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RESEARCH ARTICLE

IoT Implementation in Slaughterhouses Supply Chain: A Case Study of the Adahi Experiment in the Kingdom of Saudi Arabia

MOHAMMED ALKAHTANI, BANDAR ALJABRI, ABDULLAH ALSALEH, HUSAM ALGHAMDI, AND OMAR ALJURAIYED

Department of Industrial Engineering, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia

Corresponding author: Bandar Aljabri (bandarsalim@hotmail.com)

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ABSTRACT The Hajj season holds immense significance for Muslims globally, attracting millions of pilgrims annually to engage in sacred rituals. The Kingdom of Saudi Arabia, as the host of this pilgrimage, extends a range of services to facilitate and enhance the pilgrims' experience. Among these services, the provision of sacrificial animals for Udhiyah and Hadi, integral components of Hajj rituals, is crucial and managed by organizations like the Kingdom of Saudi Arabian Project for the Benefit of Udhiyah and Sacrifices (Adahi). Adahi's primary mission is to execute sacrificial rituals on behalf of Hajj pilgrims, ensuring the seamless progression of religious practices. Embracing technological advancements, particularly the Internet of Things (IoT), has become pivotal in enhancing various sectors, including the food supply chain. In Saudi Arabia, Adahi conducts a noteworthy experiment during Hajj, utilizing IoT to count slaughtered cattle in the supply chain. This study seeks to elucidate and assess the role and impact of IoT in Adahi's experiment, proposing a conceptual framework to enhance monitoring, counting, and tracking of slaughtered cattle during Hajj within Adahi slaughterhouses. The study adopts a descriptive methodology, thoroughly reviewing contemporary literature to identify technological gaps in automatically measuring and inspecting post-harvest meat safety during the slaughtering process. The authors recognize the challenge of implementing IoT, specifically Radio-Frequency Identification (RFID), on a large scale, such as Adahi, due to associated infrastructure and chip costs. This study aims to propose a conceptual framework for an IoT-based meat monitoring system within Adahi's slaughterhouses, contributing to technological advancements and ensuring the safety and efficiency of the Hajj sacrificial rituals.

INDEX TERMS Food supply chain, meat safety in slaughterhouses, sensors, IoT, smart devices, machine learning, Hajj.

I. INTRODUCTION

The Hajj season is a significant event for Muslims worldwide, attracting millions of pilgrims to perform sacred rituals annually. Serving thus vast crowds requires a systematic and efficient approach. The Kingdom of Saudi Arabia makes substantial efforts to facilitate pilgrimage procedures, regulate services through system development and technological utilization, enhance the competence of hospitality staff, and improve infrastructure to provide a globally standardized religious hospitality experience. Furthermore, the World Health Organization (WHO) has commended the effectiveness of general health measures implemented by the Saudi Ministry of Health to ensure a safe pilgrimage, including early disease surveillance, infection control, vaccination, risk awareness, and timely response, under international health regulations. This substantial event requires a strong focus on food safety to prevent foodborne illnesses and to preserve public health.

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The government of the Kingdom of Saudi Arabia provides many services to pilgrims to facilitate rituals with ease and convenience. One of these significant services for pilgrims is the provision of sacrificial animals for Udhiyah and Hadi, among the most important Hajj rituals. One of the critical organizations that facilitates the provision of sacrificial animals for pilgrims is the Kingdom of Saudi Arabian Project for the Benefit of Udhiyah and Sacrifices (Adahi) [1]. Adahi is a non-profit organization established by the Government of the Kingdom of Saudi Arabia in 1983, with the Islamic Development Bank (IsDB) entrusted with its implementation and management.

Adahi's primary mission is to facilitate the performance of sacrificial rituals, specifically Hady and Fidya, on behalf of the Hajj pilgrims. Additionally, Adahi conducts Udhia, Sadaqa, and Aqiqa rituals for Muslims interested in observing these practices. The project is dedicated to distributing the resulting meat to impoverished individuals within the Haram Zone and delivering surplus meat to beneficiaries in more than 25 countries.

Adahi operates eight operational units, consisting of three closed units for sheep (Moaisem 1, Moaisem 2, and Moaisem 3), and four open units with different designs than closed units (B, E, D, and H), and one unit for camels and cows. In open units, clients purchase coupons for the desired number of sheep and may either conduct the slaughter themselves or witness it. Subsequently, the Adahi personnel care for all necessary processing, cleaning, freezing, packaging, and distribution tasks. By contrast, clients using the closed slaughterhouses engage in proxy rituals. Specifically, clients purchase their coupons from an outlet, and Adahi carries out the ritual on their behalf, notifying them upon completion if desired, using the provided contact information.

Adahi's facilities have the capacity to accommodate 1.5 million sheep and 10,000 camels and cows. The meat produced is distributed to those in need within the Haram zone, and any excess meat is shipped to eligible beneficiaries in over 27 countries [1].

For massive production within a short period in Hajj, as shown in Table 1 and Figure 1, Adahi needs efficient supply chain management for efficient operations. Supply chain management (SCM) is a crucial field in logistics and operations, encompassing strategic planning, efficient execution, vigilant monitoring, and continuous optimization of all processes related to the acquisition, manufacturing, and distribution of products and services. It aims to streamline the flow of materials, information, and finances across the supply chain, from suppliers to end consumers. Effective SCM ensures cost efficiency, timely delivery, and high-quality products, thereby enhancing competitiveness.

Overall, SCM plays a crucial role in modern business operations by facilitating enhanced customer satisfaction, cost reduction, and agility in an increasingly complex global marketplace.

Stevens [2] defined a supply chain as a "connected series of activities concerned with planning, coordinating, and controlling materials, parts, and finished goods from supplier to customer."

TABLE 1. No. of slaughtered cattle for last thirteen years in Adahi project.

Year	No. of Slaughtered cattle
1444 / 2023	802,554
1443 / 2022	445,554
1442 / 2021	107,397
1441 / 2020	50,110
1440 / 2019	934,093
1439 / 2018	908,000
1438 / 2017	927,480
1437 / 2016	712,734
1436 / 2015	835,282
1435 / 2014	874,000
1434 / 2013	769,918
1433 / 2012	998,141
1432 / 2011	1,001,206
1431 / 2010	934,004

FIGURE 1. Production rate in all Adahi slaughterhouses from 1431 AH to 1443 AH.

Beamon [3] defines SCM as "a set of relationships among suppliers, manufacturers, distributors, and retailers that facilitates the transformation of raw materials into final products."

The Internet of Things (IoT) has emerged as a transformative technology with significant potential for improving various sectors, including the food supply chain. Within the context of the Kingdom of Saudi Arabia, the Project for Utilization of Hady and Adahi (Adahi) conducted a vital experiment during the Hajj season, focusing on counting carcasses in the supply chain.

The Internet of Things (IoT) is a new approach; the first person to come up with the name "Internet of Things" was Kevin Ashton in 1999 [4].

Kevin Ashton is credited with coining the term "the Internet of Things" to delineate the network that links physical-world objects to the Internet [4].

