RECYCLINK:
CAPACITY-SENSING SMART BIN NETWORK FOR RECYCLING TRUCK ROUTE OPTIMIZATION

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1 Executive Summary

1.1 Addressing the Problem

Cities face significant challenges in managing their recycling systems efficiently due to high operational costs, environmental limitations, and population changes in urban areas. Our case study of New York City currently has systems that are extremely inefficient because of inconsistent collection schedules, underutilized recycling capacities, and rising fuel expenses. New York residents generate recycling waste every day; the lack of real-time monitoring to influence routes leads to increased emissions, community disruption, and missed opportunities for cost savings. Addressing these issues is critical to increasing efficiency in the recycling management system.

1.2 Proposed Solution

The new proposed system would be a sensor-integrated recycling bin that transmits data to a truck route planning algorithm to optimize the distance traveled by the recycling trucks.
Our specific project subsystem focuses directly on the capacity sensing and data transmission aspects of the greater system. The subsystem uses Time-of-Flight (ToF) sensors which were selected for their accuracy, environmental durability, and affordability. Data from these sensors is transmitted through Long Range Wide Area Network (LoRaWAN) to a centralized hub for analysis.

The mechanical design would integrate seamlessly with the new NYC bin standard with durable materials like HDPE and PET plastics to withstand the urban environments. The electronic design features low-power components powered by Nickel-Metal Hydride (NiMH) batteries with minimal recharging requirements, helping to support an idea of low maintenance and reliable performance. This design balances technical performance, cost efficiency, and compatibility with existing infrastructure.

1.3 Value of the Solution

The proposed solution aligns with stakeholder needs and objectives, offering multiple advantages:

- **Operational Cost Reduction:** Optimized routes cuts the number of trips in half, significantly lowering fuel consumption and operational expenses.
- **System Scalability:** The design integrates with the existing NYC bin infrastructure, allowing for smooth deployment and scalability across urban areas.
- **Environmental Benefits:** By reducing truck trips, we are reducing vehicle emissions and contributing to NYC's sustainability goals.

- **Community Experience:** Real-time monitoring and collection will improve neighborhood cleanliness, and a streamlined integration will lower and community disruption.

The system is cost-effective, with an estimated initial component cost of $35.75 per unit, which will only decrease in mass production. A detailed cost analysis also shows a probable return on investment within weeks of implementing it, driven by reductions in fuel and labor.

1.4 Summary

The integration of an IoT-enabled waste management system is a pivotal step toward addressing NYC's recycling inefficiencies. By balancing the needs of our stakeholders and using sensor technology to optimize routing we see cost savings, community benefits, and positive environmental impacts. This project not only addresses current challenges but also sets the stage for long-term improvements in the city's waste collection framework. Further details on the system's implementation plan and cost analysis are available in the full report.

2 Introduction

Waste collection is a fundamental component of urban infrastructure; it often operates on fixed schedules that disregard the actual fill levels of individual bins. This misalignment between collection frequency and waste generation leads to inefficiencies, including wasted resources, unnecessary costs, and preventable environmental harm. Research consistently highlights that bins become full before collection trucks begin their routes to service those bins, and that series of partially full bins are serviced unnecessarily, consuming fuel, time, and labor without adding value.

Existing literature shows the limitations of current waste management systems in studies where the traditional collection framework was found to be poorly aligned with urban structures and population distribution. This mismatch not only caused inefficiencies in collection routes but also escalated labor and operational costs. Similarly, reviews of existing smart bin solutions reveal gaps in functionality, as many systems focus solely on fill-level monitoring without enabling real-time route optimization or communication with waste management authorities. Compounding the issue is the reliance on static routing methods based on fixed factors like population density, which fail to accommodate the dynamic nature of waste generation.

The impacts of these inefficiencies are significant. Economically, recycling plants and organizations face increased costs due to redundant truck trips, excessive fuel use, and vehicle maintenance demands. Environmentally, unnecessary trips contribute to higher CO_2 emissions and degrade urban air quality. Socially, overflowing bins not only mar the urban aesthetic but also pose significant risks to public health by attracting disease spreading vermin.

While the need for a solution is clear, the path to implementation still has many challenges. Integrating sensor technology into existing waste management systems presents technical challenges, including optimal sensor choice, reliable data transmission, and system compatibility. The high initial cost of implementing these technologies can also deter organizations with constrained budgets.

Despite these obstacles, the potential benefits of a real-time, data-driven approach to recycling collection are substantial. Existing literature already proves that smart bin integration improves the efficiency in different areas of waste management systems, and that adding a real-time data transmission feature through some sort of internet network would be the next step to improving cost reductions further. While lower economic cost is our primary focus and objective, the additional impacts to the environment and social outlook of a city are added benefits and meet within our desired constraints. This integration is designed to be implemented through our case study in an already undergoing project to improve recycling efforts in New York. This report examines the feasibility of implementing such a system, addressing its technical, economic, and environmental implications.

