An Investigation Into the Use of IoTs to Automate the Operation of the NSWMA

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Chapter 1: Introduction

Background

Access to a clean environment stands as an essential necessity for the health and sustainable progress of any community. Consequently, the National Solid Waste Management Authority, commonly known as NSWMA, holds the pivotal role of overseeing solid waste management. This represents a crucial duty for local authorities and acts as a trustworthy indicator of effective governance. As such, proficient waste management plays a pivotal role in enhancing urban living standards by reducing ecological and health hazards while safeguarding valuable resources (Abubakar et al., 2022). According to Das et al., (2019), waste management practices vary according to a nation's economic status and are usually decentralized.

However, an official from the National Solid Waste Management Authority in Jamaica affirmed that the garbage collection adheres to a fixed schedule. This implies that waste and recycling materials are exclusively collected on pre-designated days and times. A group of supervisors manages this operation, allocating trucks to specific areas and gauging the amount of waste to collect based on this schedule. The entire process relies on a conventional paper-based filing system, as no automated system is currently implemented for monitoring garbage collection. Irrespective of the location, it is imperative to emphasize that monitoring waste generation represents a crucial initial step in waste management (Das et al., 2019).

According to Farooq et al. (2020), the ongoing process of urbanization is anticipated to lead to a 70% rise in waste production by 2050, causing global waste output to surge from 2.01 billion tons to 3.4 billion tons. This raises the question: How are local residents dealing with the growing garbage issue in public spaces? Delays in garbage collection can present a significant environmental problem in Jamaica. As our modern economy generates increasingly intricate

waste, it tends to accumulate, resulting in littered streets and posing health risks. As highlighted by Morgan (2023), it is crucial to address these garbage collection challenges swiftly, but the absence of an efficient system for monitoring solid waste presents a substantial hurdle in both rural and urban areas. Moreover, public authorities in developing countries often grapple with these problems due to outdated, unscientific, and ineffective waste management methods (Thompson, 2020). These waste management challenges result from inadequate infrastructure, funding, unclear authority roles, weak regulations, and irregular collection due to resource shortages, notably insufficient garbage trucks (Thompson, 2020).

In light of these challenges, an investigation into the use of IoTs to automate the operation of the NSWMA can be essential to their operation. The rapid growth of the Internet of Things (IoT), which refers to internet-connected devices provide data on various environmental factors, can be attributed to the widespread adoption of advanced hardware and software platforms, increasing network accessibility, and the development of data analysis tools, (Rejeb et al., 2022). IoT technology has the potential to address many of these issues by providing real-time data, enabling remote monitoring, improving resource allocation, and enhancing infrastructure security. According to Aroba et al., (2023), intelligent waste systems such as smart bins can contribute to this effort by harnessing cutting-edge technologies and software, including the Internet of Things (IoT) data analytics and sensors.

In addition, the proposed smart waste bin incorporates ultrasonic and gas sensors to automatically detect hazardous gasses and manage waste levels. It utilizes cloud and mobile app-based monitoring, offering dual functionality: monitoring waste capacity and assessing gas levels. It also communicates data to relevant authorities, leveraging cloud servers for usability, accessibility, and disaster recovery. Each bin has a unique identifier tied to its location, ensuring

comprehensive waste management, (Misra et al., 2018). Furthermore, the sensors will link to a web-based system, enabling the NSWMA to identify critical areas that require their services. This helps optimize resource allocation, preventing unnecessary waste collection trips in areas with minimal garbage.

Problem Statement

The problem of the study is the persistent use of a paper-based/traditional filing system by the National Solid Waste Management Authority (NSWMA) in Jamaica for garbage management, leading to operational inefficiencies.

Purpose Statement

The objective of this research is to explore how IoT can optimize garbage collection processes, reduce operational inefficiencies caused by traditional filing systems, and ultimately improve the overall waste management operations of NSWMA.

Research Questions

1. To what extent are employees of the National Solid Waste Management Authority (NSWMA) knowledgeable about the application of IoTs for waste collection and monitoring?
2. How can the implementation of IoT technologies enhance the waste collection operations of NSWMA?

Significance

This study holds significant importance as it directly addresses the critical issue of operational inefficiencies within the National Solid Waste Management Authority (NSWMA) in Jamaica. By exploring the potential of IoT technology to optimize garbage collection and monitoring, the research aims to provide practical insights and solutions for modernizing waste

management operations. This not only benefits the NSWMA by improving its efficiency but also contributes to more effective waste management practices that can have a positive impact on the environment and public health in Jamaica.

Limitations

A potential limitation of this study is the constrained accessibility to the intended participants. To ensure the study's reliability and avoid incomplete or biased data, employees of the National Solid Waste Management Authority (NSWMA) are required to participate in questionnaires and interviews. However, engaging employees may be challenging, as their work shifts may not provide adequate time for questionnaire completion.

Delimitations

The focus will be on the implementation and practical outcomes of IoT technology in optimizing garbage collection processes, specifically addressing the operational inefficiencies resulting from the use of traditional filing systems. However, this study does not delve into the technical intricacies of IoT technology development, and it does not consider the broader socioeconomic implications associated with its adoption. Furthermore, this research is strictly limited to the National Solid Waste Management Authority (NSWMA), and data collection will exclusively focus on employees within this organization.

Definitions of Key Terms

- Automation: The use of technology to complete tasks instead of processing them manually (Littlewood, 2022).
- Data Analytics: The processing of evaluating and studying data to gain valuable insights (Frankenfield, 2023).

- Innovative IT Solutions. Using new technological concepts or using existing technological concepts in new ways to solve a particular problem (Mertelj, 2019).
- Internet of Things (IoT): A network of interconnected devices that gather, exchange and analyze information to enable real-time monitoring (Burgess, 2018).
- Sensor: A technology that measures or detects some property of the environment or changes to that property over time and converts them into readable signals (Välimäki et al., 2021).
- Smart Bin: A bin that integrates waste containers with smart sensors, which allows you to track through the waste management processes (Ultimate Guide to Smart Bins, 2022).
- Waste Collection: A labor-intensive activity that includes the transfer of solid waste from the point of use and disposal to treatment or landfill (Nathanson, 2023).

Research Methods

The aim of the research is to investigate the use of IoTs to automate the operations of the NSWMA. A descriptive research design integrating quantitative and qualitative methodologies will be used. Quantitative data will be collected to assess waste creation, waste management system efficiency, and effectiveness. Questionnaires will be administered to employees of NSWMA to obtain information. Also, to investigate individual opinions and attitudes about waste management, qualitative data will be collected through interviews. This method will provide a thorough understanding of the use of IoTs to automate the operations of the NSWMA.

Chapter 2: Literature Review

Historical Overview of the Literature's Relevance to the Topic of the Research Paper

The present research focuses on converting a traditional file system into a digital system with the use of Internet of Things (IoT) technology. Global solid waste generation is on the rise, making waste management a pressing environmental challenge. To address this, governments worldwide are turning to IoT technology for efficient smart city solutions (Chaudhari et al., 2018). In Aktay and Yalçın's, (2021) study, they describe assembling IoT sensor nodes, connecting them via long-range wide area network protocols to garbage bins for real-time data collection. This system aims to enhance smart garbage collection in cities, integrating with municipal information systems to promote urban sustainability.

Furthermore, Chaudhari et al. (2018), highlight solid waste as a vital environmental concern that deserves serious attention. IoT technologies prove effective in managing such services within smart cities. In their research, they introduced an IoT-based solid waste management system. This system facilitates the monitoring of garbage bins, dynamic scheduling, and efficient routing of waste collection trucks in smart cities. The system involves equipping garbage bins with cost-effective embedded devices situated throughout the city. Real-time data on garbage levels and bin locations are transmitted to cloud storage platforms, which streamline the waste management process. Additionally, a mobile application is provided for waste collection drivers and the Municipal Corporation to oversee and manage solid waste collection as a service.

Similarly, the National Solid Waste Management Authority (NSWMA) in Jamaica has introduced a mobile application to utilize technology in waste management. The NSWMA emphasized the severe environmental consequences of an inefficient waste management system,

such as diseases, pollution, and biodiversity loss. The app allows reporting public garbage issues, the island's pickup schedule, and recycling tips, (Earth Today | NSWMA Adopts Tech to Tackle Pollution - National Solid Waste Management Authority - Jamaica, 2020).

However, in a study by Zhang et al., (2018), to shift waste management toward a zero-waste circular economy, a new perspective and significant advances are required. The issue of increased waste output threatens sustainable environmental policies. Rethinking present waste management systems and linear economic models, as well as changing behavior, are all required to handle this complicated challenge. Despite the fact that smart technologies offer potential solutions, significant difficulties remain.

Therefore, the implementation of smart waste management systems is in its early stages, presenting a complex challenge involving citizen behavior, design, production, and policy. These systems are relatively new in waste management, with issues like data security limiting their potential. The call for interdisciplinary studies to address waste management comprehensively encompasses various fields. However, current research mainly describes the technology without addressing governmental policies, or management decisions that affect its adoption (Zhang et al., 2018).

In Ghana, studies show that despite numerous solid waste management (SWM) policies, issues like insufficient legislation, enforcement, corruption, limited public involvement, and governance frameworks hinder the creation of a sustainable SWM system. This challenge is increased by many residents living in informal settlements, where authorities bypass them due to a lack of formal tenure, considering them 'illegal,' (Oteng-Ababio et al., 2020). Despite the overall challenges in solid waste management in Ghana, it is difficult to establish an effective and sustainable system. However, the introduction of IoT technologies for monitoring solid

waste collection has brought in a more advanced approach to promote effective and efficient waste collection system management.

In summary, IoT technologies have greatly enhanced solid waste management worldwide, yet challenges remain, including financial feasibility, especially in developing nations. Further research is required for improved waste collection and environmental sustainability.