IoT significantly enhances food safety across various stages of the food supply chain. It is clear from the many defamations of IoT that there is no unified definition for the Internet of Things. In the realm of the IoT, the fundamental idea revolves around enhancing everyday objects with the ability to identify, sense, connect, and process information. This empowers these objects to communicate with each other and with other devices and services via the Internet, thereby enabling them to accomplish specific tasks or functions [5].

Advancements in technology, such as IoT, artificial intelligence (AI), and blockchain, have markedly influenced supply chain management, offering fresh prospects to streamline processes and enhance the overall performance of supply chains [6].

The following are the main aims and objectives of this research work:

1. The purpose of this study is to present a comprehensive evaluation of the role, impact, opportunities, challenges, and present status of IoT implementation within the Adahi experiment during the Hajj, specifically concerning the food supply chain.
2. Explaining the supply chain of the slaughterhouse sector in general and Adahi in particular.
3. This study introduces a conceptual approach to enhance the existing supply chain system in Adahi slaughterhouses based on IoT.
   To the best of our knowledge, this study is the first to explore the application of IoT in slaughterhouses in Saudi Arabia and in the broader Gulf region.
4. In this study, consideration has been given to:
   - **Research Question 1:** What IoT technology is implemented in Adahi slaughterhouses, and for what purpose?
   - **Research Question 2:** What is the current improvement in the efficiency of operations by using IOT in Adahi slaughterhouses?
   - **Research Question 3:** What are the opportunities for improvements in the operations of the Adahi project slaughterhouses using IoT?
   - **Research Question 4:** What are the challenges of IoT implementation in Adahi slaughterhouses?

To answers these questions, the authors used preliminary data, including interviews which conducted with personnel attached to this experiment, including executives, operations managers, and contractors. The authors also used secondary sources through articles, studies, papers, books, and references on food and meat safety and the use of IoT in food safety, which will be piloted to acknowledge the global concepts and current practices of IoT applications.

This paper is structured as follows:

Section I introduces the topic and formulates the research questions.

Section II gives the literature revies related to slaughterhouses and using IoT in field of food safety and in Hajj season.

Section III the methodology is discussed in detail.

Section IV in this section the results and data analysis are presented, this section explain the current methods used in Adahi for counting and food safety and also presented the proposed improvements for the Adahi system to enhance the process and ensure food safety and counting.

Section V provides a conclusion that summarizes the outcome of the research.

II. LITERATURE REVIEW

Numerous studies have investigated the application of the IoT technology to enhance food safety. The voluminous nature of this body of literature makes it challenging to narrow down the selection; however, the authors exercised discretion by confining their inquiry to papers that effectively aligned with the research objectives and provided substantive answers to the research questions at hand. The primary databases we consulted is Scopus, web science, and IEEE Xplore. These databases were selected to ensure a broad and thorough exploration of the existing literature related to our research topic. Combination of keywords employed to conduct the search, aiming to capture the various aspects and dimensions of the subject matter. The main keywords used during the literature review include: slaughterhouses, Hajj, slaughter process, food safety, IoT, food supply chain, supply chain, HACCAP, and RFID.

These keywords were carefully chosen to encompass the diverse elements associated with our study.

Despite numerous published papers on the uses of IoT and artificial intelligence in Hajj, they do not address slaughterhouses. For instance, Yasein and Alharthi [7] studied several technological techniques used in tracking and guiding pilgrims during the Hajj and Umrah seasons. The researchers compared different systems—GPS, land-based tracking systems, RFID/ NFC, Bluetooth, Wi-Fi, Scene analysis based on image examination systems, Barcode systems and Hybrid Solutions. The researchers pointed out the possibility of making use of these systems and employing them to serve pilgrims and Umrah performers. Also, A machine learning approach for detecting the crowd congestion in Hajj was proposed by Islam et al. [8]. The proposed system employed three bracelet sensors to collect the required data, including the sensors of temperature, humidity, and accelerometer. The collected data were then used to predict stampede potential using K-Nearest Neighbors and decision tree algorithms.

Various academic papers focused on the application of Internet of Things (IoT) technology within the food industry, specifically concerning food safety, monitoring, and supply chain management. The methodologies employed in these studies range from literature reviews and bibliometric analysis to experimental approaches and qualitative investigations. The papers address a wide array of topics, such as the development of intelligent sensor tags for assessing food freshness, the utilization of biosensors for meat inspection, the implementation of IoT in the Halal food supply chain, and the use of computer-vision systems and hyperspectral imaging for food safety inspection. Additionally, studies delve into the potential of blockchain and IoT technology for food transportation, the development of user-friendly traceability systems for fresh produce, the evaluation of current practices in slaughterhouses, and the use of AI, machine learning, and deep learning in logistics management within industrial companies.

Shambour et al. [9], analyzed technologies and their applications within the Hajj and Umrah systems. The reviewed studies were categorized into four primary branches based on their specific focus areas, encompassing research on the holy mosques and sacred sites, pre-arrival visitor studies, accommodations and service investigations, and studies on transportation and crowd management.

It is worth mentioning that the initial publication on IoT in food safety emerged in 2011, followed by a rapid surge in the number of articles, peaking in 2016 [10], [11].

Since our paper is focuses in enhancing monitoring, counting, and tracking of slaughtered cattle by using IoT in slaughterhouses process, we will explore the literatures that related to this scope.

Bouzembrak et al. [10], conducted literature review, used bibliometric networks to analyze 48 articles to investigate IoT technological solutions within the food sector pertaining to food safety, while Fadillah et al. [12], introduce a preliminary investigation on IoT within the food monitoring industry utilizing the Business Model Canvas (BMC). Gu et al. [13] concentrate more on Analyze food safety standards, risks, and IoT applications in the food supply chain by using a qualitative approach to identify risks based on Chinese food-related standards, analyzed and mapped risks across the main phases of the food supply chain.

Kim et al. [14], employed an experimental approach by creating a small, intelligent sensor tag for assessing pork freshness. Same thing done by Nastasijevic et al. [15], that investigate the potential enhancement of meat inspection and safety controls through the utilization of biosensors by using a qualitative approach to investigate the potential of biosensors in meat safety assurance. Rejeb et al. [16], utilized a qualitative methodology and conducted an analysis of papers through bibliometric methods and comprehensive content analysis to explored IoT implementation in the Halal Food Supply Chain, revealing five key advantages: improved traceability, enhanced supply chain efficiency, optimized livestock management, halal status authentication, and continuous certification monitoring.

Liu [17] suggests an IoT-assisted, bio-inspired framework for logistics and supply chain management, while Iglesia et al. [18] propose a computer-vision system for real-time beef carcass classification, integrating it with a sensitization system. Connaughton et al. [19] use dual-energy X-ray absorptiometry (DEXA) for carcass composition prediction. Sawant et al. [20] employed an experimental approach to summarize the application of hyperspectral imaging in food safety inspection Wahyuni et al. [21] focus on recognizing activities and risks in the red meat supply chain in three slaughterhouses in some areas in Indonesia, identifying distinct activities, potential risk events, and associated risk agents. They emphasize analyzing contamination risks that could hinder the slaughtering process of cattle, such as less cleaned floors after slaughtering and heightened consumer demand. Additionally, Mattoli et al. [22] outline the creation and evaluation of a Flexible Tag Datalogger (FTD) for improving logistics in food and good. Masferrer et al. [23], Contrast manual and automated pig carcass classification accuracy. The study compared manual assessments with automated Support Vector Machine algorithms, revealing higher accuracy in automated classification (75.3%).