3 Literature Review

Recycling systems have become increasingly important in urban settings, where population growth has led to a rise in recycling production and an increased need for more efficient processes. As smart city initiatives become more prevalent, automated systems for waste monitoring are critical to ensuring timely collection, optimized route planning, and reduction in operational costs. This review evaluates the existing infrastructure needed for such initiatives, past studies and their effectiveness at implementing these new systems, and current sensor technologies, presenting an analysis of their respective limitations and benefits.

3.1 Existing City Bin Infrastructure

Recycling infrastructure in urban areas plays a pivotal role in waste management, influencing both the efficiency and environmental impact of collection systems. However, cities across the United States differ in their approaches to recycling, with varying levels of standardization, accessibility, and operational complexity. These differences present unique challenges and opportunities for integrating IoT-enabled smart bins to optimize collection routes. By examining the recycling systems in Seattle, St. Louis, and New York City, this section highlights the limitations of existing infrastructure and identifies New York as the most suitable case study for implementing smart bin technology.

Seattle employs a recycling system with multiple tiers tailored to the city's diverse residential layouts. Smaller housing units utilize 96-gallon rolling bins provided and maintained by Seattle Public Utilities (SPU), while larger complexes and businesses rely on dumpsters or compactor systems (Figure 1a, Figure 1b, and Figure 1c). For instance, compactors (Figure 1c) are common in new or renovated buildings with more than 7-10 units [1]. This flexibility ensures accessibility for all residential types but presents significant challenges for smart bin integration due to the variation in container sizes and types. These differences complicate sensor standardization and real-time route optimization, reducing the system's overall efficiency for IoT-based waste management.

(a) 96-gallon Rolling Bin (b) Dumpster (c) Compactor

Figure 1: Recycling container types in Seattle [2][3][4].

Similarly, St. Louis offers residents a mix of collection options, including blue alley recycling dumpsters, 96-gallon rollcarts, and over 25 drop-off recycling sites provided by the city (Figure 2a, Figure 2b, and Figure 2c) [5]. This decentralized system provides wide accessibility, particularly for apartment residents without direct access to alley dumpsters. However, the dispersed nature of collection points and reliance on multiple container types pose logistical difficulties for implementing IoT-enabled solutions. Real-time data collection and route planning would require significant customization to accommodate the city's fragmented infrastructure, limiting the feasibility of a cohesive smart bin system.

(a) 96-gallon Rolling Bin (b) Dumpster (c) Dropoff Locations

Figure 2: Recycling container types in St Louis [6][7][8].

In contrast, New York City is actively transitioning toward a standardized recycling and waste collection system, positioning it as an ideal city for smart bin integration. Recent policy changes, effective November 2024, require all residents to containerize their trash, introducing the NYC Bin (Figure 3) as the standard option for properties with 1-9 residential units. Recycling, while mandated by the city, does not require the use of the standardized NYC Bin for recyclable materials [9]. However, it is reasonable to assume that many residents will adopt these bins due to their convenience and alignment with the city's broader waste management initiative. This standardization of bin design for trash and widespread adoption for recycling minimizes logistical hurdles, such as varying container dimensions and types, that often complicate IoT sensor implementation in other cities. By addressing these challenges more effectively than Seattle and St. Louis, New York's system supports a cohesive approach to optimizing recycling collection routes and minimizing costs and emissions.

Figure 3: The NYC Bin [10].

New York's transition to standardized bins reflects a broader effort to improve waste management infrastructure, making it uniquely suited for implementing IoT-enabled smart bins. Unlike Seattle and St. Louis, whose infrastructures hinder scalability, New

York's approach offers a streamlined, scalable foundation that aligns with the goals of our proposed system. Additionally, the mandated adoption of bins means a larger number of collection points are standardized, enhancing the effectiveness of a route planning system by providing more reliable data and maximizing the efficiency of routes. As such, New York provides an ideal environment to demonstrate the feasibility and impact of smart bin technology.

3.2 Routing Optimization Impacts for Cost

Studies consistently demonstrate that optimizing truck routes can significantly lower operational costs in waste management by reducing travel distances and fuel consumption. Sallang et al. explain that implementing strategies such as pre-planned patterns or integrating sensor data minimizes unnecessary travel, thereby reducing fuel expenses. Optimized systems incorporate factors like population density and real-time bin fill levels to adjust routes dynamically, avoiding redundancy and delays in the collection process [11]. Khan et al. emphasize that vehicles equipped with Internet of Things (IoT) tracking devices can operate far more efficiently, requiring roughly half as many trips as vehicles without such tracking, shown in Figure 4. This reduction in trips leads to significant decreases in fuel usage and operational expenses [12].

