia: STC, Zain, and Mobily. The signals, connections, and data rates of the three providers are very efficient. The signal strength of these networks is very efficient in the holy mosque and can efficiently handle any huge traffic of data, especially in crowded seasons such as the pilgrimage and Umrah. So, there is no extra infrastructure needed to establish and deploy the proposed system using any of the three available cellular networks. The communication system sends sensor data to the cloud. The cloud subsystem receives processed data and stores it in a time series database. Next, the data received is quickly checked and analyzed, and classified according to the statuses of all tanks. Also, the cloud provides deep analytics for the massive historical data of movable Zamzam tanks to make strategic decisions. The cloud provides a control dashboard for administrators. In the proposed system, we suggest using any one of the mostly used cloud platforms, including AWS, Azure, or Google Cloud. All these providers can perform the required tasks of the proposed IoT system. Also, the cloud system provides data visualization representing tank statuses through graphs, maps, and dashboard. The analytics may include descriptive analytics such as statistics of tank statuses, locations of large demand, and locations of large supply. Also, the cloud can provide predictive analytics that is used to predict the demand and supply in a certain season and a certain location in the holy mosque. Cloud prescriptive analytics determines the best future actions that could be taken regarding handling, operations, and maintenance of movable Zamzam tanks. Periodic reports are also possible about the supply, demand, and maintenance of tanks and their connected systems. Administrators can also monitor performance through dashboards on their mobile phones.

Fig. 4. The modified sign actuator of movable Zamzam unit.

The actuator subsystem is controlled through the cloud. After quick analytics, the cloud may send alerts and notifications for Zamzam tanks operators with status information of moderate and semi-empty tanks to be filled. So, the system will be proactive in this case. Zamzam operators receive these commands and reports regarding movable Zamzam tank statuses through a mobile application connected to the cloud. For holy mosque visitors, the proposed system has two advantages. The first advantage is that the system provides a mobile application to visitors containing information about all nearby filled or semi-filled Zamzam tanks with a dynamic indoor map. Indoor maps [4] are excellent in floors and corridors and provide interactive navigation. This enhances visitor experience, safety, convenience, and fast navigation, especially in crowded seasons. We also modify the whole Zamzam unit, which includes a group of tanks, as a second advantage for visitors. Fig. 4 shows the modified Zamzam unit by adding color signs, like traffic signs, to the axis of the unit. The added color sign shows the status of the tanks connected to it. This sign can be controlled from the cloud or also controlled from the microcontroller itself based on the status of the tank. The sign may include only three colors: Green, Yellow, and Red that represent the statuses: Full, Moderate, and Empty, respectively. Visitors can know the status of each tank either through directly noting the color sign or indirectly through indoor map navigation connected to their mobile application. The integration of all these subsystems provides real-time monitoring and control of movable Zamzam tanks in the holy mosque.

## V. Simulation and Discussion

In this section we will present the model, simulation, and discussion of the proposed system. The proposed system could be modeled as a stochastic M/M/1 queuing system, and that the movable smart tanks represent clients. Those clients require a service from a service center, which is the cloud. The details of the model are explained in the following subsection.

### A. Simulation

Let $S_1, S_2, S_3, \dots, S_N$ represent a group of N sensors connected to Zamzam tanks that send messages, representing the water level status of each tank, to the cloud system approximately every minute [25]. The messages are waiting for service on the cloud. So, this system follows M/M/1queuing model [26]. So, the messages that arrived at the cloud represent a Poisson process with Poisson arrivals. The time between arrivals is modeled by exponential distributed with average arriving rate equals λ. Also, the average service time follows an exponential distribution with a service rate $\mu$. The system assumes one large server that handles all received messages from input sensors (the cloud). So, the queue of messages waiting for service is of infinite length. All received messages are served according to the First-Come First-Service (FCFS) strategy [26]. These are the requirements of M/M/1 queuing model. In fact, all these conditions are satisfied with our case when using the cloud for service due to the unlimited scalable processing and storage capabilities of the cloud. Let K represent the buffer size of the queue. In our case, K is approximately ∞. Also, the queue length $L$ is infinite. We want to address some performance metrics of the system, such as throughput, loss probability, average waiting time $W_q$, average system time (delay) $W$, and utilization $\rho$ [25]. So, the sum of the arrival rates $\lambda$ of all sensors $S_i$ is given by Eq. (2) as:

$$\lambda = \sum_{i=1}^{N} \lambda_{S,i} \tag{2}$$

where, N is the total number of Zamzam tanks equipped with sensors. $\lambda_{s,i}$ represents the arrival of each sensor. Arrival number in an interval with length $t$ represents a homogeneous Poisson process, and it is given by Eq. (3) as:

$$P\{N(t) = k\} = e^{-\lambda t} \frac{(\lambda t)^k}{k!} \tag{3}$$

The interarrival times of the messages from the sensors follow an exponential distribution with parameter $\lambda$ that is given by Eq. (4) as:

$$f(t) = \lambda e^{-\lambda t} \tag{4}$$

For service time, the arrivals are served according to the first-come, first-served strategy. The service time also follows an exponential distribution with a service rate equal $\mu$ that is given by Eq. (5) as:

$$f_S(t) = \mu e^{-\mu t} \tag{5}$$

Due to the huge cloud capabilities, the buffer is approximately of infinite length. So, no packets are dropped from the system. Therefore, the system can afford high traffic received from the sensors even if many devices are connected. The utilization $\rho$ can be calculated from Eq. (6) as follows:

$$\rho = \lambda / \mu \tag{6}$$

where, λ is the average arrival rate, and μ is the average service rate. Utilization should be less than 1 to keep the system stable. However, keeping utilization less than 70% is good for to ensure service quality. In the proposed system, $\rho$ is much less than this rate because the capabilities of the cloud service rate is very high. The mean waiting time of the transmitted messages in the queue is given by Eq. (7) as:

$$W_q = \frac{\rho}{\mu - \lambda} \tag{7}$$

Again, due to the fact that the service rate is much higher than the arrival rate, the waiting time is very small. The blocking (loss) probability is given by Eq. (8) as:

$$P_K = \Pr\{N = K\} = \frac{(1-\rho)\rho^K}{1-\rho^{K+1}} (\rho \neq 1) \tag{8}$$

where, K is the system capacity, which is approximately infinite. So, the blocking probability is very small, that is $P_K \approx 0$. So, the effective throughput of the system $\lambda_{\text{eff}}$ can be computed from Eq. (9) as:

$$\lambda_{\text{eff}} = \lambda(1 - P_K). \tag{9}$$

Because $P_K$ is approximately zero, leading to $\lambda_{\text{eff}} \approx \lambda$, which is the optimal throughput [25]. To simulate this M/M/1 system, we used both the Python library SimPy and MS Excel for simulations and graphing. The simulation input parameters are illustrated in Table I. It is clear from the table that the total number of simulated tanks equals 50000. This number is approximately twice the number of currently available movable tanks in the holy mosque. Each sensor sends one message, including the SIM number representing the tank identifier and one byte representing the water level status in the tank. So, the total number of sent bytes in each message is approximately 5 bytes every minute. Practically wise, the bytes sent are less than the simulated bytes. So, the messages sent by each sensor are about 0.016 bytes/ Second. Therefore, the total number of bytes sent every second equals about 833 bytes. In the simulation, different values of the service rate μ are simulated. Practically wise, the value of μ is very large due to cloud capabilities. The simulated number of arrivals equals 200000 messages for each scenario. The simulated scenarios are 5 scenarios. Table II shows the results of the simulation. Five different values of the service rate μ are tested, ranging from 900 upto 5000, representing five scenarios. From the table, it is noted that the utilization ρ equals 92% in the worst scenario where the service rate equals 900.

The system is still stable in the worst-case scenario, which represents the least value of μ. However, the utilization is enhanced to about 16% only when the service rate is high. The throughput of the system is about 833 in all cases, which equals the original number of messages sent. This means that there are no message droppings. The waiting time ranges from 0.015 seconds in the worst-case scenario to only 0.00024 seconds in the best scenario simulated. The simulation times of all scenarios are almost the same, which are approximately equal to 240 seconds.