Tragas and Manolakos [24] concentrate on developing an RFID-based traceability system in the food supply chain. Significant benefits include extensive information storage, but challenges arise, especially with low-margin products Kaur et al. [25] investigate the use of blockchain and IoT technology for food transportation.

Affia et al. [26] performed a methodical examination of peer-reviewed journal articles through a systematic literature review to explore elements influencing the integration of IoT in supply chain management while Tagarakis et al. [27] Propose the design of a user-friendly traceability system for fresh produce.

Methodology: Proposed the design of a traceability system named AgroTRACE.

Regarding implementation of HACCAP system in slaughterhouses in Saudi Arabia El Tawila et al. [28] evaluate current practices at the Jeddah Northern slaughterhouse and explore methods for its improvement by implementing the HACCP system.

Hasanah et al. [29], develop a system to notify slaughterhouses of food safety hazards. McEvoy et al. [30] conducted a study on microbial counts in Australian sheep meat. The methodology employed an analytical-descriptive approach. Pearce et al. [31] identified critical areas in slaughterhouses, focusing on Salmonella contamination and its impact on carcasses. The methodology involved an analytical-descriptive approach.

Woschank et al. [32] used analytical-descriptive approach to analyzed literature focusing on the use of artificial intelligence, machine learning, and deep learning in the context of efficient logistics management in industrial companies.

III. METHODOLOGY

This study provides an in-depth exploration of the implementation and impact of IoT technology to enhance slaughterhouses supply chain in general and during the Hajj season in Adahi slaughterhouses.

The authors used descriptive/ qualitative methodology by reviewing of papers, studies, and references related to cattle slaughter supply chain, with gathering preliminary data through interviews which conducted with personnel attached to this experiment. These interviews were conducted with the Deputy Supervisor General of Operation Affairs at Adahi, who elucidated the slaughterhouse's current operational system and the integration of IoT technology into this system, and an interview was also conducted with Adahi IT and Adahi vendors. This comparative analysis seeks to highlight the unique aspects and technology implemented by Adahi in relation to similar initiatives and the recent literature. The descriptive/ qualitative methodology aimed to explore the uses of the IoT to achieve the two goals that Adahi seeks to clarify and achieve, which are:

1. **Meeting Pilgrims' Demands:** The accurate counting of slaughtered cattle holds immense religious and financial significance. The Adahi project focuses on the 84-hour slaughter window during the Hajj season, from 7 AM on the 10th day of Dhul-Hijjah to 12 PM on the 13th day of Dhul-Hijjah This enables pilgrims to procure coupons and entrust the project with the responsibility of conducting sacrifices on their behalf within the religious time window. It also serves as a crucial financial accountability measure for contractors responsible for sheep and labor during the slaughter operation.
2. **Ensuring Meat Safety Standards**: Ensuring meat safety during and after slaughter is paramount, given its subsequent distribution to those in need.

As seen in Figure 2, the authors adopted the Hazard Analysis and Critical Control Point (HACCP) system as a guiding framework to achieve the second crucial objective which is ensuring meat safety during the slaughterhouses supply chain process. Using HACCP is to evaluate how Adahi harnessed IoT to identify and mitigate hazards at critical control points within its processes.

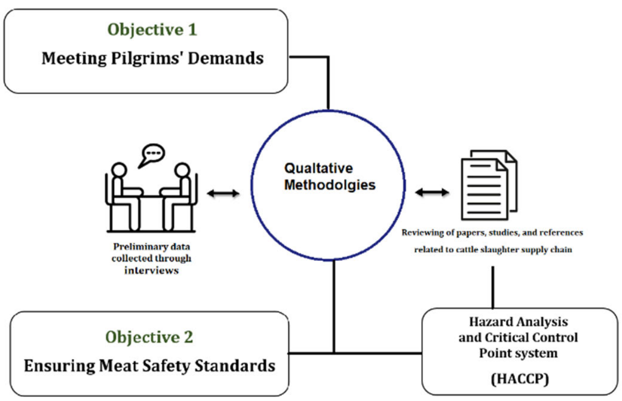

FIGURE 2. Qualitative methodologies used in this study.

The supply chain of the slaughterhouse sector has been explained, and an efforts haves been made to ascertain the factors affecting the sector's supply chain.

In addition to evaluating the current state of IoT deployment in Adahi, this study proposes a conceptual framework for implementing an IoT-based meat monitoring system within Adahi's slaughterhouses.

IV. RESULTS AND DATA ANALYSIS

This section provides the data analysis and results.

A. CURRENT METHODS USED IN ADAHI FOR COUNTING

In previous years (before (2023), Adahi usually hired more than 20 people in each slaughterhouse in every Hajj season to count slaughtered cattle by the naked eye. This method of counting usually leads to counting errors reaching 15%, and the Adahi management can only confirm the accurate number of slaughtered cattle once they finish cutting after Hajj.

Counting objects with the naked eye or without using any technical tool can have some difficulties or challenges, that depend on the context and the surrounding factors. The common problems encountered when attempting to count objects with the naked eye are as follows:

- Rapid Counting: Achieving accuracy when counting quickly can be challenging and may result in errors.
- Scattering and Divergence: Confusion and divergence may occur when trying to count a large number of objects simultaneously, making it difficult to determine the total count.
- Visual Interference: Visual interference, such as bright lights or scattered colors, can make counting difficult.
- Variability in sizes and Shapes: Counting can become more complex when objects vary significantly in size and shape.
- Fatigue and Distraction: Counting for an extended period or feeling fatigued can affect the accuracy of the count.
- Mental Distraction: Thinking about other matters or being mentally preoccupied can lead to counting errors.

To overcome this issue, Adahi used two advanced techniques for two types of slaughterhouses (See Figure 3) to accurately count slaughtered cattle in the 2023 Hajj season:

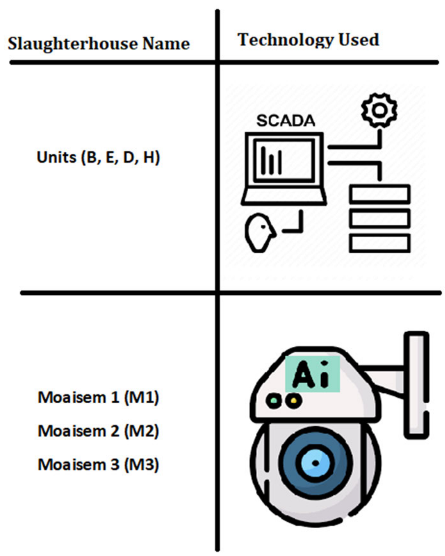

FIGURE 3. Components of a counting system by machine learning in Adahi.

The first technique used for counting slaughtered cattle in slaughterhouses (Moaisem 1 (M1), Moaisem 2 (M2), and Moaisem 3 (M3)), was **machine learning**.