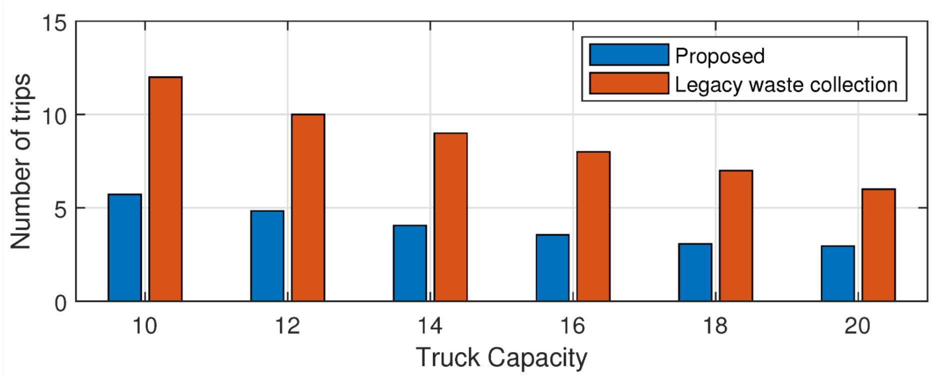

Figure 4: Comparison of number of trips between existing route planning and a fill-level route planning method [12].

A cost analysis in related studies highlights that implementing IoT-based waste collection systems with real-time bin capacity data can reduce the number of required trips by at least 50% compared to legacy systems. The fewer trips alongside the rest of system directly correlate to lower costs shown in Figure 5. Furthermore, a study conducted by Erfani et al., demonstrated the impact of route optimization using a capacitated vehicle routing problem model. The optimized routes resulted in a 48% reduction in travel distances during night shifts and a 57% reduction during day shifts, directly correlating to lower fuel consumption and operational costs [13].

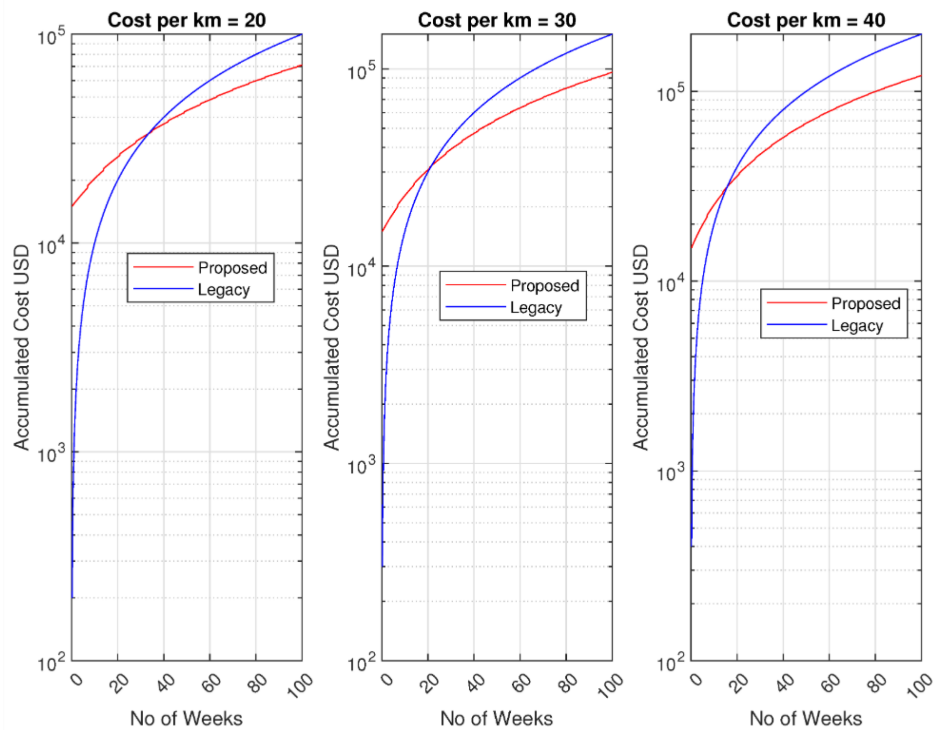

Figure 5: Cost analysis comparison of between existing route planning and a fill-level route planning method [12].

The data from Figure 5 shows three cases of a cost of 20, 30, and 40 USD per kilometer in a study cases. With enough time, the cost of implementing this system is nullified within 30 weeks, and that's if it only costs 20 USD per kilometer. If operational costs per kilometer is 30 or 40 USD, the system will show cost savings by weeks 20 or 17.