Literature Review specific to the Technical area being researched

The Conventional Method of Waste Monitoring, Collection and Management

In ancient cities, waste was thrown onto unpaved streets and roadways, where they were left to accumulate. It was not until 320 BCE in Athens that the first known law forbidding this practice was established. In the latter half of the 1800s, a technological approach to solid-waste management started to take shape. In the United States, the use of stronger vehicles for waste collection and transportation coincided with the introduction of waterproof garbage cans (Nathanson, 2023). In the first part of the 20th century, technological advancements continued, leading to the creation of pneumatic collection systems, compaction trucks, and garbage grinders. However, by the middle of the 20th century, it was clear that improper incineration and open dumping of solid waste were endangering public health and causing pollution issues. It was evident that a new means of garbage collection was needed.

In Jamaica, the National Solid Waste Management Authority (NSWMA) controls the operations of collecting, transporting, and disposing of solid waste. The National Solid Waste Management Act (2001) mandates the National Solid Waste Management Authority (NSWMA) to take all necessary steps to effect the management of solid waste in Jamaica. By carrying out this mandate, measures to protect public health and guarantee that waste is gathered, stored,

transported, recycled, and reused, or disposed of in an environmentally responsible manner are made easier (About Us - National Solid Waste Management Authority – Jamaica, 2023). Public concern over Jamaica's solid waste management, particularly with regards to garbage collection, has existed for a long time. Concerns about the poor quality of services, the accumulation of trash in neighborhoods and along roads, and the threat to public health and the environment have all been raised by the public. The concerns are due to the ineffective garbage collection system in Jamaica. Internet of Things (IoT) Control measures can be implemented to assist in minimizing the problem.

The Advantages and Difficulties of utilizing Internet of Things (IoT) for Garbage Collection and Monitoring

Universal Objects are getting smarter and connected with each passing day. All objects can now be uniquely identified and made to communicate with one another thanks to the constantly expanding Internet of Things (IoT) (Ray et al., 2018). An IoT-driven solid waste management system incorporates dustbins that gives prior information of the status to the municipality so that they can clean the bins on time and safeguard the environment (Elmustafa & Mujtaba, 2019). Outfitted bins are equipped with ultrasonic and gas sensors to automatically detect hazardous gasses and manage waste levels. Once bins reach their predetermined gasses and waste thresholds, the relevant authorities will be notified.

There are advantages that can be derived from using the IoT-driven garbage monitoring systems. Through the use of cloud computing, it will be more efficient in storing data for analytics. By accessing available Wi-Fi, or using GPRS in GSM modules, the device can access the internet. Ultrasonic sensors are able to detect the capacity of the dustbin filled. When a dustbin is full to capacity, a message is sent to the authorized personnel instructing them to pick

up the trash from that specific location. The authorized personnel can then use his web application to send an SMS message to the garbage collectors letting them know the location.

According to (Kamm et al., 2020) implementing such ideas comes along with some almost insurmountable challenges related to wireless data transfer, battery lifetime, and IoT infrastructure. These independent end-node devices, such as the ultrasonic sensors and gas sensors, frequently run on batteries or accumulators, which presents energy-related issues. Therefore, minimizing the energy consumption required for inquiring and transferring data is fundamental. As a result, these devices are connected using low-bandwidth, low-energy data transfer methods. Regardless of how useful smart garbage monitoring systems are, resources must be available to handle garbage collection based on the data provided by such a system. Individuals or entities considering implementing similar systems should weigh the benefits against the challenges.

Specific Gaps in the Literature that may Justify the Pursuit of the Current Research Effort

The Internet of Things (IoT) has become a widespread approach in numerous organizations and day-to-day operations. When it comes to automating waste management processes, there are substantial gaps in the existing literature that must be filled. Issues that need greater exploration are the data security and privacy implications of employing IoTs to automate the waste management process. To maintain data security and privacy while implementing IoT systems to automate waste management operations, encryption, rigorous access control, frequent software upgrades, secure communication protocols, device security, and user education are essential to limit these gaps.

Another gap is the need for user adoption and involvement, which could improve efficiency, lower costs, and promote sustainability by efficiently monitoring and controlling trash

disposal, recycling, and resource use through real-time data analysis and automated operations. Also, accessibility has a major effect on the use of IoT technology to automate waste management activities. Accessibility is not only an ethical obligation; it is also required for maximum productivity, user engagement, and legal compliance. These loopholes must be filled in order to boost productivity and efficiency while using IoT to automate waste management activities (Aleyadeh & Taha, 2018).

Another critical gap in the use of IoT to automate waste management operations is the long-term maintenance and reliability. While IoT simplified waste management operations and proven to offer a more productive and efficient way in doing so, reliability and maintenance comes into question. This complicates the robustness, reliability, and productivity of using IoT; thus, it is critical to guarantee that IoT is reliable and properly maintained for both the effectiveness and long-term success of these automated waste management systems (Dubey, Singh, Yadav, & Singh, 2020).

In conclusion, while the use of IoT to automate waste management operations has shown a promising future in terms of making these processes easier and more efficient, there are specific gaps in the use of IoT to automate waste management operations that provide valuable insights into the challenges and opportunities faced in this area. As a result, the purpose of this research is to investigate the use of IoT to automate the operations of NSWMA.

Contributions of the Literatures being reviewed to current research effort

Improper waste management has become a significant universal issue and as a result, numerous research has been done to propose possible solutions which includes automating the system through Internet of Things (IoT). Sohag et al. (2020) presented an integrated system which consists of an identification system, an automated lid system, a display system, and a

communication system, all being synchronized by Arduino Uno, a microcontroller board. Sensors will be used to identify personnel, to measure the amount of garbage in the bin, and to detect when someone is close to the bin, to prompt the lid to automatically open. The percentage of how filled the bin is, will be displayed on a liquid crystal display (LCD) screen to help with continuous monitoring.

Communication will be facilitated by a global system for mobile communications (GSM) which will alert the corresponding jurisdiction to collect the waste when the bin is filled. The system presented not only automates waste collection, but it also prevents citizens from getting in contact with the bin, thus reducing health risks. Haque et al. (2020) proposed a similar system, however, a navigation system will also be implemented as bins will be emptied in a cycle. This system determines the quickest route to get to the bin, which lessens the amount of time the bin remains full as well as allowing for the reduction of money spent on fuel for the trucks. In addition to that, the research done by Jajoo et al. (2018) presents a similar system as the two mentioned above. A notification will be sent to the respective authorities once the bin is full so that the garbage can be collected. However, if the notification is ignored, the message is sent to higher authorities. This feature allows for mandatory garbage pickup once a bin is full, it cannot be ignored.

Kumar et al. (2016) research proposed a smart alert system for garbage collection. This system will send an alert to the corresponding jurisdiction for the waste to be collected from the bin. The bin will be equipped with an ultrasonic sensor which is interfaced with Arduino UNO to check the amount of garbage in the bin. After collection, the driver will confirm that the bin is emptied with the use of Radio Frequency Identification (RFID) Tag, a computing technology that is used for verification. This system will allow for real-time monitoring for both the bin and

human labor. Rajuu et al. (2019) proposed a similar system whereby an alert, a notification in their scenario, is sent to the corresponding jurisdiction. It also allows for real-time monitoring of employees by higher authorities. However, their proposition is facilitated by solar energy and ZigBee, which is an open, global, packet-based protocol designed to provide an easy-to-use architecture for secure, reliable, low-power wireless networks.

The research carried out by Abuga et al. (2021) proposed a Smart Garbage Bin Mechanism (SGBM) for smart cities which features three subsystems, the smart garbage bin (SGB), garbage collecting vehicle (GCV) and a centralized database (CDB). This system will be implemented using the NetLogo platform, which is widely used in multi-agent modeling environments. These features aim to address the problems of inaccessibility to required data, lack of throughput all done through the fuzzy logic process, a technique that embodies human-like thought process into a control system. Yusof et al. (2017) presented a similar system specifically for flats in their research and features the same SMS notification sent to respective authorities for collection as Rajuu et al. (2019) proposed system.

Concluding Remarks

In conclusion, the literature review underscores the significance of IoT technology in transforming waste management. It highlights the potential benefits, including real-time monitoring, cost savings, reduced environmental impact, data-informed decision-making, and improved public engagement. However, challenges such as data security, user adoption, accessibility, and maintenance are also evident. Numerous research studies propose innovative solutions for automated waste management using IoT. These include integrated systems, advanced notification mechanisms, navigation optimization, and centralized databases. These

approaches aim to improve waste collection efficiency, reduce health risks, and enhance communication with relevant authorities.

Chapter 3: Methodology

Research Design

In the effort to eradicate the persistent use of paper-based systems at NSWMA and assess the potential for IoT integration to enhance operational efficiency, this study employs different research methodologies. Quantitative data will be collected through structured surveys distributed to NSWMA employees, while qualitative insights will be derived from in-depth interviews with key stakeholders. In addition, document analysis will be conducted to review relevant reports. Furthermore, data will be analyzed using statistical software and thematic analysis for quantitative and qualitative data, respectively. The research methodologies were chosen to gather both quantitative and qualitative data for a comprehensive analysis of the transition from paper-based systems to IoT integration at NSWMA. Surveys and statistical software provide numerical insights, while interviews and document analysis offer qualitative context and stakeholder perspectives. This mixed-methods approach ensures a well-rounded evaluation of the research objectives.

Population Sample

The sample for this study was chosen through a purposive or non-probability sampling method. The selection process was deliberate and specific, targeting individuals who are directly associated with the research objectives. The sample includes employees working at the National Solid Waste Management Authority (NSWMA) in Jamaica, including various roles such as operational staff, senior management, and key stakeholders. Furthermore, the survey anticipates the participation of about 30 employees of approximately 350 employees at the NSWMA. This sample size has been determined to be sufficient for the study's objectives while ensuring statistical significance and meaningful insights from the data collected.

Instrument Design

Survey

Development and History. The survey instrument has been custom-designed for this study, taking into consideration the specific research objectives and questions. It draws on existing survey research methodology and principles. The survey was developed by the research team in consultation with experts in survey design to ensure its appropriateness for the study. Surveys have a rich history in research, emerging in the early 20th century and gaining widespread use after World War II. Their effectiveness lies in their ability to efficiently gather large-scale data from diverse samples, their adaptability to various research domains, and their cost-effectiveness. Well-designed surveys provide structured data for statistical analysis, making them valuable for exploring attitudes, behaviors, and demographics.