Artificial intelligence (AI) a field encompassing the development of intelligent machines, primarily focusing on the creation of intelligent computer programs [33]. Machine learning (ML), an integral component of AI, involves automated identification of significant patterns within datasets. ML tools aim to enhance algorithm efficiency by enabling learning and adaptation based on extensive data analytics [34]. Furthermore, deep learning (DL), a subset of ML within AI technologies, delves into multiple layers of non-linear information processing. It facilitates supervised and/or unsupervised feature extraction and transformation, along with pattern analyses and classification [35], [36].

This method was used for the first time in the 1444 AH-2023 Hajj season. Figure 4 shows the components of the system. Adahi developed a one-stage AI system for counting that uses trained AI cameras to recognize and count sacrifices. In this system, they used a geometry recognition algorithm, and they sued 2000 sacrifices per camera to train the system to recognize slaughtered cattle. There are two dashboards in this system: the local dashboard at the slaughterhouse and the central dashboard at the Adahi management control room. The dashboard shows the following:

1) Number of slaughtered sacrifices. 2) Number of arrivals (waiting) sacrifices. 3) Estimated time to finish.

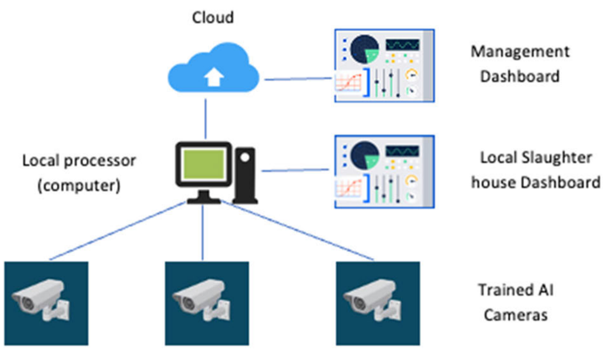

FIGURE 4. Components of a counting system by machine learning in Adahi.

In this algorithm, the system is equipped with specific dimensions for slaughtered cattle, as illustrated in Figure 5. If the dimensions of the slaughtered cattle passing in front of the camera match the dimensions on which the system has been trained, the system will count only one slaughtered cattle. After continuous training, the models were directly connected to the video recording device to analyze the extracted images and provide the required analyses, such as object recognitions, objects counting, and objects classification. The extracted analyses are then linked to the data dashboard to be presented in a simplified and easy-to-understand manner. They coded the algorithm in a Python program to detect objects by geometry using the OpenCV library. This program will detect objects in the image (image.jpg) and draw bounding boxes around them. Objects are detected based on their geometry, i.e., the number of sides of their bounding polygons.

The program can be modified to detect more complex objects by using more sophisticated geometric features. Using this system, Adahi benefited from the following:

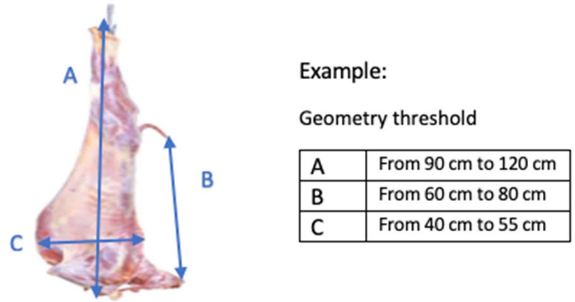

FIGURE 5. Geometry recognition algorithm.

1. Errors, Previously, during manual counting, the error rate averaged 10%, and sometimes reached 15%. After implementing artificial intelligence in this experiment, the error rate decreased significantly, as shown in the Table 2.

TABLE 2. The errors percentage in each slaughterhouse that implemented the machine learning method for counting slaughtered cattle.

Slaughterhouse Name	No. of slaughtered cattle in Hajj season 1444 AH – 2023	Error
Moaisem 1	251,467	0.76 %
Moaisem 2	85,128	0
Moaisem 3	84,901	0

The error percentage in counting was calculated by comparing the numbers counted by artificial intelligence system during Hajj season to the actual numbers of slaughtered animals that were cut and placed in cartons after the Hajj season in preparation for distribution.

2. Cost saving by salaries and other expenses (such as food and transportation) that are related to people who usually count slaughtered cattle by naked eyes.

Get real-time data on the number of slaughtered cattle.

The second technique used for counting slaughtered cattle in slaughterhouses B, E, D, and H, is Supervisory Control and Data Acquisition system **(SCADA)**; which used for weight sensing of targeted objects.

SCADA is a software package primarily designed for supervisory-level control and data acquisition. It operates in collaboration with hardware components, typically interfacing with Programmable Logic Controllers (PLCs) and other commercial hardware modules [37].

SCADA systems are widely used to overseeing and manage equipment in industries such as telecommunications, water and waste control, energy, oil and gas refining, and transportation, particularly in geographically dispersed systems [38].

Originally, the core emphasis of an SCADA system was to ensure precise and efficient process execution within a singular setting, such as a manufacturing plant, rather than prioritizing the security of network information [39].

SCADA provides real-time production data to management, implements advanced control methods for increased efficiency, enhances safety for both plant operations and personnel, and reduces operational costs [40].

SCADA can automatically turn equipment on and off through software control or remote human interface devices. It monitors parameters such as temperature, pressure, flow rate, and triggers alarms based on the collected and observed data. Remote access to SCADA can be facilitated through a web-based interface or specialized software on networked machines. A typical depiction of the SCADA system is shown in Figure 6 [41].

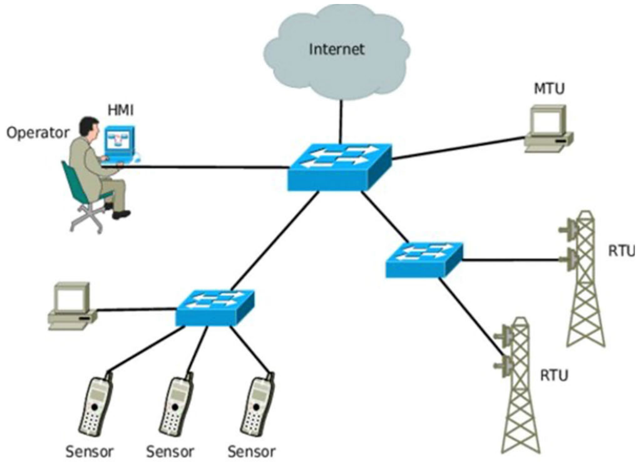

FIGURE 6. Typical SCADA system.

Adahi used the SCADA system to automatically count and weigh cattle slaughtered in modern slaughterhouse units (B, E, D, and H).

Each unit within the modern slaughterhouse (B, E, D, and H) has an integrated SCADA system specifically designed, implemented, and installed. This system is intended to calculate and maintain a database of the actual numbers and weights of livestock at each point and line, with real-time displays of the executed numbers and on-demand report generation. The system was developed using a livestock weighing method involving the installation of weight cells and all necessary equipment.

The SCADA system is operated from the main control room in each slaughterhouse, and integrated with the current weighing system. The system is configured to display executed numbers and weights from all units over the internet for viewing and monitoring purposes, which are accessible only by authorized personnel via computer or mobile devices. Additionally, surveillance cameras were added to monitor the system's operation, allowing for the observation of livestock entry into the automated counting and weighing stations, with live feeds displayed in the main control room.