These findings strongly support the financial benefits of routing optimization. By using real-time data and advanced algorithms, waste management systems can achieve substantial cost savings, reduce environmental impact, and improve overall service efficiency.

3.3 IoT Capabilities with Joint Communication

The Internet of Things (IoT) is pivotal for developing intelligent waste management systems that incorporate sensors for data collection and remote monitoring capabilities. IoT-enabled sensors are essential for monitoring waste levels, bin status, and optimizing collection routes. Kishori et al. discussed a potential IoT-based framework involving a system "monitored by the cloud," where ultrasonic sensors would be used to detect waste levels and transmit data to a server for analysis. This data would then be used to inform route adjustments and schedule collections, allowing for an adaptive response to bin fill status [14].

This framework discussed by Kishori et al. of the communication between sensors and the cloud was confirmed to work in the study performed by Ismail, Zanawi, and Yusof and is demonstrated in Figure 6. Using an ultrasonic sensor connected to a Raspberry Pi, the Raspberry Pi was able to both send an email to a centralized address as well as use MySQL to store data and send that data to a Node-RED dashboard for monitoring [15]. This method allowed for multiple Raspberry Pi's to be connected to one database which ultimately verified the validity of the framework presented by Kishori et al. This ability to use IoT technology in combination with sensors would allow for a streamlined communication, automatic data collection, and optimized waste management processes, which would lead to a reduction in operational costs and environmental impact.

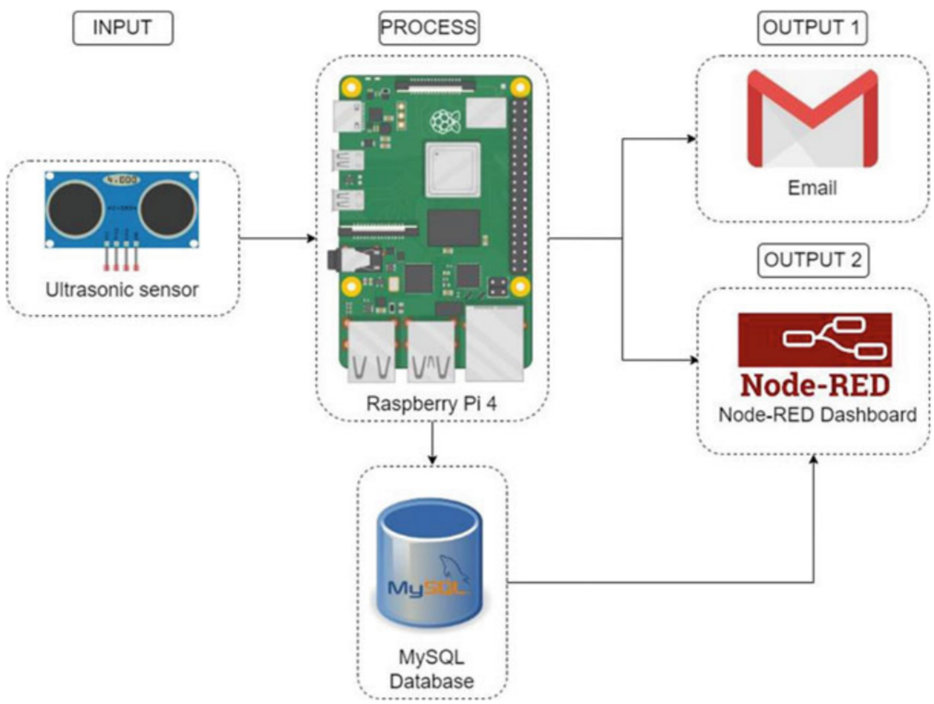

Figure 6: Example IoT framework block diagram [15].

To better suit the needs of our urban environment, we look to the study performed by Kaur and Singh. This study describes an IoT-based waste management system that "uses LoRa and TensorFlow deep learning for waste segregation and monitoring bin status." In this system, ultrasonic sensors monitor the percentage of bin fill, a GPS module collects real-time location data, and a LoRa module transmits information to a central receiver at a frequency of 915 MHz. This usage of LoRa would allow for the signals produced to pass through the dense urban environment surrounding the system and work to reduce the amount of data loss if internet was used [16].

The LoRaWAN tranciever method proved to have all of the benefits of the centralized frameworks from the studies by Kishori et al. and Ismail et al. With the additional upsides that LoRaWAN has in urban environments, it made it a clear choice for our data transmission final decision.