Validity and Reliability. To assess the reliability of this survey, a test-retest assessment will be employed, evaluating the consistency of questionnaire responses from the same individuals participating in the survey at two different intervals. In addition, to ensure the validity of the survey, questionnaire questions will be aligned with the research question. This alignment will be achieved through expert review and pretesting to identify any discrepancies in the questions.

Administration and Scoring. The survey will be administered electronically using an online survey platform to ensure ease of access and data collection efficiency. Respondents will be provided with a unique link to access the survey. The survey consists of closed-ended questions. The responses will be scored numerically for quantitative analysis.

Rationale. This survey instrument was chosen because it allows for the collection of quantitative data on employees' perspectives regarding the integration of IoT technology at

NSWMA. It provides structured data that can be statistically analyzed to evaluate the potential for IoT integration to enhance operational efficiency. Additionally, the use of an online survey ensures ease of data collection and analysis, making it a practical choice for a large sample size.

Interview

Development and History. An in-depth interview was developed based on established qualitative research principles and practices. The questions were designed to capture a range of insights from key stakeholders. Interviews have a century-long history, evolving from informal discussions to structured formats, and they are effective for gathering in-depth, context-rich data, with the quality depending on skilled interviewers and sample representativeness.

Validity and Reliability. The interview questions were reviewed by qualitative research experts to ensure that they align with the research objectives and would elicit rich, meaningful data. To assess reliability, a pilot interview was conducted with a key stakeholder, and the interview process was refined based on feedback. The research team will undergo training in qualitative interview techniques to ensure consistency in data collection.

Administration and Scoring. In-depth interviews will be conducted in person depending on the preferences and availability of the participants. All interviews will be recorded with participants' consent to perform careful analysis. A structured interview guide will be used to maintain consistency in data collection.

Rationale. In-depth interviews were chosen as the instrument for qualitative data collection because they allow for a deep exploration of stakeholders' perspectives and experiences with IoT integration at NSWMA. These interviews provide a more solid understanding of the topic, which can complement the quantitative survey data. The use of

qualitative interviews also allows for flexibility in probing for detailed insights and uncovering unexpected findings.

Data Analysis

Following data collection, a hybrid approach will be employed, combining content analysis with statistical techniques to ascertain the research questions. Upon analyzing the data, content analysis will help assess the language used in the interviews to detect bias. For survey data, visual aids like bar charts, line graphs, and pie charts will illustrate research findings, particularly when revealing correlations between independent and dependent study variables. However, in order to transform this data into a more meaningful basis for decision-making, descriptive statistics can be applied to delineate the general attributes of the dataset. This process gauges the central tendencies and variability of the data, leading to a concise summary of the survey report.

Procedure

Before initiating the analysis, the data collected will be subjected to preparatory steps. These steps are as follows, the initial step in accomplishing this research involves formulating interview and questionnaire questions that align with the research queries. Following this, a thorough examination and improvement of the interview and survey questions will take place by an expert before they are distributed. Furthermore, the survey anticipates the participation of about 30 employees of approximately 350 employees at the NSWMA. These members will be recruited via WhatsApp.

In order to secure the active involvement of these participants, it is crucial to establish transparent and efficient communication to convey the survey's objectives and importance. As a result, constant communication will be done through WhatsApp to facilitate efficient

communication. Furthermore, building trust by handling their data responsibly is key to motivating their participation in the survey. As such, no sensitive data will be collected from participants. All data collected for the research will be deleted at the end of the research.

Once participants have given their full consent, the survey questions will be administered electronically through Google Forms, ensuring both ease of access and efficient data collection. Respondents will receive a distinct link to access the survey via WhatsApp. In-person interviews will be arranged based on participant preferences and availability, with the conversations recorded using a voice recording medium for meticulous analysis.

After the survey and the interview are completed, analyzing the data will be done as follows. A content analysis is used to identify interview bias through language evaluation of the interviewee. Visual aids (bar charts, line graphs, pie charts) depict survey data and reveal correlations. In addition, the statistical treatment of the study looks at descriptive statistics highlighting central tendencies and dataset attributes, offering a concise survey report summary for decision-making. Finally, in follow-up on the survey done, a test-retest is used to evaluate the consistency of the questionnaire responses from the same employees to determine if there were any deviations in their responses.

Project Design

The project design encompasses a structured roadmap for the research, beginning with the establishment of the project team and the formulation of a project charter. A thorough literature review is then conducted to build a foundational understanding of IoT applications in waste management, followed by the design of data collection tools, survey questionnaires, and interview guides. Ethical approvals and informed consent are secured for data collection. The research then proceeds to collect both quantitative and qualitative data, and subsequent steps

involve data analysis, integration, and synthesis to generate recommendations for the National Solid Waste Management Authority (NSWMA). The final product is a comprehensive research report with clear headings, findings, and recommendations, and all pertinent project documents and data are included in the appendices, ensuring transparency and facilitating future replication of the study.

Description of Target Population

The primary beneficiaries of this project are the employees of the National Solid Waste Management Authority (NSWMA) in Jamaica, who will experience improved workplace efficiency through the implementation of IoT technology in waste management. Furthermore, the broader population of Jamaica, encompassing residents, businesses, and communities, indirectly benefit from the project's outcomes. An optimized waste management system, as facilitated by IoT technology, will lead to improved waste collection, reduced environmental impact, and enhanced public health.

Project Evaluation

The project's effectiveness will be assessed through a combination of quantitative measures, such as performance metrics and post-implementation surveys, and qualitative measures, including stakeholder interviews and direct feedback. As such, if the objectives of the project are met and both the analysis and methodology are consistent with reliable and valid data relevant to the research questions, it is proven to be effective. To continuously improve the project, we will maintain feedback channels, stay updated on technology advancements, provide ongoing training, and conduct regular evaluation reviews. This ensures that the project remains adaptable and effective, addressing evolving needs within NSWMA and the Jamaican community.

Chapter 4: Findings

Introduction

The findings have been organized around the study's research aim, which is to explore how IoT can optimize garbage collection processes, reduce operational inefficiencies, and improve overall waste management operations at NSWMA. The findings are broken up into two sections, Findings from a survey and also from an interview conducted. Findings related to the survey are organized based on the Tenure of Employees, method and current systems used for determining garbage collection locations, Familiarity with the concept of IoT and its associated benefits and implications of the implementation of IoT for waste collection. On the other hand, insights from the interview are structured around exploring the NSWMA's current waste collection operations, including challenges in adherence to schedules, mobile application functionality, potential benefits of IoT integration, and considerations for technological advancements.

Data Analysis for The Questionnaire Responses

Tenure of Employees

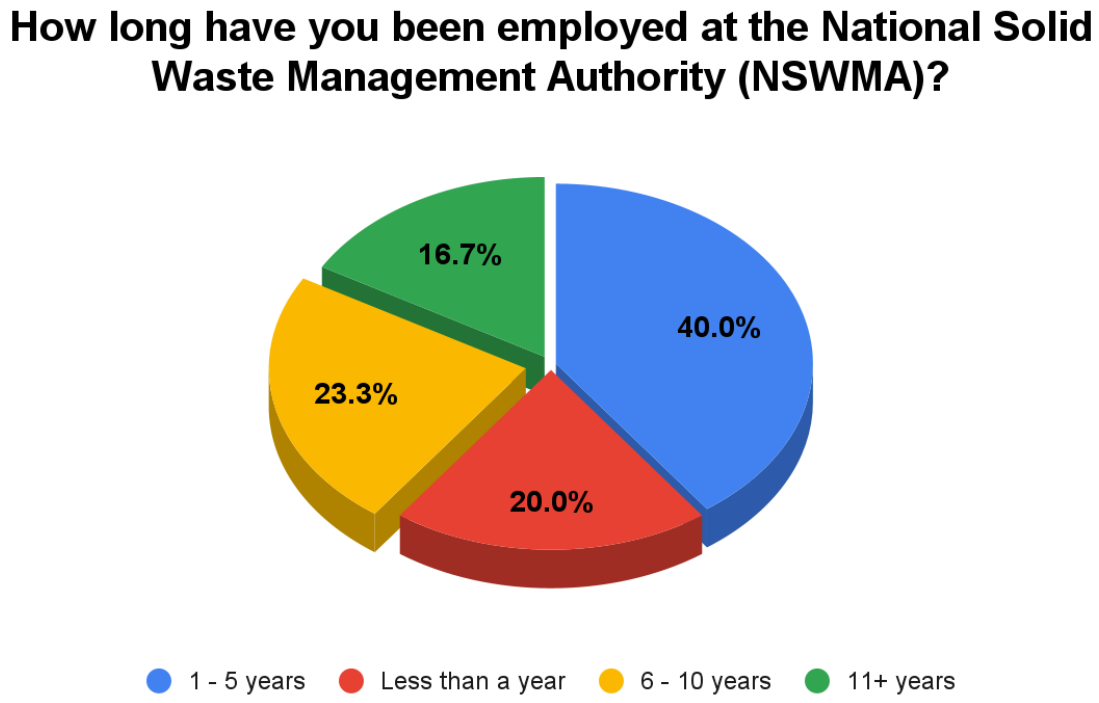

Figure 1

The pie chart indicates that the majority of employees at the NSWMA have relatively short tenures with the organization. Specifically, 40% of employees have been with the organization for 1–5 years, suggesting a turnover rate that may be higher than desired. It is also worth noting that 20% of employees have been with the organization for less than a year, which may indicate challenges in retaining new employees or potential issues in onboarding and training processes. On the other hand, 23.3% of employees have been employed for 6–10 years, indicating a significant portion of the workforce that has demonstrated long-term commitment to the organization. Additionally, 16.7% of employees have been with the NSWMA for 11+ years,

suggesting a core group of employees who have remained with the organization for an extended period of time.

Overall, these findings suggest a mix of employee tenure at the NSWMA, with a significant portion of employees having relatively short tenure, but also a substantial number of employees who have demonstrated long-term commitment to the organization. This data can be further used to show the overall understanding of this organization and its operations. So an employee with a longer working years often shows a better knowledge of the organization.