The system operates automatically, significantly reducing the margin of error (almost zero) and minimizing human intervention. System monitoring is easily accomplished through the SCADA system interface, and reports can be generated at any time for each point and line, with data stored automatically and accessible as needed and, sorted by date and time.

The system has been linked to an electronic cloud (CLOUD) for direct, real-time number and weight displays (LIVE).

For counting, a weight sensor was installed to read the weight of the slaughtered cattle. When the slaughtered cattle pass over the sensor and the weight falls within a range of one to ten kilograms, the system counts it as one slaughtered cattle, and so on. Figure 7 shows components of the SCADA system in units (B, E, D, and H).

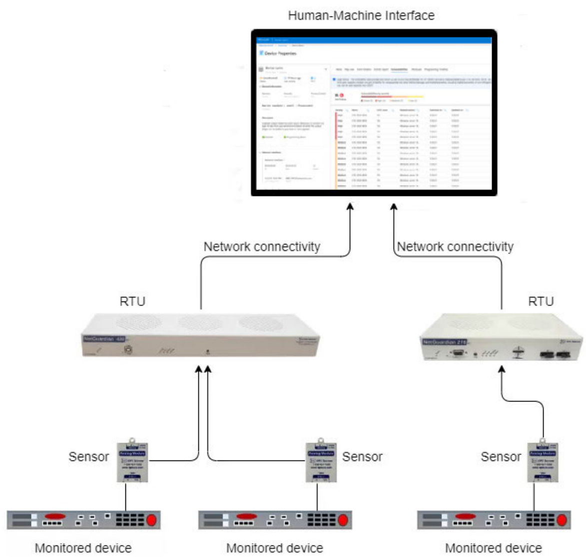

FIGURE 7. Components of the SCADA system in Units (B, D, E, and H) in Adahi.

B. CURRENT METHODS USED IN ADAHI FOR MEAT SAFETY

The meat supply chain encompasses numerous stakeholders, leading to safety concerns regarding meat [42]. As a result, it becomes imperative to exert control at every stage of the chain, commencing from the farm of origin, the transportation of animals before and after slaughter, handling, and the storage of meat and its products up to the point of consumption [46].

For meat safety, Adahi uses the SCADA system to control and monitor refrigerators in all slaughterhouses 24/7.

Adahi also used automatic washing to clean the slaughtered cattle, and after washing, Adahi appointed one person for manual sterilization by a safe bacterial sterilizer chemical to reduce the bacteria levels in the slaughtered cattle.

To check the bacteria levels, Adahi periodically took a sample from slaughtered cattle and checked it during the slaughtering process.

TABLE 3. Key control points, essential limits, supervision, and remedial measures.

Critical Control Point (CCP)	Significant Hazard	Critical Limits	Monitoring				Corrective Action
			Who	Frequency	How	What	
CCP1 Final Cleaning	Not removing microbial contamination from the previous steps	The surface of the slaughtered animal is free from any visible contamination	Washing worker or slaughter monitor	Each slaughtered animal	Visual inspection	Monitoring the washing process and not seeing any visible contamination	– Re-washing
		– Washing water temperature is 82°C	Washing worker or Slaughtering Hall supervisor	Before washing	Temperature measuring device	Water temperature	- Re-washing - Ensuring the calibration of the thermometer and boiler maintenance
CCP2 Cooling	– Inadequate cooling can lead to microbial growth. - Incidental contamination from other carcasses or from the refrigerator walls and floor.	The refrigerator temperature is less than 7°C	Hall Supervisor	Every shift	Temperature measuring device	The refrigerator temperature	– Calibrating or changing the thermometer. – Maintaining refrigeration equipment.

The authors investigate the capability of the current IoT technology to satisfy the requirements of food safety in slaughterhouses.

The authors employed Critical Control Points (CCP), as identified within the HACCP system, to safeguard meat safety at these specific stages. Given that the Adahi slaughterhouses have not implemented the HACCP system, the authors draw upon prior studies conducted in meat processing facilities globally where the HACCP system was applied. A particularly significant investigation within this domain examines the current practices at the Northern Slaughterhouse of Jeddah and explores methods for its development by applying the HACCP system [28], chosen because of its resemblance to the work environment of Adahi slaughterhouses. This assessment scrutinized the technical specifications and hygiene practices at the northern slaughterhouse of Jeddah, with the aim of evaluating microbial contamination across all slaughtering stages. Moreover, it sought to explore the potential for implementing the HACCP system within the slaughterhouse and to identify specific barriers hindering its application. Critical control points were identified using decision tree: the final washing process (CCP1) and cooling step (CCP2). For each critical control point, precise critical limits were established, along with proposed monitoring procedures and corrective actions (Table 3).

Based on the authors' prior knowledge of the slaughtering processes and steps conducted within the sacrificial slaughterhouses belonging to Adahi, it is necessary to add two additional critical points: the third critical control point is the stamping and holding phase. The carcasses may remain in the stamping and holding room for extended period, and if the temperature in the stamping and holding room is not maintained at the required level, it may affect the safety of the carcasses. The fourth critical control point is the cutting of carcasses after the Hajj season and their placement in cartons for distribution to the needy. During this stage, the meat comes into contact with many hands during the cutting process, as well as with the surfaces of the cutting equipment. Therefore, Table 3 was modified to include the third and fourth critical control points (Table 4).

The authors identified risks within the Adahi slaughterhouses using the HACCP concept, aiming to detect hazards and determine critical control points where IoT technology could help eliminate or mitigate these hazards. Understanding the food chain, meat slaughtering systems, hazard analysis, and critical control points (HACCP) is crucial. The primary framework leverages the HACCP to establish a food safety monitoring system and develop food chain information [29]. This food chain information structures the IoT model for the food monitoring system and serves as the foundation for the system's infrastructure [29].

Typically, the processes conducted in slaughterhouses are similar, and slaughterhouses affiliated with sacrificial projects are no exception. Govender and Reuben [42] presented a hazard analysis methodology. They formulated a standardized HACCP plan for a theoretical cattle processing abattoir. A suggested hazard analysis approach was employed to evaluate generic risks to determine their significance. Subsequently, critical control points (CCPs) were identified using a CCP decision tree. This process was aimed at enabling a relevant comparison between the HACCP-based CCPs and HMS-based CPs.

(Figure 8) depicts the supply chain a standard meat slaughterhouse. In Adahi, there were seven sheep slaughterhouses and one camel and cow slaughterhouses. All sheep slaughterhouses follow a similar supply chain to any other slaughterhouse, with a minor additional stage of cutting slaughtered cattle after the Hajj season (Figure 9) and (Figure 10).

The work in the Adahi slaughterhouses has a unique nature, as their slaughter rate is high per hour in one slaughterhouse, and in order to ensure the safety of meat during work, this matter requires finding innovative ways to measure

TABLE 4. Key control points, essential limits, supervision, and remedial measures within the adahi slaughterhouses.