3.4 Sensor Technology

The use of sensing devices to monitor recycling bin fill status is integral to optimizing waste management operations. For our IoT-based bin proposal, the sensing system must meet key criteria: accuracy, reliability, and cost-efficiency. This ensures the system provides meaningful data, performs reliably despite environmental factors, and is cost-effective enough to offset initial investment through operational savings. To this end, we examined ultrasonic, infrared, optical, and radar-based sensors.

- Ultrasonic sensors, commonly used in waste management, operate by emitting sound waves and measuring the time delay of their reflection. These sensors are cost-effective and widely available; however, their performance can be inconsistent when faced with irregularly shaped or distributed waste. Additionally, environmental factors such as temperature and humidity can affect their accuracy, limiting their reliability in real-world scenarios [16].

- Infrared (IR) sensors detect objects through changes in heat signatures or light reflection and are also cost-effective. However, they require a clear line of sight, making them less effective when waste obstructs their beam. Additionally, their accuracy is compromised when dealing with materials that reflect IR light unevenly. These limitations restrict their adaptability and overall reliability in waste management settings [17].

- Radar sensors use electromagnetic waves to detect objects and reconstruct images, offering high accuracy and the unique ability to penetrate certain materials. This makes them particularly effective for volume estimation, even under challenging conditions. Despite their reliability and precision, radar sensors are significantly more expensive, making them impractical for large-scale waste management systems due to high initial costs [18].

- Optical sensors, on the other hand, provide a high-resolution alternative for waste detection, leveraging light-based measurement to capture detailed data, such as the shape and color of objects. These sensors are less affected by environmental conditions compared to ultrasonic or infrared options. While optical sensors are costlier than ultrasonic and infrared solutions, they offer enhanced recognition capabilities and are better suited to managing irregular or complex waste configurations [16].

Among these options, the optical Time-of-Flight (ToF) sensor, shown in Figure 7, combines the strengths of ultrasonic and optical technologies. ToF sensors measure distances with high accuracy while maintaining resilience to environmental variations, such as changes in lighting or bin contents. By integrating precise distance measurement with environmental tolerance, ToF sensors address the shortcomings of ultrasonic, infrared, and radar sensors. Furthermore, their performance and cost-effectiveness make them an ideal choice for our system. This combination of advantages ensures a robust waste management solution that supports optimized collection routes, minimizes errors, and aligns with the sustainability goals of smart cities.

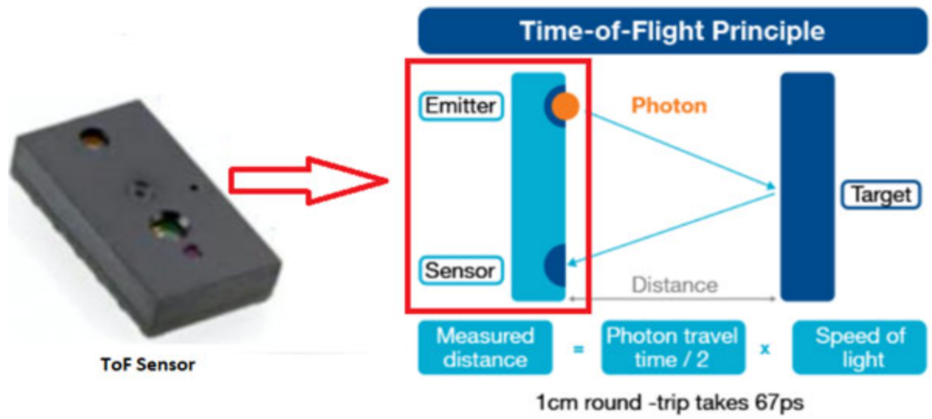

Figure 7: Time of Flight(ToF) sensor [19].

3.5 Summary

This literature review underscores the feasibility of employing advanced sensor technology and IoT-based communication to optimize waste management operations in existing city infrastructures. Studies confirm the benefits of route optimization, cost reduction, and real-time monitoring via IoT, making recycling collection more sustainable and efficient. Current evidence suggests that ToF sensors could serve as a reliable, effective tool for fill-level monitoring in smart recycling systems. Integrating ToF sensors, alongside IoT infrastructure, presents a promising direction for future advancements in waste management solutions.

4 Case Study

It is clear that these inefficiencies occur in all urban environments. As a case study, we have decided to focus on New York City due to its ongoing efforts to modernize waste management infrastructure. The Department of Sanitation for New York (DSNY) has launched a comprehensive initiative to address the visual, health, and logistical challenges posed by traditional waste collection methods. This initiative involves transitioning from trash bags left on curbs to a standardized, rodent-proof bin, dubbed the NYC Bin, that consolidates waste in a more controlled and sanitary manner [9].