Method and Current system for Determining Garbage Collection

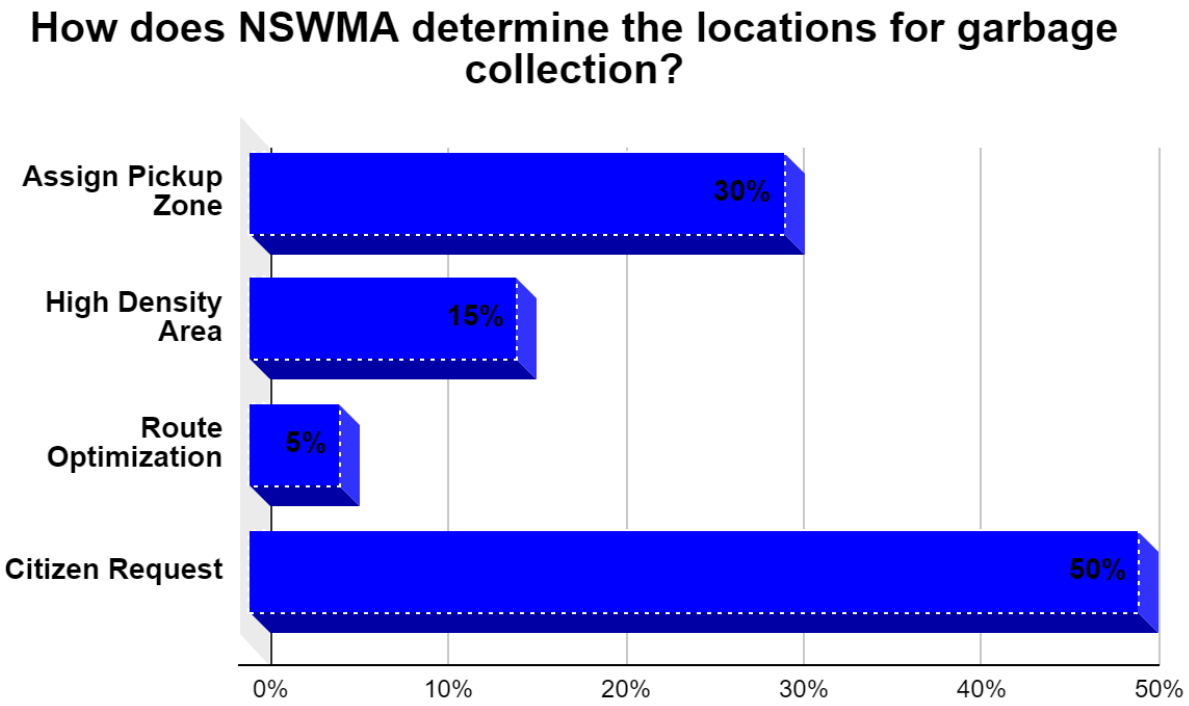

Figure 2

The findings regarding NSWMA's approach to determining garbage collection locations shed light on areas where IoT integration could address existing challenges and enhance operational efficiency. The heavy reliance on citizen requests (50%) underscores the importance of community engagement in waste management decision-making. However, this reliance on manual feedback channels may lead to delays in response times and inefficiencies in service delivery, indicating a need for more streamlined communication processes. Furthermore, while Pickup Zones (30%) and High-Density Areas (15%) are considered in resource allocation, the lack of real-time data insights hampers the optimization of waste collection routes. With only a small percentage allocated to route optimization (5%), there is a clear opportunity to enhance operational efficiency through IoT integration. By incorporating IoT sensors to monitor fill levels

in bins and leveraging real-time data analytics, NSWMA could dynamically adjust collection routes, leading to reduced travel time, fuel consumption, and operational costs.

Software Used for Garbage Collection

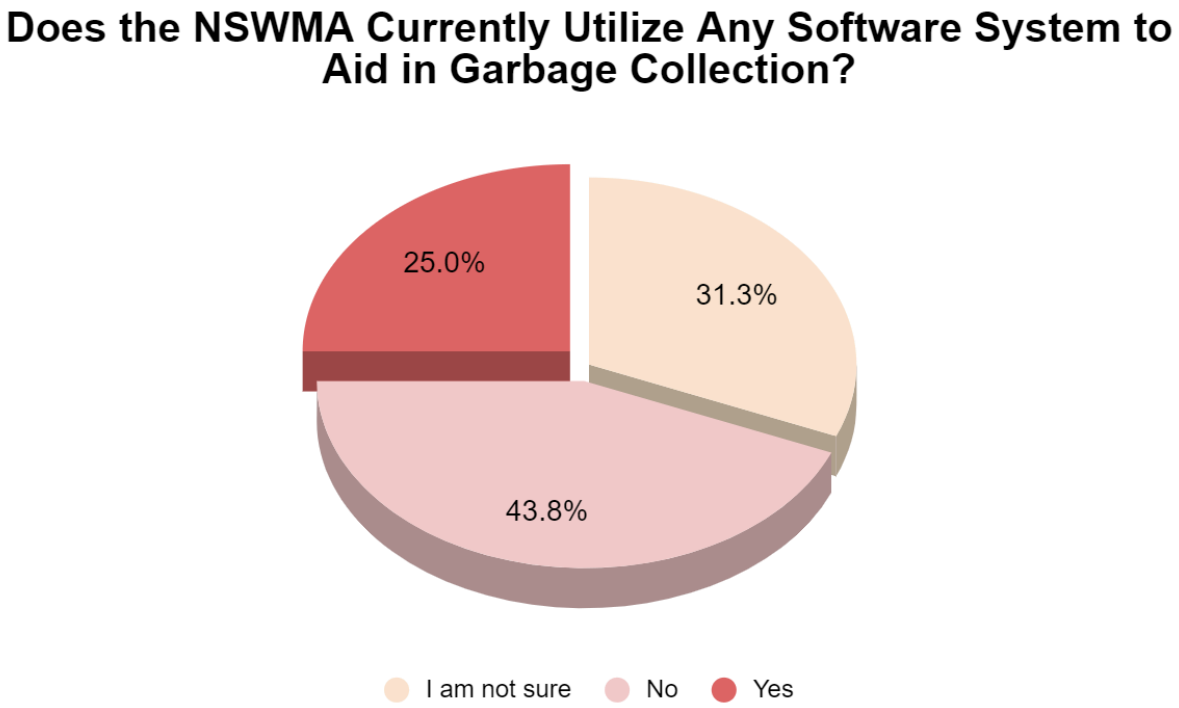

Figure 3

The pie chart above shows the results of a survey asking respondents if the NSWMA currently utilizes any software system to aid in garbage collection. 25% of respondents were unsure, 43.8% said no, and 31.3% said yes. This indicates that a significant portion of respondents are not aware of the NSWMA's use of software for garbage collection, with slightly more saying no than yes.

Overall, the data suggests that there may be a lack of awareness or transparency regarding the NSWMA's use of software systems for garbage collection. With 25% of respondents unsure, there is a clear need for better communication or education on this topic. Additionally, the fact that 43.8% said no and only 31.3% said yes indicates that there may be room for improvement in terms of utilizing technology for garbage collection within the

NSWMA. It would be beneficial for the NSWMA to address this issue by providing more information to the public about the software systems they currently utilize for garbage collection. This could help increase awareness and trust in the organization's efficiency and effectiveness in waste management. Additionally, the survey results suggest that there may be an opportunity for the NSWMA to further invest in and leverage technology to improve their garbage collection processes and overall operations.

Familiarity with the Concept of IoT and its Associated Benefits

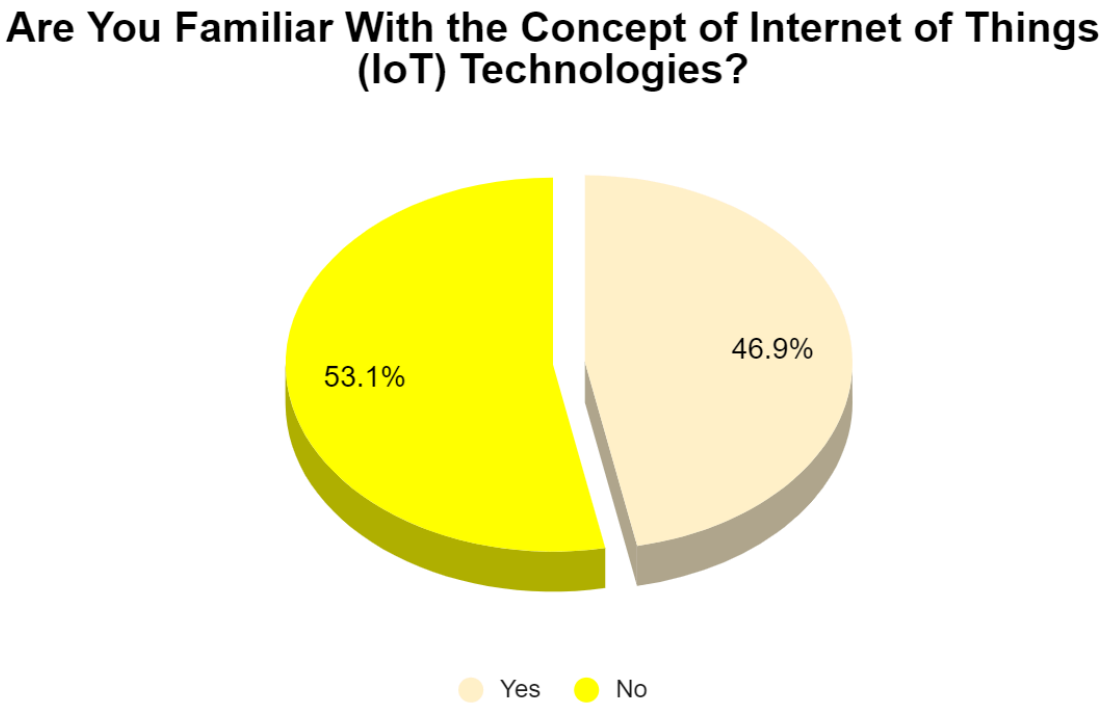

Figure 4

During the initial phase of IoT development, the spotlight has been on industrial and consumer applications such as autonomous machines. However, a shift towards a human-centered approach is in progress, emphasizing personal augmentation via "living services" facilitating adaptable programming and connectivity among smart devices (Shah et al., 2015). As a result, according to the data depicted in the above graph, 53.1% of the population are knowledgeable about utilizing this technology to enhance their daily lives, while 46.9% remain unaware of its potential applications.