Critical Control Point (CCP)	Significant Hazard	Critical Limits	Monitoring				Corrective Action
			Who	Frequency	How	What	
CCP1 Final Cleaning	Not removing microbial contamination from the previous steps	The surface of the slaughtered animal is free from any visible contamination	Washing worker or slaughter monitor	Each slaughtered animal	Visual inspection	Monitoring the washing process and not seeing any visible contamination	Re-washing
		Washing water temperature is 82°C	Washing worker or Slaughtering Hall supervisor	Before washing	Temperature measuring device	Water temperature	• Re-washing • Ensuring the calibration of the thermometer and boiler maintenance
CCP2 Cooling	Poor cooling can lead to microbial growth incidental contamination from food or refrigerator walls or surfaces	Refregerator Temperature is less than 7° C	Slaughtering Hall supervisor	Every shift	Temperature measuring device	Refregerator Temperature	• Maintening refreagrators • calibration of the thermometer devices
CCP3 Stamping and holding	Inadequate cooling can lead to microbial grwth incidental Incidental contamination from other carcasses or from the refrigerator walls and floor.contamination from food or refrigerator walls or surfaces	• Refregerator Temperature is more than 18° C • The duration of staying in the room must not exceed 3 hours	stamping and holding room supervisor	Every shift	Temperature and humidity measuring device	Burial Hall Temperature	• Maintening burial hall aircondationing sysytem • calibration of the thermometer devices
CCP4 Cutting and packing	Failure to sterilize equipment used and workers not following personal hygiene instructions can lead to microbial grwth	The surface of the slaughtered animal is free from any visible contamination	Cutting Hall supervisor	Every shift	Visual inspection	• Ensure sterilizing of equipment used. • ensure workers following personal hygiene instructions	• sterilizing of equipment used • ensure workers following personal hygiene instructions

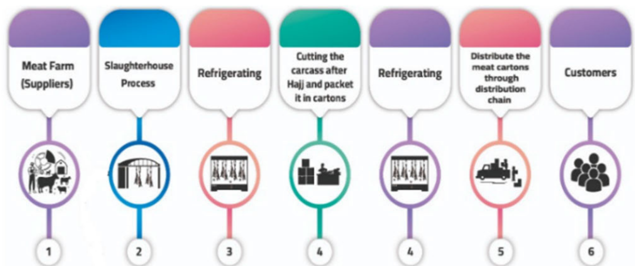

FIGURE 8. Normal slaughtering supply chain.

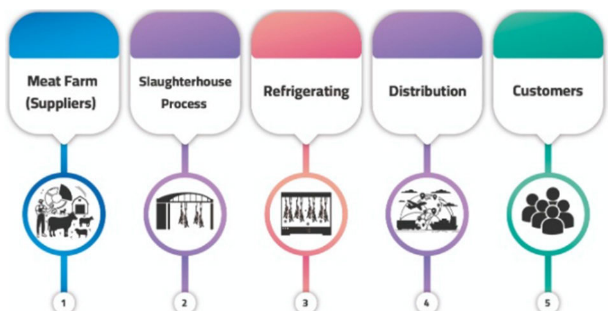

FIGURE 9. Adahi slaughtering supply chain.

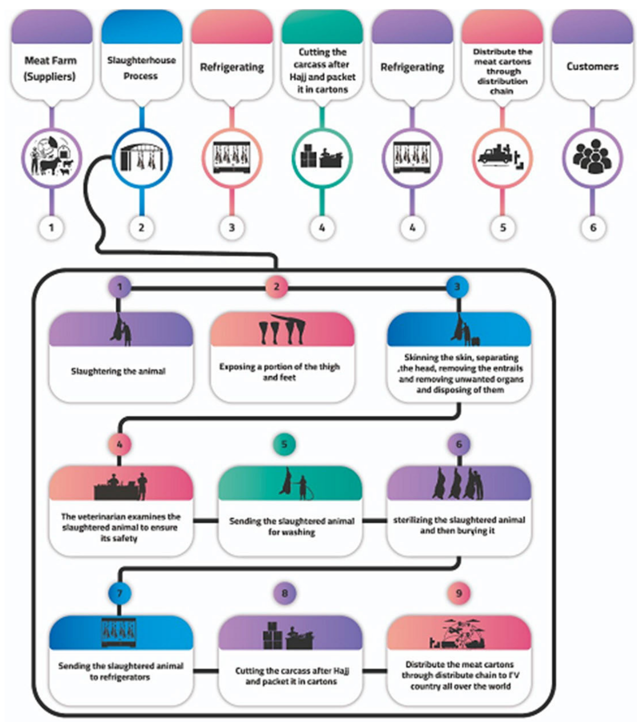

FIGURE 10. Adahi slaughtering supply chain & slaughterhouses process.

the safety of meat during work very quickly, as there is no time to obtain a sample of meat and examine it in the laboratory.

Many previous studies have shown that contamination of fresh meat often occurs after slaughtering and bleeding, especially during skinning and evisceration. Animal skin is considered one of the primary sources for transferring various types of microbes to meat. Additionally, sick animals, errors in the evisceration process, contact of meat with the ground or slaughterhouse walls, refrigeration failure, mishandling, and storage at inappropriate temperatures are among the main causes for microbial contamination that can lead to human poisoning [28].

For CCP1(washing):

A. A sensor was installed to slaughter cattle. When the slaughtered cattle passed the beam of the sensor, the washing nuzzle automatically starts to work for a certain period, after which, it was automatically closed (Figure 11). There is no automatic monitoring for this operation; in the event of a sensor failure, no one knows,

FIGURE 11. Washing area in Adahi slaughterhouses (the picture was taken by the researchers).

and there is a large opportunity for some of the slaughtered cattle to pass without washing.

A. After the automatic washing area, Adahi appointed one person for manual sterilization using a safe bacterial sterilizer chemical to reduce bacteria levels in slaughtered cattle.

For CCP2 (cooling), the SCADA system was used to monitor and control all refrigerators inside the slaughterhouse, and this system was efficient for such a job.

For CCP3 (stamping and holding room, there is no monitoring of the stamping and holding room temperature or humidity.

For CCP4 (cutting and packing):

A. The only precaution is sterilization of the equipment used for cutting by a safe bacterial sterilizer chemical to reduce the bacteria levels in slaughtered cattle.
B. There is no tracking for the carton shipped to the final customer.

V. PROPOSED IMPROVEMENTS FOR THE ADAHI SYSTEM TO ENHANCE THE PROCESS AND ENSURE FOOD SAFETY AND COUNTING

An Internet of Things (IoT) system was designed to serve the main goals of the Adahi project based on the two primary objectives of the project, which is **meeting Pilgrims' demands and ensuring meat safety standards**

A. PROPOSED IMPROVEMENTS FOR MEETING PILGRIMS' DEMANDS

The objective is to ensure the accuracy of counting; what Adahi is doing is somewhat insufficient; it focuses only on counting and does not include tracking or utilizing the technology more effectively. For this reason, we recommend to use RFID technology.