New York City's ambitious containerization program presents a unique opportunity for innovation. While the program primarily aims to remove trash bags from the streets to combat the city's rodent problem, it also provides an avenue to promote sustainable urban practices. These ongoing efforts to improve waste management can be expanded to normalize and encourage recycling, integrating it as an essential component of the city's broader sanitation strategy. This approach not only tackles persistent cleanliness challenges but also creates a standardized infrastructure into which new technologies, like our proposed smart bins, can be seamlessly incorporated to optimize recycling collection.

Our project builds on this foundation by enhancing the functionality of the NYC Bin with IoT sensors that monitor fill levels in real time. By integrating our technology into the existing bin distribution process, these smart bins can provide valuable data to optimize recycling routes. Focusing on New York City allows us to demonstrate the potential of our system in a dense urban environment with an ongoing citywide program. With its large-scale waste generation and diverse recycling needs, New York serves as an ideal testbed for validating the technical, economic, and environmental benefits of our smart bin solution.

5 Stakeholder Analysis

New York City's recycling ecosystem is populated by a varied group of stakeholders. This group is a mix of public and private entities, legislators, and regulators. These entities weave a complex web of connections. To reduce this complexity, we have identified 4 types of stakeholder in the recycling space. Table 2 names and provides examples of the stakeholders in recycling for New York City.

Table 1: Stakeholders and Examples

Stakeholder	Examples
Policymakers	United States Congress, New York City Council
Regulators	Environmental Protection Agency
Operators	New York City Department of Sanitation
Community	Residents, Local Businesses

5.1 Stakeholder Identification

5.1.1 Policymakers

Policymakers have the highest control over the recycling space, as they control the regulatory bodies governing recycling. For example, the passing of the Resources Recovery Act of 1970 brought about state-level solid waste management programs across the country [20]. In drafting legislation, policymakers balance the needs of regulators, operators, and the will of the community.

5.1.2 Regulators

Regulators like the Environmental Protection Agency (EPA) enforce the laws passed by policymakers. For example, in accordance with the Clean Air Act, the EPA implemented the ban on uncontrolled solid waste burning [20]. The EPA is joined by the New York State Department of Environmental Conservation, with the two regulating the solid waste management of the State of New York. We found that regulators role in New York's recycling system is largely monitoring emissions. We are confident that our system will not interact with regulators, and will not violate any environment restrictions.

5.1.3 Operators

New York City's recycling is operated by both public and private entities. The New York Department of Sanitation (DSNY) handles recyclable collection, and delivers unsorted materials to material reclamation centers. Private entities sort, process, and transport reclaimed materials to manufacturers for reuse. Operators overall need to service the community by conducting recycling while complying with regulations. This position puts pressure on operators to satisfy all stakeholders in the space.

5.1.4 Community

The community represents private citizens and local businesses. The will of the community indirectly controls the operators through the decisions of policymakers and regulators. This is exemplified by New Yorkers' outcry against the rat population, which lead to the containerization program [21].

5.2 Stakeholder Prioritization

Our identification and categorization of stakeholders showed that Policymakers and Regulators would have negligible impact on the effectiveness of our system. We have chosen to prioritize operators and the community as our primary stakeholders for the design. An operator's primary need is a reliable data input into a route-planning algorithm. The technical aspects of which are discussed in the following section of this document. The community needs the system to be minimally disruptive, as the containerization program itself has already disrupted recycling for New York residents [22]. The containerization mandates that New Yorkers buy an official trash bin else incur fines from the city. A disruptive data collection system installed on bins would exacerbate the issue. We see the needs of the operator and community as mutually attainable, and as a result we believe we can prioritize both equally.

6 Design Rationale

The findings of the literature review suggest that implementing a recycling collection routing algorithm informed by container fullness will effectively reduce overhead cost on recycling operators. A sensor unit is required in each individual bin to supply container fullness data to the route planning algorithm. The following design review shall describe the requirements and implementation of the sensor unit implemented into recycling containers.

6.1 Design Requirements

The sensor unit must be designed to operate within the conditions and constraints of current DSNY recycling operations. To reduce the cost of operations, the sensor unit must be low cost such that the initial investment by the operators will be minimal. The sensor unit must be accurate such that data provided to the routing algorithm will have a low rate of false bin-fullness detections. In terms of reliability, the subsystem shall be resistant to all weather conditions and external factors. These factors include but are not limited to; snow, rain, collisions from the disposal of recyclables, and rodents. In terms of cost, the subsystem shall be composed of low cost materials and require little maintenance. In terms of integration, the subsystem shall function with existing container emptying mechanisms and require infrequent charging by residents.