TABLE I SIMULATION PARAMETERS

| Parameter | Value | Calculation Method |
|---|---|---|
| Total number of simulated sensors | 50000 | Input Parameter |
| Messages /sensor | 1 | Input Parameter |
| Message size for each sensor | 5 bytes approximately | Input Parameter |
| Messages sent by each sensor /Sec. | 0.016 | 1/60 |
| Number of messages / Sec. (λ) | 833.33 | 50,000 * (1/60) |
| Service-rate (μ) | Different values | Simulated |
| Number of arrivals for each scenario | 200000 | Input Parameter |
| Numbers of Scenarios Tested | 5 | - |

TABLE II SIMULATION RESULTS

| | Scen. 1 | Scen. 2 | Scen. 3 | Scen. 4 | Scen. 5 |
|---|---|---|---|---|---|
| μ | 900 | 1000 | 1200 | 2000 | 5000 |
| Theoretical Utilization (ρ) | %92 | %83 | %69 | %41 | %16 |
| Theoretical throughput | 833.33 | 833.33 | 833.33 | 833.33 | 833.33 |
| Waiting time (W) | 0.015 | 0.006 | 0.002 | 0.0008 | 0.00024 |
| Simulated throughput | 833.00 | 832.82 | 829.80 | 834.94 | 832.84 |
| Simulated utilization | %92 | %83 | %68 | %41 | %16 |
| Simulation time in seconds | 240 | 240 | 241 | 239 | 240 |

As expected, the waiting time and queue length decrease significantly as μ increases. Fig. 5 shows the relationship between utilization and service rate. The horizontal axis represents the service rate. The vertical axis represents utilization. From the figure, when the service rate is low, i.e., μ is approximately equal to 700, in this case, the system is fully utilized. However, this case rarely occurred because of the huge capabilities of the cloud. The system utilization decreased gradually as the service rate increased. If the service rate is more than 30000, for example, the system is almost empty of packets. This is the ideal case. Practically wise, the system utilization is about 20 to 30 % which is very good.

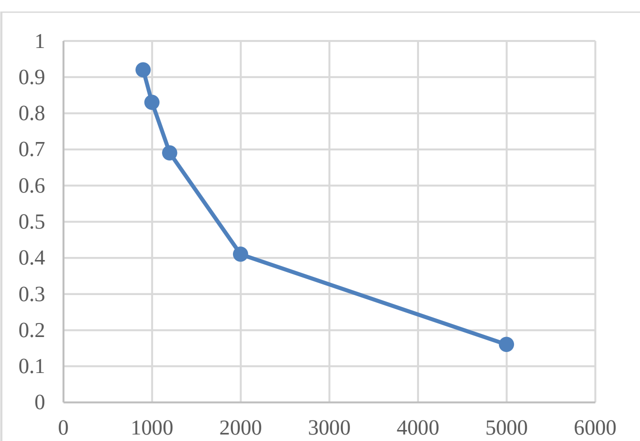


Fig. 5. Utilization vs. Service rate.

Moreover, the results of the performed simulations almost coincide with the theoretical M/M/1 model results. Fig. 6 compares the computed utilization with the simulated utilization. It is clear from the figure that the two curves are approximately coincident with each other. This figure indicates that the simulation performance is almost the real performance of the system.

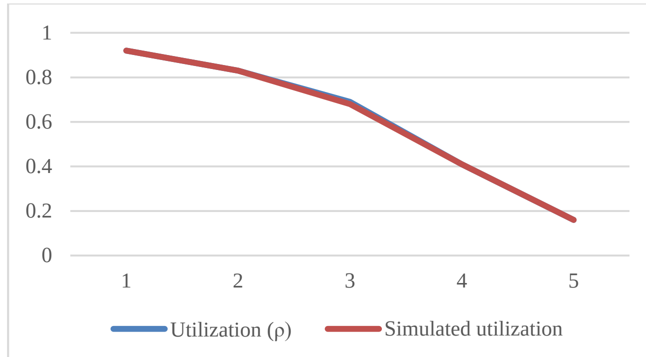


Fig. 6. Theoretical utilization vs. Simulated utilization.