- **First proposed improvement: RFID**

Other techniques can be used simultaneously or substitute the current AI system for counting, tracking, is uses RFID technology. Incorporating RFID technology can significantly enhance a project's ability to ensure the accuracy of counting and tracking sacrificial animals simultaneously, ultimately improving the overall efficiency and quality of the process. Folinas et al. [43] emphasized that the effectiveness of a traceability system depend on its capacity to trace and track each product and logistics unit, facilitating continuous monitoring from the initial production through to the final disposal by the consumer. A key component of the IoT is Radio-Frequency Identification (RFID) technology, which enables remote data storage and retrieval through electronic tags without the need for physical contact. This feature allows the ongoing monitoring and tracking of objects following their identification. An essential advantage of RFID technology is its ability to read tags in challenging conditions, such as snowy, foggy, or harsh environments, with rapid recognition speed [44]. RFID chips can be directly applied to animals after slaughter and before they enter the washing area. Consequently, the system can promptly count and track the animals. The use of RFID technology has several advantages:

1. Time Monitoring: RFID technology effectively contributes to knowing the time animals spend after slaughter to enter the refrigerator. For example, it can track the time spent in the stamping and holding room and the time spent in the corridors before entering the refrigerator. Adahi can benefit from these data to evaluate the efficiency of their operating contractors and ensure that slaughtered cattle do not spend much time in corridors before entering refrigerators, which can lead to spoiling the meat.
2. Accurate Inventory: RFID technology can be used to accurately inventory slaughtered cattle placed in refrigerators. Using RFID to count slaughtered cattle can prevent overloading of refrigerators beyond their capacity, ensuring the effectiveness of the cooling process.
3. RFID technology can prevent meat spoilage by accurately tracking animals after slaughter, which can prevent meat from remaining in unfavorable conditions for extended periods before entering the refrigerator. This reduces the chances of meat spoilage, especially in areas with inappropriate temperature and humidity levels, such as corridors leading to refrigerators or embalming rooms.
4. Tracking of Cut and Packaged meat: RFID can also accurately track slaughtered cattle cut and packaged into carton.
5. Cooperating RFID (Radio-Frequency Identification) tags into the slaughtering process for pilgrims during Hajj can enhance communication and provide real-time updates. Here's a step-by-step explanation:

[1.] Assign RFID Tags to Animals:

- Attach RFID tags to each sacrificial animal. These tags will contain unique identification information associated with the specific animal.

[2.] Link RFID Tags to Pilgrims:

- Connect each RFID tag to the pilgrim who has purchased or sponsored the sacrificial animal. This linkage can be done through a database or an information system.

[3.] Automated Scanning Stations:

- Set up RFID scanning stations at key points in the slaughtering process, such as at the entrance of the slaughterhouse and along the processing line.

[4.] Slaughtering Progress Tracking:

- As the animal progresses through the slaughtering process, RFID tags are scanned at each station, updating the system about the current status of the animal.

[5.] Real-time Updates for Pilgrims:

- Develop a centralized system that communicates with the RFID tags and provides real-time updates to pilgrims. This can be a mobile application, SMS notifications, or an online platform.

[6.] Notification upon Completion:

- Once the slaughtering process is completed, the system triggers notifications to the respective pilgrims, informing them about the status of their sacrificial animal.

[7.] Customized Information for Pilgrims:

- The system can provide detailed information to pilgrims, including the time of slaughtering, the condition of the sacrificial animal, and any additional details they may be interested in.

[8.] Integration with Mobile Apps:

- Create a user-friendly mobile application that pilgrims can install on their smartphones. This app can receive push notifications and display detailed information about the slaughtering progress.

[9.] Security and Privacy Measures:

- Implement robust security measures to ensure the privacy and confidentiality of pilgrims' information associated with the RFID tags. Encryption and secure communication protocols should be employed.

[10.] User Feedback Mechanism:

- Include a feedback mechanism within the application to allow pilgrims to provide comments or ask questions regarding the slaughtering process.
- **Second proposed improvement: Camera training for AI systems**

Adahi has currently trained their AI cameras to recognize only one hanged sacrifice; we recommend going to the next step of developing their AI cameras to be able to:

- Recognize and detect double or tribble hanging sacrifices.
- In addition, it is recommended to train their AI cameras to determine the quality of meat based on the color of the meat.

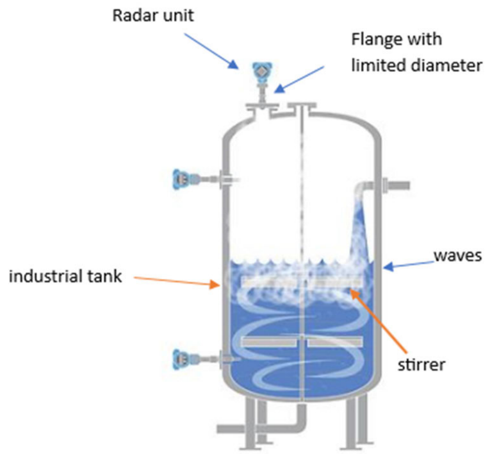

FIGURE 12. How radar level sensors are installed in mixing tanks [45].

B. PROPOSED IMPROVEMENTS FOR ENSURING MEAT SAFETY STANDARDS

As we discussed earlier, we employed Critical Control Points (CCP), as identified within the HACCP system, to safeguard meat safety at these specific stages and we will build our recommendations for meat safety during slaughtering process based on CCP within HACCP recommended system.

- **For CCP1 (washing):** at the washing stage, three steps can be performed to improve the washing process:

First: connect washing nozzles with a sensor to start the washing operation automatically to detect any failure between the sensor and nozzles. In addition, Adahi can install digital pressure sensors at washing pumps and integrate the sensors with the IOT system; which will be programmed to send alert messages through the system, monitoring local and centralized dashboards in case of pressure drop or unused for a specific time, which may be due to mechanical failure or labors stoppage which will enhance the reaction to avoid massive blockage. The IoT system is supposed to start calculating the time from sacrifice slaughter; if it exceeds a certain programmed period, it will send an alert through dashboards to avoid spoilage.

Second: converting manual sterilization to automatic sterilization by creating a special tank for sterilization chemicals and mixing chemicals with water automatically to ensure proper mixing. The level of the mixing tank can be monitored by level radar sensors and integrated with the IoT system, and (Figure 12) shows how radar level sensors are installed in mixing tanks.

Third: **Applying the pH test and integrating it with the IOT system:** A heightened pH level can create an optimal breeding ground for bacteria, thereby increasing the risk of foodborne illnesses [46]. Therefore, it is crucial for the Adahi to regularly monitor meat pH levels and implement appropriate measures to ensure its safety and quality.

A pH test was used to gauge the acidity or alkalinity of the substance. The pH ranged from 0 to 14, with a neutral value of seven. Substances with a pH below seven were categorized as acidic, whereas those above seven were considered alkaline.

To maintaining meat quality, the pH test is extensively used, with the ideal pH range for meat falling between 5.5 and 6.2 [46]. This pH range plays a pivotal role in ensuring that the meat is safe for consumption and exhibits desirable quality traits.

Adahi could consider using digital pH meters to ensure meat quality. These meters or sensors can be programmed and integrated into IoT system. They take readings and send alerts via dashboards if any readings fall beyond the acceptable pH range. Unfortunately, to the best of our knowledge, the only means of measuring pH is manual, and there exists no automated method for measuring pH.