This data indicates that the population is evenly distributed in terms of individuals' awareness of IoT technology. Analysis of the data concerning the duration of employment at the organization reveals that 40% have been working there for up to five years. This suggests that

this subgroup of employees may be younger or more technologically inclined, hence more aware of global technological advancements. Conversely, the remaining respondents have been with the organization for a longer period, potentially indicating a lesser involvement in technological developments and a lack of awareness thereof.

Insights from the Benefit of IoT

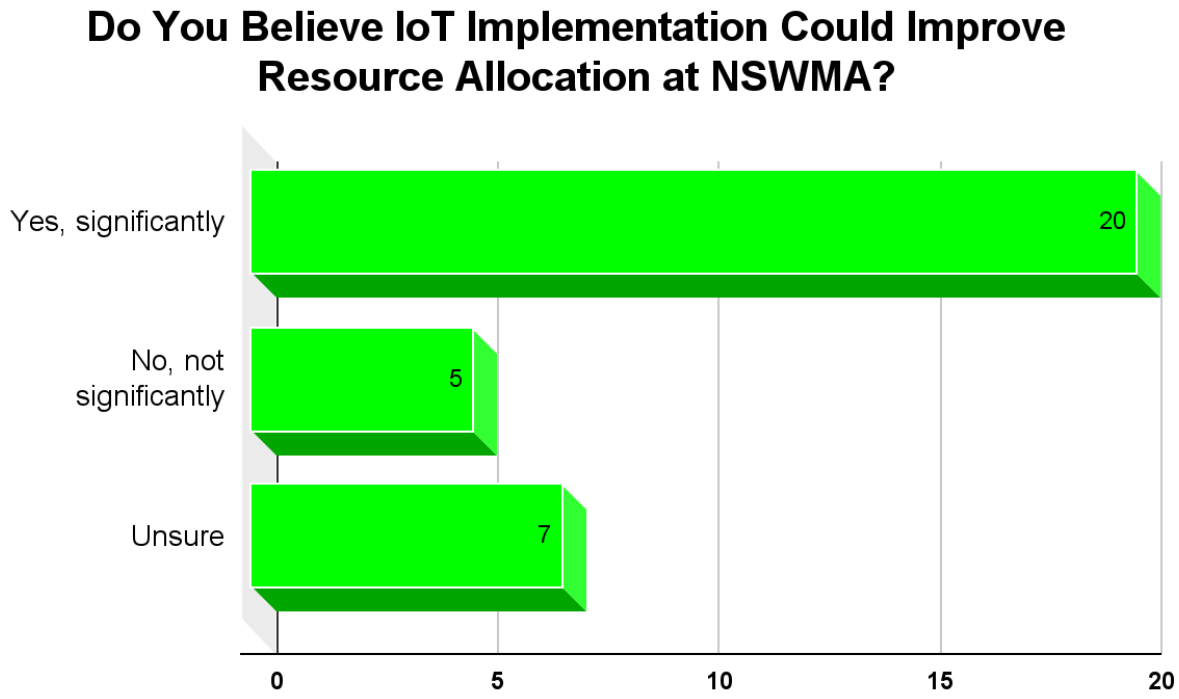

Figure 5

In figure 5 above, it is clear that there is a positive sentiment towards IoT implementation for improving resource allocation at NSWMA. Out of the total 32 respondents, 20 believe that IoT implementation could significantly improve resource allocation. This shows that the majority of respondents see the potential benefits of implementing IoT technology in this context.

On the other hand, only 5 respondents believe that IoT implementation would not significantly improve resource allocation at NSWMA. This suggests that there are some doubts or reservations among a minority of respondents about the effectiveness of IoT in this specific area. Additionally, 7 respondents are unsure about whether IoT implementation could improve resource allocation at NSWMA. This could indicate a lack of knowledge or understanding about IoT technology and its potential applications, or it could suggest a need for more information or

clarity on how IoT could be utilized in this context. Overall, the data indicates that there is support for exploring the implementation of IoT technology to improve resource allocation at NSWMA, but there are also some concerns and uncertainties that need to be addressed. Further research and communication about the benefits and challenges of IoT implementation in this specific context may help to increase understanding and buy-in from all stakeholders.

Anagnostopoulos et al. (2022) suggest that in smart cities, the integration of IoT enables Waste Collection as a Service (WCaaS), facilitating online scheduling and routing of collection trucks. This process entails determining the timing of waste collection from bins and planning the routes for collection trucks. Various technologies, including IoT, RFID, sensors, and Wireless Sensor Networks (WSNs), are utilized to manage both physical infrastructure and collected data. IoT technology enables the identification of physical objects as 'smart things' through RFID tagging. Sensors and WSNs measure physical quantities and convert them into digital signals for wireless processing. Actuators engage with digital systems at the physical layer, while the Future Internet enables the interconnection of smart things via IPv6 over Low Power Wireless Personal Area Networks (6LoWPAN) protocol.

Key Areas in Waste Management that could Benefit from IoT

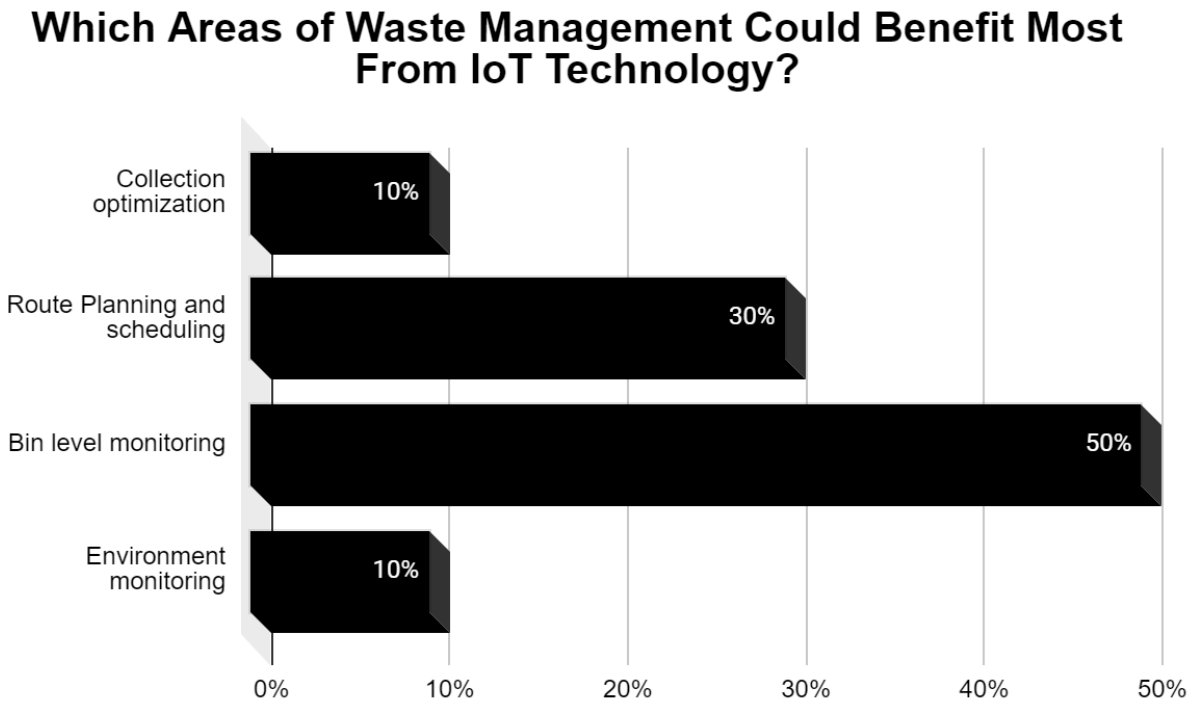

Figure 6

This question aimed to identify key areas within waste management where IoT technology could significantly improve its performance. Among the four areas, bin level monitoring received the highest amount of responses at 50%. This implies a strong consensus among the respondents regarding the potential advantages of implementing IoT technology to monitor bin levels, which may include operational efficiency and better resource management. Following closely behind, route planning and scheduling garnered 30% of the responses. This percentage of responses indicates a significant recognition of the importance of optimizing collection routes and schedules to improve resource allocation as well as operational efficiency. Collection Optimization and Environment Monitoring both got 10% of the responses. Even though that's a small amount compared to Bin Level Monitoring and Route Planning and

Schedule, it still shows that implementing IoT technology to monitor these areas can have a positive impact. Regardless of the percentage, they were still selected by the respondents which alludes to Collection Optimization and Environment Monitoring benefiting from the implementation of IoT.

According to the conducted study by Faye et al. (2019), within the domain of waste collection, IoT demonstrates efficacy in facilitating a data management layer encompassing models for analyzing and predicting container fill trends. Additionally, it establishes a multifaceted optimization layer aimed at devising collection routes that mitigate environmental impact while optimizing service quality.