Fig. 7 shows the simulated throughput of the system compared to the theoretical one. From the figure, it is noted that, in some cases, the two curves coincide with each other.

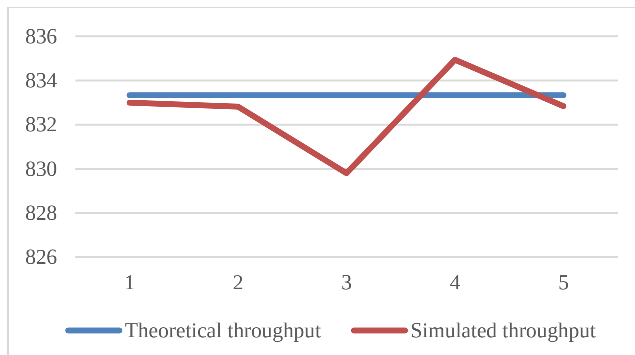


Fig. 7. Theoretical throughput vs. Simulated throughput.

In another case, there are small differences between the two curves. For example, the simulated throughput equals 830 while the theoretical throughput equals 833. That is the difference between them equals 3, which represents about 0.003, which is a small difference. So, the conclusion is that the throughput of the system represents over 99% indicating that delay and transmission errors are minimal.

## *B. Discussion*

The proposed system uses non-contact strain gauge sensors that read the weight of the tank. This type of sensor is suitable for handling Zamzam tanks by operators, and it is more convenient. Also, the sensors are protected during tank cleaning and other hygiene routines. The non-contact sensors prevent physical and chemical contamination of Zamzam water inside the tanks. The power required for operating these sensors can be obtained from small solar panels. We propose a modified base of the tank that contains the sensors, battery, SIM module, and microcontroller. These components are isolated from the tanks and are isolated from the water for protection. Moreover, the data sent is very small that can save battery and decrease the bandwidth required. Cloud's huge capabilities and cellular network capabilities allow adding more Zamzam tanks, with sensors, to the system. So, the system is scalable. The cellular networks have excellent coverage in the holy mosque that do not need any extra configuration. Also, the proposed system satisfies the tradeoff between network crowding and fast refilling actions. Therefore, the system is efficient in the case of crowded seasons of the holy mosque. Usage of both mobile application and indoor map guides the holy mosque visitors to the nearby filled Zamzam tanks which provide more convenience, decreasing efforts, and saving time. Also, the proposed modified Zamzam unit, with filling status signs, facilitate recognizing of the filled tanks throughout the holy mosque without using mobile application by visitors. This may be considered as a backup strategy for visitors, to guide them to the nearby filled tanks. Occasionally, the signs may be controlled either by the cloud or through the microcontroller connected to them. This also provides fast responses and a backup in case of failure. For Zamzam operators, the proposed system prompts operators immediately to fill empty tanks through their mobile application connected to the cloud. The holy mosque administrators benefit from the system in monitoring tank status, make necessary actions, performing data analytics, and performing machine learning tasks for prediction and forecasting. A dashboard is provided through the system for real-time monitoring and decision-making. This helps in deciding strategic decisions in the future. The proposed system ensures that Zamzam water, in the holy mosque, is managed with highest levels of efficiency and reliability. However, awareness and training among all stakeholders is required to adopt the proposed system.

## VI. Conclusion

In this study, we propose an integrated IoT system for Zamzam tanks monitoring and control. The proposed system consists of many subsystems including sensors, microcontrollers, communication, cloud computing, and actuators. The proposed system provides real-time monitoring and control of the water level inside movable Zamzam tanks. The proposed system provides many benefits for all stakeholders including the holy mosque administration, Zamzam operators, and the visitors of the holy mosque. The proposed cloud services include data analytics, control signals, and future prediction. Mobile applications are also proposed that are controlled from the cloud for both visitors and operators. Zamzam tank base is also modified to add sensor circuit. Besides, Zamzam unit is also modified to include color guides for visitors. Simulation results show that the proposed system is efficient in delay, throughput, and many other performance metrics. The proposed system is very useful especially in crowded seasons, when the visitors of the holy mosque are millions of people, especially in Hajj and Umrah seasons. Moreover, the system is compatible with the Saudi Vision 2030 that include modernization and digitalization of services and targeting 30 million Umrah performers by the year 2030. Future work include expanding the proposed system to include all fixed and movable Zamzam units in the holy mosque.