6.2 Electronic Design

Given its higher accuracy compared to other sensors for measuring the volume of complex geometries, a ToF sensor shall be utilized for the sensor unit. In terms of connectivity, a LoRaWAN radio transceiver shall be utilized to transmit bin fullness data to operators. The LoRaWAN radio was selected over traditional WiFi transceivers due to its lower power usage, longer range, and ability to automatically form a mesh network with other bins. The subsystem shall be powered by a Nickel Metal Hydride (NiMH) battery; a reliable and more stable alternative to traditional Lithium Ion batteries due to their low self-discharge rates and chemical stability when punctured. Shown below in Figure 8 is a component level diagram of the sensing unit.

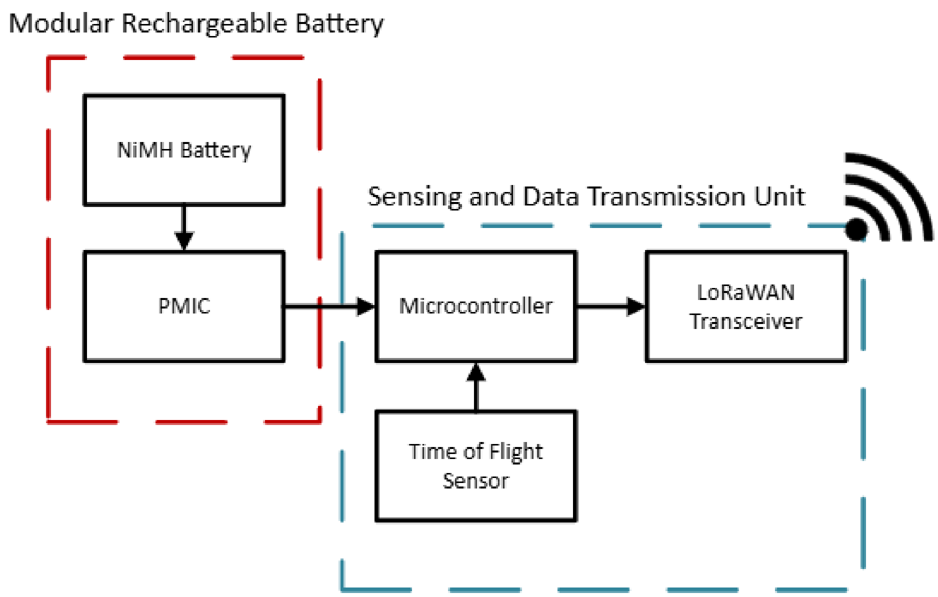

Figure 8: Component Level Diagram of Electronics Design

The sensing unit shall utilize a removable battery unit, supported by a Power Management Integrated Circuit (PMIC) which allows residents to recharge the unit without the safety risk of handling an open battery. The subsystem shall employ a messaging system in which the operator automatically sends a notification for the owner of the bin to recharge the battery when needed.

6.3 Mechanical Design

The sensing unit shall be integrated into the center of the lid of existing DSNY containers to facilitate compatibility with preexisting container-emptying truck mechanisms. The placement of the subsystem is shown below in Figure 9.

Figure 9: Rendering of Sensing Unit Placement on DSNY Bin

The subsystem shall utilize an High-density polyethylene (HDPE) enclosure to protect its components. HDPE, a recyclable and durable plastic, was chosen as the material for the enclosure due to its current use by the DSNY in recycling containers as a weather resistant and rodent resistant material. A lens for the ToF sensor shall be constructed from Polyethylene terephthalate - a recyclable plastic which is waterproof, electrically insulating, and durable against impacts. The size of the enclosure is constrained such that it may be large enough to fit both the removable battery and electronic components.

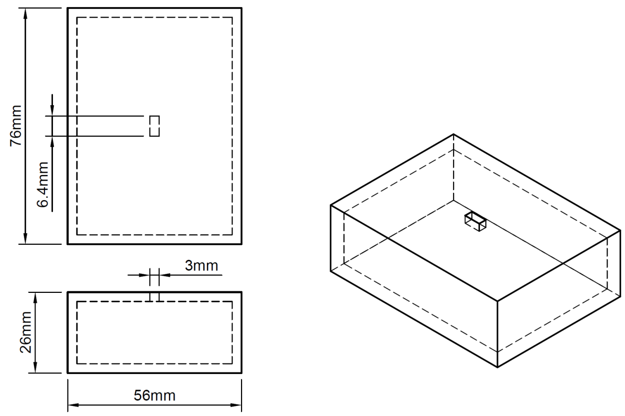

Figure 10: Mechanical Drawing of Enclosure

In terms of a preliminary analysis using Commercial Off-The-Shelf (COTS) components and allowing for a 3mm wall thickness, the dimensions of the enclosure are approximately 56mm by 26mm by 76mm.