Insights on how IoTs can be used to Prevent Delays in Garbage Collection

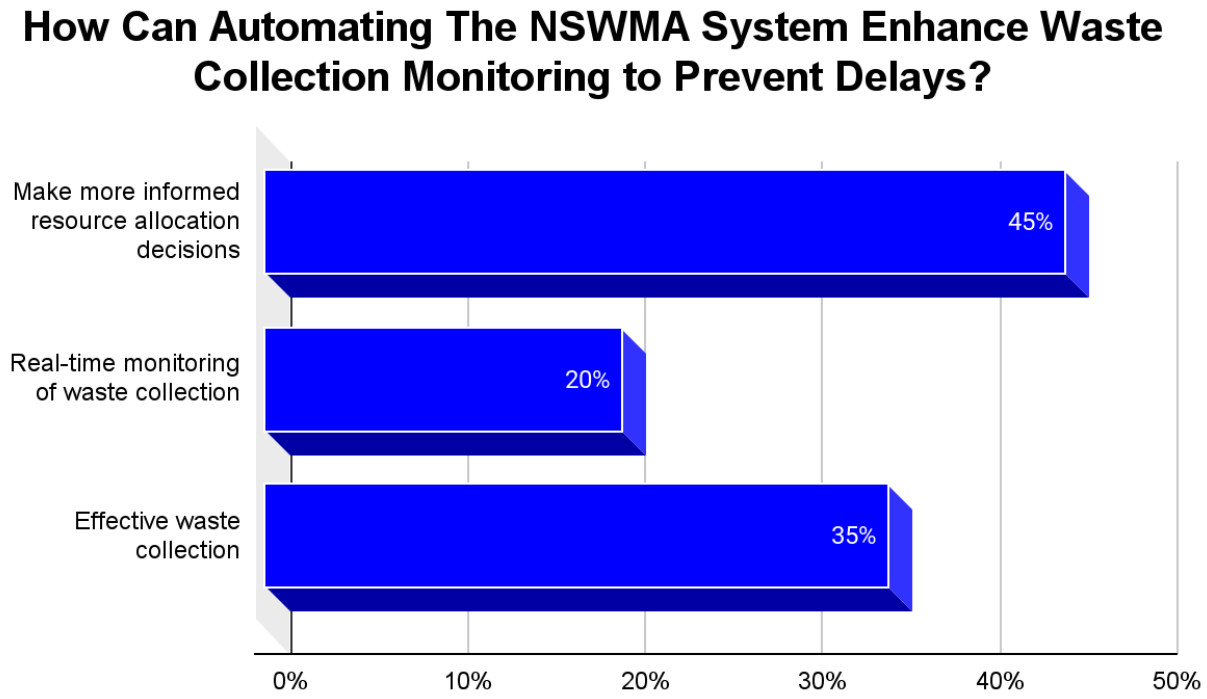

Figure 7

The responses reveal a persuasive case for the implementation of an automating system within the NSWMA. Nearly half of the respondents, 45%, expressed that automating these systems could significantly improve resource allocation decisions. This alludes to a recognition of the potential benefits that is achievable through automating their system. By automating tasks such as route optimization, scheduling, and resource allocation, NSWMA can streamline operations, reduce costs, and enhance service delivery, which results in cost savings and improved service quality.

Furthermore, a notable portion of respondents, 20%, highlighted the importance of real-time monitoring capabilities enabled by automation. Real-time monitoring will allow the NSWMA to track the status of collection vehicles, monitor bin fill levels, and respond promptly

to any issues or disruptions. This level of visibility and control will allow the NSWMA to make well informed decisions, such as rerouting vehicles to address in regard to priorities or optimizing collection routes based on real-time conditions. This will allow timely and effective waste collection services.

Additionally, the responses indicate that 35% of respondents emphasized the potential for automation to improve the overall effectiveness of waste collection operations. Automation can mitigate truck delays, reduce missed collections, and optimize the utilization of resources, leading to more reliable and efficient waste collection services by the NSWMA. By automating repetitive tasks and leveraging technologies such as IoT sensors and data analytics, the NSWMA will be able to identify opportunities for process improvement, and enhance the quality of service offered to citizens.

Implications of the Implementation of IoT for Waste Collection

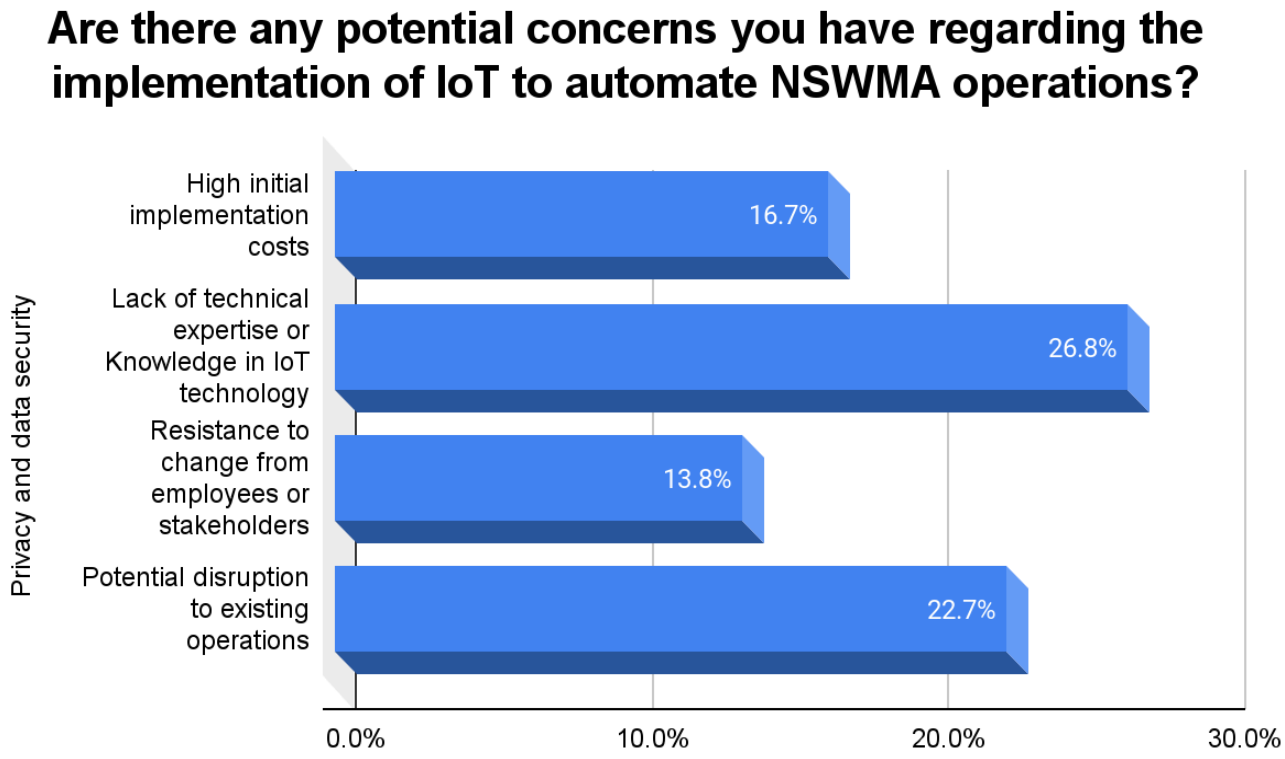

Figure 8

The figure above highlights various concerns regarding the implementation of IoT technology to automate the NSWMA operations. A significant amount of the respondents, 16.7%, expressed apprehension about the high initial implementation costs associated with adopting IoT solutions. This concern highlights the financial considerations that the NSWMA must undergo when evaluating the feasibility of IoT integration. While the upfront investment may be substantial, it's essential to assess the potential long-term benefits and return on investment that the implementation of IOT automation can offer in terms of operational efficiency, cost savings, and improved service quality.

Another noteworthy concern identified is the lack of technical expertise or knowledge in IoT technology, voiced by 26.8% of respondents. This highlights the importance of ensuring that the NSWMA have the necessary skills and capabilities to successfully implement and manage IoT systems. Addressing this concern may involve providing training and education to employees or partnering with external experts to bridge the knowledge gap and facilitate a smooth transition to IoT-enabled operations.

Additionally, 13.8% of respondents voiced resistance to change from employees or stakeholders as a potential barrier to IoT implementation. This concern highlights the importance of organizational change management and stakeholder engagement strategies to mitigate resistance and foster buy-in for IoT initiatives. Clear communication, involvement in decision-making processes, and demonstrating the benefits of IoT automation can help alleviate concerns and garner support from key stakeholders.

Furthermore, 22.7% of respondents expressed concerns about potential disruptions to existing operations resulting from IoT implementation. This highlights the need for careful planning and risk management to minimize disruptions during the transition phase. The NSWMA should conduct thorough impact assessments, develop contingency plans, and communicate effectively with stakeholders to mitigate any potential disruptions and ensure a smooth integration of IoT technology into existing operations.

In summary, the data illustrates the multifaceted considerations and challenges associated with implementing IoT technology to automate garbage collection operations. Addressing concerns related to cost, technical expertise, resistance to change, and operational disruptions is essential for successful IoT adoption and realizing the full potential of automation in enhancing garbage collection efficiency and effectiveness.

Insights from the Interview

On April 15, 2024, an interview session was arranged at the headquarters of the NSWMA in Kingston, Jamaica. The interview lasted approximately one hour, during which valuable insights were obtained regarding the organization's operation for collection and monitoring solid waste, as well as its perspective on the advantages of incorporating IoT into these operations.

The initial inquiry was directed towards strategies for ensuring the completion of tasks by waste collection personnel. The interviewee’s responses indicated that Regional Operation Managers oversee solid waste operations within designated areas known as Metropolitan Parks and Markets. These regions comprise a team including a regional operation manager, public cleansing inspectors, zonal monitors, collection crews, and sanitation workers. According to the interviewee, the person acting as the zonal monitor decides if garbage collection is done in a scheduled area. However, it was revealed that there is currently no system in place to alert them when an area becomes saturated with garbage, or when the next pick-up will be because they face challenges in adhering to the schedule displayed on their website due to inadequate resources.

Additionally, prior to the interview, information was obtained from an employee at the organization indicating that the mobile application that we had discovered as a tool used for the monitoring of garbage collection was inactive, although they couldn't provide further details on its usage. However, during the interview, the second question posed was regarding the effectiveness of the mobile application utilized for waste collection monitoring by the NSWMA. The interviewee clarified that the mobile application is not employed for monitoring waste collection, but rather for reporting illegal dumpsites or areas that have not undergone garbage collection for some time. According to our understanding, individuals are required to capture

images of accumulated garbage, pinpoint their location, and once the garbage is collected, it is reflected in the application as completed. Nonetheless, the interviewer specified that the primary purpose of this application is to publicly display the collection schedule and enable reporting of dumpsites but based on the activities the application is used to perform we associate it to be monitoring the collection process but at the same time this application was inactive up to the point of the interview.