## Acknowledgment

This work was funded by the University of Jeddah, Jeddah, Saudi Arabia, under Grant No. (UJ-22-DR-53). The authors, therefore, acknowledge with thanks the University of Jeddah for its technical and financial support.

## References

[1] Rahman J, Thu M, Arshad N, and Van der Putten M, "Mass Gatherings and Public Health: Case Studies from the Hajj to Mecca", Ann Glob Health. 83(2), 2017, pp.:386-393, doi: 10.1016/j.aogh.2016.12.001. PMID: 28619416; PMCID: PMC7104005.

[2] Emad Ahmed Fathy Hussein, Ahmed A. Rawwash, Amr Moustafa Yehia Mohammed, Mohamed F.F. Bayomy, Shahira Hassan Ibrahim Negm, Amber Mushtaq, Tabish Ishaq Shaikh, Rani Parveen, "The Chemical Composition, Therapeutic Benefits, and Safety of Zamzam Water: A Systematic Review", European Journal of Ecology, Biology and Agriculture, Vol. 2, No. 2, (2025).

[3] Anissa Zergui, Muhammad Aledeh, Salah Hamad, "Metallic profile of Zamzam water: Determination of minerals, metals and metalloids by ICP-MS", Journal of Trace Elements and Minerals, Vol. 2, December 2022.

[4] Joune Li, Sisi Zlatanova, J. Torres-Sospedra, A. Perez-Navarro, and Christos Laoudias, Adriano Moreira, "Survey on Indoor Map Standards and Formats", International Conference on Indoor Positioning and Indoor Navigation (IPIN), Pisa, Italy, 2019.

[5] Mohamed, T.M., Alharbi, A., Alhassan, I., Kholeif, S, "Applications of Industry 4.0 on Saudi Supply Chain Management: Technologies, Opportunities, and Challenges", In Machine Learning and Data Analytics for Solving Business Problems", Book Chapter, Springer, 2022, Cham. https://doi.org/10.1007/978-3-031-18483-3_10.

[6] Jaskó, S. and Ruppert, T., " The Future of Manufacturing and Industry 4.0", Applied Sciences, 15(9), 4655, 2025, https://doi.org/10.3390/app15094655.

[7] Petri Helo and Vinh V. Thai, "Logistics 4.0 – digital transformation with smart connected tracking and tracing devices", International Journal of Production Economics, Vol. 275, 2024.

[8] Princy Sharma, "Internet of Things (IoT): Study of Arduino and Raspberry Pie and their Applications in Various Domains", International Journal of Research Publication and Reviews, Vol. 4, no 9, pp 2468-2477, September 2023.

[9] Milan Milenkovic, "Internet of Things: Concepts and System Design", Textbook, Springer, 2020.

[10] Mariem Mrad and Mohamed Amine Frikha, "Robust Control of Cyber-Physical Teleoperation Systems for Synchronized Healthcare Supply Chain Management ", International Journal of Advanced Computer Science and Applications (IJACSA), Vol. 16, Issue 9, 2025, DOI: 10.14569/IJACSA.2025.0160964.

[11] R. Tharwin Kumar, R. K. Padmashini, R. Ramani, B. Varsha, S. Ragul, J. Daniel Sathyaraj, "IoT Based Smart Irrigation Tracking and Management System Using Arduino UNO Microcontroller", International Journal of Advanced Trends in Engineering and Management (IJATEM), Vol. 2(08), August 2023, pp. 34-43.

[12] M Senthil Vadivu, M Purushotham Reddy, Kantilal Rane, Narendra Kumar, A Karthikayen and Nitesh Behare, "An IoT-Based System for Managing and Monitoring Smart Irrigation through Mobile Integration", Journal of Machine and Computing, 3(3), 2023.

[13] Jan, F., Min-Allah, N., Saeed, S., Iqbal, S. Z., and Ahmed, R, "IoT-Based Solutions to Monitor Water Level, Leakage, and Motor Control for Smart Water Tanks", Water, 14(3), 2022. https://doi.org/10.3390/w14030309.