6.4 Cost Analysis

The cost of the subsystem shall be low enough such that it does not place a burden on the residents who are required to purchase the containers. In order to model potential cost, COTS components were selected to create a preliminary cost analysis. The table below displays the preliminary cost analysis [32][33][34].

Table 2: Preliminary Cost Analysis

Component	Cost
Microcontroller with LoRaWAN Transceiver	$21.90
NiMH Battery	$3.88
PMIC	$9.02
Total	$34.80

It should be noted that, when manufactured at scale, the cost of the subsystem will be significantly lower than modeled due to bulk purchasing and streamlined components.

For instance, the microcontroller and LoRaWAN tranceiver board when custom designed and produced at mass scale would cost less given that its design could be streamlined since not all of the features of the COTS version are necessary to the sensing unit.

7 Conclusion

While our system has been shown to be efficient and effective in the aid of recycling collection through literature, the fact remains that this system has yet to be tested and validated. To address this limitation in the research, we have created the next steps to continue this research and validate they system. These three steps are to create an individual prototype, test the prototype in the field, and find a way to deploy the system.

7.1 Prototype (Individual)

The first step is to create a prototype of the individual system to verify the efficacy of it. When creating this system there are four requirements it must pass which are as follows:

1. The ToF sensor must be able to both accurately and reliably sense the level of recycling of a given bin. This is to ensure that data from the ToF sensor is reliable. Additionally it will also provide information about error margins of the sensor.

2. The information provided by the ToF must be sent to an external server via LoRaWAN. This is to ensure that data can be transmitted wirelessly which is essential to provide real time data to the route planner.

3. The battery must be able to supply power for a substantial amount of time. This is to ensure the system can run autonomously for extended periods which will reduce the amount of labor needed to maintain the system.

4. The system must be low cost. This is to ensure that adoption of the system would lead to minimal negative impact on our community stakeholders.

Once all of these requirements are met, proceed to the second step of field testing the prototype.

7.2 Prototype (Field Test)

The second step is to verify that the prototype can both work in an urban environment and prove to be effective. This step involves creating a small batch of prototypes and encasing them in HDPE. Afterwards, attach these prototypes to the lid of multiple recycling cans and perform a small test of system with route planning. In this test, there are two requirements it must pass which are as follows:

1. The information provided by the ToF must be sent to an external server via LoRaWAN. This is to ensure the system can reliably send data to an external server while maintaining stable operation when in an urban environment

2. The system must prove to increase efficiency of route planning compared to without it. This is to ensure that when the system is in use, it will prove beneficial to the stakeholders.

If either of these requirements are not met, then proceed back to the first step and redesign the prototype so that it can succeed in an urban environment. Otherwise, the system is considered validated to work in the field and procedure to the final step is granted.

7.3 Deployment

The last step is to verify that this design can be deployed on a mass scale. When verifying deployment, there are 2 requirements that must be met which are as follows:

1. NYC Recycling Bin Manufactures must be able to integrate this system into the recycling bins. This is to ensure that the system can be adopted into current standardize bins.

2. The manufacturing cost of integrating the system must not substantially increase the price of the bin. This is to ensure that negative impact on community stakeholders is kept to a minimum.

If all these requirements are met, then the system has been validated and is ready for mass production.

A visual representation of the steps are provided below in Figure 11 to better visualize how to validate the efficacy of this system.

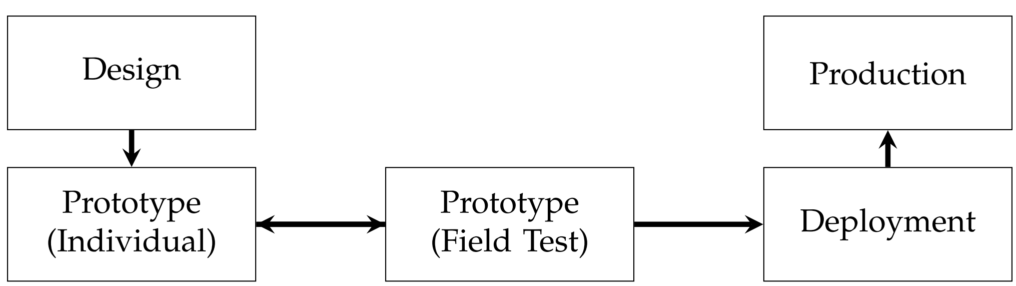

Figure 11. A diagram that shows the timeline of how to navigate the next steps of validation of the system.

While this system has yet to be verified, both the literature and the steps to verification lead to the conclusion of the feasibility that not only can this system be integrated, but it would prove effective. Overall the integration of an IoT-enabled waste management system with route planning would be a pivotal step toward addressing NYC's recycling inefficiencies.