Thirdly, concerning the current hurdles experienced by the NSWMA in its waste collection processes, how could the incorporation of IoT technologies prove advantageous? Based on the response given, garbage collection presently occurs either once or twice a week, or on a bi-weekly basis, contingent upon the specific area and its topography. The challenge arises from limited truck accessibility to these areas, leading to persistent accumulations of waste. Nonetheless, IoT implementation is seen as a means to mitigate the proliferation of pests and bacteria associated with waste accumulation. In addition, the interviewee noted that our proposed solution is better suited for commercialized zones, contrasting with the predominantly residential collection approach adopted by NSWMA. Specifically, urbanized regions, where larger skip bins are prevalent, stand to gain from IoT-enabled automation, facilitating timely collections and optimizing resource utilization to address prevalent inefficiencies.

Additionally, the interviewee provides minimal insight into the potential effects of IoT on the workforce of the NSWMA and what measures should be implemented to facilitate a seamless transition and optimize advantages for employees. The response suggests that the implementation would enable better tracking and supervision of the collection process. It is implied that job losses are unlikely, as the existing regional operational staff will still be necessary, except for a newly designated role for the zonal monitor. This individual's reporting

when garbage collection is done would become redundant, allowing for reassignment of responsibilities during the IoT integration.

In conclusion, the interviewee was asked in what ways do you see technological advancement being incorporated into the current systems and infrastructure at NSWMA, and are there any obstacles or potential problems that should be of concern? Based on the interviewee responses, some advancement includes a mobile application mirroring the automate system used in the office to receive assignments, report issues, and access collection areas, streamlining communication and eliminating paperwork. According to the interviewee, analytical tools can offer insights into waste generation and collection, optimizing resource allocation and decision-making for NSWMA. Regarding the constraints of implementing such a system, the interviewee mentioned that limited access to dependable internet connectivity and insufficient IT infrastructure could hinder the adoption and utilization of technology-based solutions, especially in remote or underserved areas. Additionally, staff training costs could escalate as employees need to stay abreast of new technological changes or security threats. Furthermore, upgrading systems and infrastructure to accommodate technological advancements requires significant investments in hardware and software as such, NSWMA must carefully evaluate the costs and benefits associated with these investments.

Chapter 5: Summary, Conclusion & Recommendations

Summary

The study focused on addressing the persistent use of a paper-based/traditional filing system by the National Solid Waste Management Authority (NSWMA) in Jamaica, leading to operational inefficiencies. The research aimed to explore how IoT can optimize garbage collection processes, reduce operational inefficiencies, and improve overall waste management operations at NSWMA. The research questions revolved around the knowledge of NSWMA employees regarding IoT application for waste collection, and the potential benefits of implementing IoT technologies for waste management.

A descriptive research design was employed, integrating quantitative and qualitative methodologies. Quantitative data was collected through questionnaires to assess waste creation and management system efficiency. Qualitative data was gathered through interviews, investigating individual opinions and attitudes about waste management practices.

The survey and interviews provided valuable data into garbage collection procedures, knowledge with IoT ideas, and the consequences of IoT implementation. Furthermore, the interview findings provided insights on NSWMA's present garbage collection operations, meeting schedule issues, possible IoT integration advantages, and technical progress considerations.

Overall, the study provided valuable insights into the potential of IoT technology to enhance waste management operations at NSWMA, addressing operational inefficiencies and paving the way for more efficient and effective waste management practices in Jamaica.

Conclusions From Findings

Conclusion of the Data Collected for The Questionnaire Questions

Figure One. These findings underscore the importance of understanding the dynamics of employee retention and turnover within the organization. This indicates that a significant majority, comprising 60% of the workforce, has relatively short employment durations, leading to potential gaps in their understanding of the organization's operational systems. Consequently, the organization may suffer from a lack of transparency in information processes, often managed through a hierarchical structure, potentially hindering effective communication and decision-making.

Figure Two. According to the information provided regarding the process for identifying uncollected garbage in specific areas, it becomes apparent that citizens are the primary initiators of complaints about accumulated garbage in their vicinity. This indicates a deficiency in management, as it suggests a failure to adhere to the information displayed on the website of the NSWMA. This underscores the importance of embracing technological advancements to enhance waste management practices and meet the evolving needs of communities effectively.

Figure Three. The utilization of software for garbage collection by the NSWMA indicates that approximately 75% of the population lacks awareness of the organization's implementation of such a system. This conclusion can be attributed to Figure One, suggesting a lack of transparency in the organization's operations, resulting in limited knowledge among individuals. Moreover, firsthand information from an employee at the organization highlighted the existence of a mobile application for waste monitoring, although details about its usage remain scant. This observation implies a potential gap in knowledge among the collection crew regarding the organization's operational procedures. Addressing this gap by providing clearer

information to the public about existing software systems could not only bolster trust in the organization's capabilities but also pave the way for further advancements in garbage collection processes through technology integration.

Figure Four. The conclusion drawn from the employee's familiarity with IoT suggests that employees working at the organization for less than five years are younger and more tech-savvy, and are more acquainted with the concept of IoT. Conversely, the remaining employees, possibly older with longer tenures, may be less familiar with IoT advancement, reflecting differing levels of technology engagement due to age within the organization.

Figure Five. The insights gathered from the benefits of IoT indicate widespread agreement among individuals. This option appears promising in its ability to tackle all the operational challenges faced by the organization.

Figure Six. Based on our observation, implementing IoT technology to monitor bin level would be highly effective. This is because garbage tends to accumulate there for weeks without attention. With IoT, decision-making improves significantly, enabling the organization to assess routes more efficiently with fewer resources. As a result, garbage can be collected promptly.

Figure Seven. Based on the data depicted in Figure Six, the utilization of IoT technology for waste collection monitoring enables the organization to formulate more strategic decisions. This leads to a more efficient waste collection system, with real-time communication of information to prevent any backlog or delays.

Figure Eight. The conclusion regarding the implementation of IoT for waste collection suggests concerns about high initial costs, highlighting the importance of assessing long-term benefits. Additionally, the need for technical expertise calls for investment in training or external help. Overcoming resistance to change requires effective organizational strategies, while

addressing concerns about disruptions underscores the significance of meticulous planning and risk management. Resolving these issues is crucial for enhancing efficiency in waste management operations.

Conclusion of the Data Collected for the Interview Questions

From the information gathered from the interview session, it's evident that the current waste collection processes at the NSWMA face several challenges, including inadequate monitoring of garbage saturation, inactive mobile application usage, and limited accessibility to certain areas for waste collection trucks. Incorporating IoT technologies could offer solutions to these challenges by enabling real-time monitoring of waste accumulation, optimizing collection routes, and enhancing communication between staff and management.

Implementing IoT can streamline processes and reduce resource inefficiency, but seamless integration is crucial. Smooth transition and maximizing employee benefits require adequate training and support. Additionally, utilizing the mobile application for task management and adopting analytical tools for data-driven decision-making are suggested advancements. However, overcoming these obstacles such as limited internet access, insufficient IT infrastructure, and training costs is necessary to fully leverage technology in the waste management operations by NSWMA.

Conclusions About the Project

The reliance on manual feedback channels and limited use of software systems for garbage collection at NSWMA indicate potential inefficiencies in communication processes and a need for improved technology utilization. The data highlights opportunities for IoT integration, particularly in real-time monitoring of bin fill levels and optimization of collection routes, to enhance operational efficiency and resource allocation.

Concerns regarding high initial costs, technical expertise, resistance to change, and potential disruptions highlight the challenges associated with IoT integration at NSWMA. Addressing these concerns through strategic planning, stakeholder engagement, and investment in training and infrastructure is essential for successful implementation and maximizing the benefits of IoT technology. Addressing issues such as cost, technical expertise, resistance to change, and potential disruptions is crucial for successful IoT adoption and realizing its full potential in improving garbage collection operations. There is an even distribution of awareness regarding IoT technology among employees, suggesting that younger or more recently employed individuals may possess greater familiarity with technological advancements compared to those with longer tenures.

Furthermore, while there is recognition of the potential benefits of IoT integration for waste collection operations at NSWMA, addressing challenges such as cost, technical expertise, and organizational resistance is crucial for successful implementation. Strategic planning, stakeholder engagement, and investment in training and infrastructure are essential for realizing the full potential of IoT technology in enhancing garbage collection efficiency and effectiveness. The project's primary beneficiaries, NSWMA employees, stand to benefit from improved workplace efficiency through the implementation of IoT technology in waste management.

Additionally, the broader Jamaican population indirectly benefits from enhanced waste management systems, leading to reduced environmental impact and improved public health.

Lastly, the project's effectiveness is further enhanced by the implementation of continuous improvement strategies, including feedback channels, ongoing training, and regular evaluation reviews. This ensures that the project remains adaptable to evolving needs within NSWMA and the Jamaican community.

In summary, the project demonstrates effectiveness in its comprehensive research design, robust data collection and analysis methods, structured project management approach, and potential positive impact on NSWMA employees and the broader Jamaican population.

Recommendations

1. Given the identified potential benefits of IoT integration in waste management operations, NSWMA should prioritize investment in IoT technology. This includes allocating resources for acquiring IoT devices for real-time monitoring of waste accumulation and optimizing collection routes.
2. Alongside investment in technology, there should be provisions for comprehensive training programs aimed at familiarizing staff with IoT devices and software. Training sessions should cover not only the technical aspects of using IoT technology but also emphasize its importance in enhancing operational efficiency and improving service delivery.
3. Additionally, the potential challenges associated with IoT implementation, particularly regarding high initial costs, technical expertise, resistance to change, and potential disruptions, NSWMA should develop robust risk management and change facilitation strategies. This involves conducting thorough cost-benefit analyses to justify investment in IoT, engaging stakeholders to address resistance to change, and implementing contingency plans to mitigate potential disruptions during the transition phase.
4. Furthermore, given the complexity and potential risks of IoT integration, consider testing IoT solutions in specific areas or pilot projects before implementing them on a larger scale. Pilot testing enables the identification of potential challenges, fine-tuning of technological solutions, and validation of their efficacy in real-world scenarios.
5. Lastly, IoT technology could also be incorporated in organizations looking to streamline waste management processes, offering real-time monitoring and data analytics to optimize collection schedules, reduce costs, and enhance environmental sustainability.