[14] Wong, L., Deo, R., Rathnayaka, S., Shannon, B., Zhang, C., Chiu, W. K., Kodikara, J., & Widyastuti, H., "Leak Detection in Water Pipes Using Submersible Optical Optic-Based Pressure Sensor", Sensors, 18(12), 4192, 2018, https://doi.org/10.3390/s18124192

[15] S. Behrad, S. Tuffin, E. Bertin and N. Crespi, "Network Access Control for the IoT: A Comparison Between Cellular, Wi-Fi and LoRaWAN", 22nd Conference on Innovation in Clouds, Internet and Networks and Workshops (ICIN), Paris, France, 2019, pp. 195-200, doi: 10.1109/ICIN.2019.8685884.

[16] Ahmad Alkhatib, Ameen Shaheen, and Rand N Albustanji, "A Comparative Analysis of Cloud Computing Services: AWS, Azure, and GCP", International Journal of Computing and Digital Systems 18(1), April 2025, pp. 1-15, DOI:10.12785/ijcds/1571111846.

[17] Md. Mustaqim Roshid, Abdul Waaje, Tamanna Nusrat Meem, and Apurba Sarkar, "Logistics 4.0: A Comprehensive Literature Review of Technological Integration, Challenges, and Future Prospects of Implementation of Industry 4.0 Technologies", The International Journal of Technology Knowledge and Society, 20(1) May 2024, pp. 65-85, DOI:10.18848/1832-3669/CGP/v20i01/65-85.

[18] J. Li, R. Qin, C. Olaverri-Monreal, R. Prodan and F. -Y. Wang, "Logistics 5.0: From Intelligent Networks to Sustainable Ecosystems" in IEEE Transactions on Intelligent Vehicles, vol. 8, no. 7, pp. 3771-3774, July 2023, doi: 10.1109/TIV.2023.3295796.

[19] M. Sharma, A. Tomar, and A. Hazra, "Edge Computing for Industry 5.0: Fundamental, Applications, and Research Challenges", in IEEE Internet of Things Journal, vol. 11, no. 11, pp. 19070-19093, 2024, doi: 10.1109/JIOT.2024.3359297.

[20] Rayed AlGhamdi and Sunil Kumar Sharma, "IoT-Based Smart Water Management Systems for Residential Buildings in Saudi Arabia", Processes, 10, 24622022, https://doi.org/10.3390/pr10112462.

[21] S. Parveen, S. M. Nabeel Mustafa, S. Soomro and S. Bano, "Smart Water Level Monitoring System Using Internet of Things (IoT)," 2023 Global Conference on Wireless and Optical Technologies (GCWOT), Malaga, Spain, 2023, pp. 1-7, doi: 10.1109/GCWOT57803.2023.10064661.

[22] Akshay Sharma A S, "Review on IoT based water level sensing and controlling", International Journal of Engineering Research & Technology (IJERT), Vol. 9, Issue 07, July-2020.

[23] Wister, M. A., Leon, E., Alejandro-Carrillo, A., Pancardo, P., & Hernandez-Nolasco, J. A. "Using IoT for Cistern and Water Tank Level Monitoring", Applied System Innovation, 7(6), 2024, https://doi.org/10.3390/asi7060112.

[24] Mahmood A. Al-Shareeda, Ahmed Mohammed Ali, Mustafa Adel Hammoud, Zaid Haider Muhammad Kazem, Muslim Aqeel Hussein, "Secure IoT-Based Real-Time Water Level Monitoring System Using ESP32 for Critical Infrastructure", Journal of Cyber Security and Risk Auditing, Vol. 2025, No.2, 2025.

[25] Moshe Haviv, "Queues A Course in Queueing Theory", International Series in Operations Research and Management Science, ISOR, Springer, Vol. 191, 2013.

[26] Yulu Wang, "Research on the Queuing Theory based on M/M/1 Queuing Model", Highlights in Science Engineering and Technology, pp. 80-87, July 2023, DOI:10.54097/hset.v61i.10276.