- **For CCP3 (stamping and holding room)**, adding temperature and humidity sensors to measure and monitor the temperature and humidity inside the room can prevent meat from remaining in unfavorable conditions for extended periods before entering the refrigerator. These sensors are continuously monitored by a central system through SCADA or a separate IoT system that alerts the user if the temperature and humidity levels become unsuitable. Prolonged stays of slaughtered cattle in stamping and holding room can cause meat spoilage.
- For CCP4 (cutting and packing):
  - To ensure proper sanitation during the cutting process, the authors suggest employing a sterilization phase post-cutting, achievable using the same machine utilized for packaging the meat in cartons.
  - The authors recommend using the same idea of a Flexible Tag Datalogger proposed by Mattoli et al. [22] and placing the FTD in the cartoon. This compact device combines two sensors (temperature and humidity) with a microcontroller responsible for managing the sensors in an energy-efficient mode. It recorded the measurement ranges in its memory. For data transmission, the device uses infrared communication, offering an alternative to RFID technology. This feature allows the device to communicate with common personal devices such as smartphones or PDAs equipped with integrated infrared ports.

VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION AND RECOMMENDATIONS

Adahi used two advanced techniques for the two types of slaughterhouses to accurately count slaughtered cattle in the 2023 Hajj season; the first technique used for counting slaughtered cattle in slaughterhouses (Moaisem 1 (M1), Moaisem 2 (M2), and Moaisem 3 (M3)), is machine learning. The second technique used for counting slaughtered cattle in slaughterhouses B, E, D, and H is the SCADA system; which use SCADA for weight sensing of the targeted objects. Adahi used the same SCADA system for controlling and monitoring refrigerators system in all slaughterhouses.

The authors identified a need for technological advancements that automatically measure and inspect post-harvest meat safety in the slaughtering process by extracting live samples from the meat.

The authors suggest various systems to improve counting accuracy and ensure meat safety. Despite the high cost associated with RFID technology, it remains one of the most highly recommended systems for use within slaughterhouses. Implementing RFID can significantly enhance a project's capacity to ensure precise counting and tracking of sacrificial animals, ultimately enhancing the overall efficiency and quality of the process.

Furthermore, the authors recognized the challenge of implementing IoT technologies such as RFID on a large scale, such as Adahi, owing to its associated costs in infrastructure and chip costs.

The authors propose an alternative approach by recommending the training of the current AI system to evaluate meat quality based on its color, avoiding the introduction of new IoT technology for quality assessment.

Additionally, the authors suggest transforming manual sterilization into an automated process by establishing a dedicated tank for sterilizing chemicals. This setup automatically mixes sterilization chemicals with water, ensuring precise quantity and proper mixing. The level of the tank can be monitored through radar sensors and integrated with the IoT system.

To avoid meat spoilage during its time in the steaming and holding room, the authors proposed the inclusion of temperature and humidity sensors. These sensors would measure and oversee the conditions within the room, preventing the meat from being exposed to unfavorable conditions for prolonged periods before being transferred to the refrigerator.

To ensure proper sanitation during the cutting process, the authors suggest employing a sterilization phase post-cutting, which is achievable using the same machine utilized for packaging the meat in cartons.

The authors additionally proposed using the same Flexible Tag Datalogger (FTD) placed within the carton during transportation to the final destination, enabling the monitoring of temperature and humidity to ensure that they remain within acceptable levels.

Owing to a lack of time, the research team did not implement the proposed systems to check the validity and enhance the methodology if required.

B. FUTURE RESEARCH

This study was conducted using a qualitative approach. The key findings of this study are compared with those in the existing literature. After discussing the key findings of this study, recommendations for future research are as follows:

- Implementing the developed model in slaughterhouses.
- Compare the benefits of the recommended system and the system expenses (calculating the return on investment (ROI)).

C. VARIOUS CHALLENGES OF IoT ADOPTION IN ADAHI SLAUGHTERHOUSES

1. To the best of our knowledge, we did not find no study has been conducted on implementing IoT to check and inspect meat safety in meat slaughterhouses. There is a lot of IoT technology implemented in slaughterhouses and farms for tracing and tracking, such as RFID. However, there is a shortage of technology that measures and inspects meat safety after harvesting inside slaughterhouses without taking a life sample from the meat.
2. One of the significant challenges in ensuring meat safety is that there is no automatic detection of bacteria or pH levels.
3. Employing RFID technology is expensive; typically, the cost of a single RFID chip amounts to nearly 0.25 USD, not including the expenses for installing the RFID infrastructure within the slaughterhouse. This cost can substantially escalate owing to the high production volume in the Adahi slaughterhouse, adding to the overall expense for each slaughtered animal.

DECLARATION OF INTEREST STATEMENT

We have no conflicts of interest to disclose.

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MOHAMMED ALKAHTANI received the B.Sc. degree in industrial engineering from King Saud University (KSU), Riyadh, Saudi Arabia, the M.Sc. degree in industrial engineering from the University of Central Florida, Orlando, FL, USA, and the Ph.D. degree in manufacturing engineering from Loughborough University, Loughborough, U.K. He was the Chairperson of the Industrial Engineering Department, College of Engineering, KSU, for over four years (2014–2018). He is currently a Professor of industrial engineering and the Vice-Dean of the Advanced Manufacturing Institute, KSU. He has diverse expertise in analysis, modeling, and design of manufacturing systems, supply chain and operations management, responsiveness measurement, and leanness and agility in manufacturing and supply chain.

BANDAR ALJABRI holds a Ph.D. degree in business administration. He is currently pursuing the Ph.D. degree in industrial operation systems and logistics with the Faculty of Engineering, King Saud University, holding a Six Sigma black belt, certified strategic planning professional CSPP, certified Key Performance Indicators Professional C-KPIP®, MBTI®, Strong®. He has done many consultations in these fields during the last 15 years of management, engineering, HR, and organization development consultants. He has extensive and different experience in fields of strategic, organizational development, industrial engineering, and human resources management.

ABDULLAH ALSALEH received the B.Sc. degree in industrial systems engineering from the Faculty of Computer, King Fahd University of Petroleum and Minerals, and the M.Sc. degree in industrial systems from the Faculty of Engineering, King Saud University, where he is currently pursuing the Ph.D. degree in industrial operation systems and logistics. He was a Business Analyst with Tasnee, with a focus on economic and business performance. He completed the Nanodegree Program in business analytics from Udacity and the McKinsey's Forward Program. He was certified on process hazard analysis. He is holding the Executive Leadership and Strategy Program. He was a member of the Saudi Society for Data Science and Supply Chain and Procurement.

HUSAM ALGHAMDI received the bachelor's degree in mechanical engineering from the King Fahd University of Petroleum and Minerals and the master's degree in engineering and systems management from Alfaisal University. He is currently pursuing the Ph.D. degree in industrial engineering with the College of Engineering, King Saud University.

OMAR ALJURAIYED received the bachelor's degree in mechanical engineering from the King Fahd University of Petroleum and Minerals and the master's degree in engineering and systems management from Alfaisal University. He is currently pursuing the Ph.D. degree in industrial engineering with the College of Engineering, King Saud University. He has started his career path as an Operations Engineer with Schlumberger Oil Services Company. He is the Chief Operating Officer with Labab Company/Jarir Group. He has been awarded many professional certifications: PMP, 6 Sigma Master Black-Belt, and Professional Retail Banking.