References

Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., AlShihri, F. S., AlShammari, M. S., Ahmed, S. M. S., ... & Alrawaf, T. I. (2022). Environmental sustainability impacts of solid waste management practices in the global South. *International Journal of Environmental Research and Public Health*, *19*(19), 12717.

Aktay, E., & Yalçın, N. (2021). A smart city application: A waste collection system with long range wide area network for providing green environment and cost effective and low power consumption solutions. *IET Smart Cities*. https://doi.org/10.1049/smc2.12014

Aleyadeh, S., & Taha, A.-E. M. (2018). *An IoT-Based Architecture for Waste Management*. Retrieved from IEE Xplore: https://ieeexplore.ieee.org/abstract/document/8403750/authors#authors

Anagnostopoulos, T., Zaslavsky, A., & Kolomvatsos, K. (2022, January 8). ,. , - YouTube. Retrieved May 7, 2024, from https://ieeexplore.ieee.org/abstract/document/7892970

Aroba, O. J., Xulu, T., Msani, N. N., Mohlakoana, T. T., Ndlovu, E. E., & Mthethwa, S. M. (2023, March). The adoption of an intelligent waste collection system in a smart city. In *2023 Conference on Information Communications Technology and Society (ICTAS)* (pp. 1-6). IEEE.

Burgess, M. (2018, February 16). *What is the internet of things? wired explains*. WIRED UK. https://www.wired.co.uk/article/internet-of-things-what-is-explained-iot

Chaudhari, S. S., & Bhole, V. Y. (2018). Solid waste collection as a service using IoT-solution for smart cities. In *2018 International Conference on Smart City and Emerging Technology (ICSCET)* (pp. 1-5). IEEE.

Das, S., Lee, S. H., Kumar, P., Kim, K. H., Lee, S. S., & Bhattacharya, S. S. (2019). Solid waste management: Scope and the challenge of sustainability. *Journal of cleaner production*, *228*, 658-678.

Dominic Abuga, N.S Raghava, Real-time smart garbage bin mechanism for solid waste management in smart cities, Sustainable Cities and Society, Volume 75, 2021, 103347, ISSN 2210-6707, https://doi.org/10.1016/j.scs.2021.103347.

Dubey, S., Singh, P., Yadav, P., & Singh, K. K. (2020). *Household Waste Management System Using IoT and Machine Learning*. Retrieved from ScienceDirect : https://www.sciencedirect.com/science/article/pii/S1877050920306876

Earth Today | NSWMA Adopts Tech To Tackle Pollution - National Solid Waste Management Authority - Jamaica. (2020, June 18). https://www.nswma.gov.jm/earth-today-nswma-adopts-tech-to-tackle-pollution/

Elmustafa, S. A. A., & Mujtaba, E. Y. (2019). Internet of things in Smart Environment: Concept, Applications, Challenges, and Future Directions. https://www.semanticscholar.org/paper/Internet-of-things-in-Smart-Environment%3A-Cncept%2C-Elmustafa-Mujtaba/45684ebcff3d915c155fee4a8d24accce5d699f4

Farooq, M., Cheng, J., Khan, N. U., Saufi, R. A., Kanwal, N., & Bazkiaei, H. A. (2022). Sustainable Waste Management Companies with Innovative Smart Solutions: A Systematic Review and Conceptual Model. *Sustainability*, *14*(20), 13146.

Faye, S., Melakessou, F., Mtalaa, W., Gautier, P., AlNaffakh, N., & Khadraoui, D. (2019, November). SWAM: A novel smart waste management approach for businesses using IoT. In *Proceedings of the 1st ACM International Workshop on Technology Enablers and Innovative Applications for Smart Cities and Communities* (pp. 38-45).

Frankenfield, J. (2023, August 9). *Data analytics: What it is, how it's used, and 4 basic techniques*. Investopedia. https://www.investopedia.com/terms/d/data-analytics.asp

Littlewood, W. (2022, November 4). *Task automation: Types of tasks that can be automated and how to automate them*. The All In One Project Management Platform - Teamwork.com. https://www.teamwork.com/blog/task-automation/

Kamm, M., Gau, M., Schneider, J., & Vom Brocke, J. (2020, January 7). Smart Waste Collection Processes - A Case Study about Smart Device Implementation. https://scholarspace.manoa.hawaii.edu/items/81034dfb-00e9-411e-98c3-e6859e1c716c

K. F. Haque, R. Zabin, K. Yelamarthi, P. Yanambaka and A. Abdelgawad, "An IoT Based Efficient Waste Collection System with Smart Bins," 2020 IEEE 6th World Forum on Internet of Things (WF-IoT), New Orleans, LA, USA, 2020, pp. 1-5, doi: 10.1109/WF-IoT48130.2020.9221251.

Mertelj, B. (2019, December 2). *What are innovative solutions?* PGN.global. https://www.pgn.global/post/what-are-innovative-solutions

Minhaz Uddin Sohag, Amit Kumer Podder, Smart garbage management system for a sustainable urban life: An IoT based application, Internet of Things, Volume 11, 2020, 100255, ISSN 2542-6605, https://doi.org/10.1016/j.iot.2020.100255.

Misra, D., Das, G., Chakrabortty, T., & Das, D. (2018). An IoT-based waste management system monitored by cloud. *Journal of Material Cycles and Waste Management*, *20*(3), 1574–1582. https://doi.org/10.1007/s10163-018-0720-y

Morgan, V. (2023). *Erratic garbage collection causing serious problems | Letters*. Jamaica Gleaner. Retrieved September 28, 2023, from

https://jamaica-gleaner.com/article/letters/20230317/erratic-garbage-collection-causing-serious-problems

Nathanson, J. A. (2023, July 2). solid-waste management. Encyclopedia Britannica. https://www.britannica.com/technology/solid-waste-management

National Solid Waste Management Authority . (2023, March 17). *About Us - National Solid Waste Management Authority - Jamaica*. National Solid Waste Management Authority - Jamaica - An Agency of the Ministry of Local Government and Community Development. https://www.nswma.gov.jm/about-us/

N. S. Kumar, B. Vuayalakshmi, R. J. Prarthana and A. Shankar, "IOT based smart garbage alert system using Arduino UNO," 2016 IEEE Region 10 Conference (TENCON), Singapore, 2016, pp. 1028-1034, doi: 10.1109/TENCON.2016.7848162.\

Oteng-Ababio, M., Ablo, A., & Wong, B. (2020). Community based solid waste management. In *Cost-Benefit Analysis of Urbanisation challenges in Accra, Ghana: Ghana Priorities* (pp. 26–32). Copenhagen Consensus Center. http://www.jstor.org/stable/resrep26145.7

P. Jajoo, A. Mishra, S. Mehta and V. Solvande, "Smart Garbage Management System," 2018 International Conference on Smart City and Emerging Technology (ICSCET), Mumbai, India, 2018, pp. 1-6, doi: 10.1109/ICSCET.2018.8537390.

Ray, S., Tapadar, S., Chatterjee, S. K., Karlose, R., Saha, S., & Saha, H. s. (2018, February 26). *Optimizing routine collection efficiency in IOT based ... - IEEE xplore*. Optimizing routine collection efficiency in IoT based garbage collection monitoring systems. https://ieeexplore.ieee.org/abstract/document/8301629/references

Rejeb, A., Rejeb, K., Simske, S., Treiblmaier, H., & Zailani, S. (2022). The big picture on the internet of things and the smart city: a review of what we know and what we need to know. *Internet of Things*, *19*, 100565. https://doi.org/10.1016/j.iot.2022.100565

Shah, B., Whipple, B., & Wilson, J. (2015, October 28). *How People Are Actually Using the Internet of Things*. Harvard Business Review. Retrieved April 26, 2024, from https://hbr.org/2015/10/how-people-are-actually-using-the-internet-of-things

Smart Garbage Monitoring System for Waste Management Norfadzlia Mohd Yusof, Aiman Zakwan Jidin, Muhammad Izzat Rahim MATEC Web Conf. 97 01098 (2017) DOI: 10.1051/matecconf/20179701098

Thompson, S. (2020). *A Policy Report on Improper Solid Waste Management in Jamaica*. Medium. Retrieved September 28, 2023, from https://iamshellyan.medium.com/a-policy-report-on-improper-solid-waste-management-in-jamaica-1b3dbd273705

Välimäki M, Hipp K, Chen J, et al Sensor technology to monitor health, well-being and movement among healthcare personnel at workplace: a systematic scoping review protocolBMJ Open 2021;11:e054408. doi: 10.1136/bmjopen-2021-054408

V. Aswin Raaju, J. Mappilllai Meeran, M. Sasidharan and K. Premkumar, "IOT Based Smart Garbage Monitoring System Using ZigBee," 2019 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN), Pondicherry, India, 2019, pp. 1-7, doi: 10.1109/ICSCAN.2019.8878742.

Zhang, A., Venkatesh, V. G., Liu, Y., Wan, M., Qu, T., & Huisingh, D. (2019). Barriers to smart waste management for a circular economy in China. *Journal of Cleaner Production*, *240*, 118198.

Appendix

Name	**Task**
Austin Peck	Delimitations, Significance, Concluding Remarks, Research Methodology, Animated video of IOT Based Garbage Collection, Findings and Recommendations.
Aviel Reid (**Group Leader**)	Definition of Key Terms, Reference, Contribution of Literatures, Findings and Conclusion From Project.
Kemar Christie	Limitations, Literature Review specific to the technical area being researched, Simulation of IOT Sensors, Research Questions
Steve Anderson	Research Methods, Literature Review (Specific Gaps), Findings and Summary.
Tyriece Parkinson	Background, Lit Review (Historical Overview) Research Methodology, Findings, Conclusion From Finding and Reference.