

CHANGEMAKERS: CREATIVITY AND VALUE CREATION

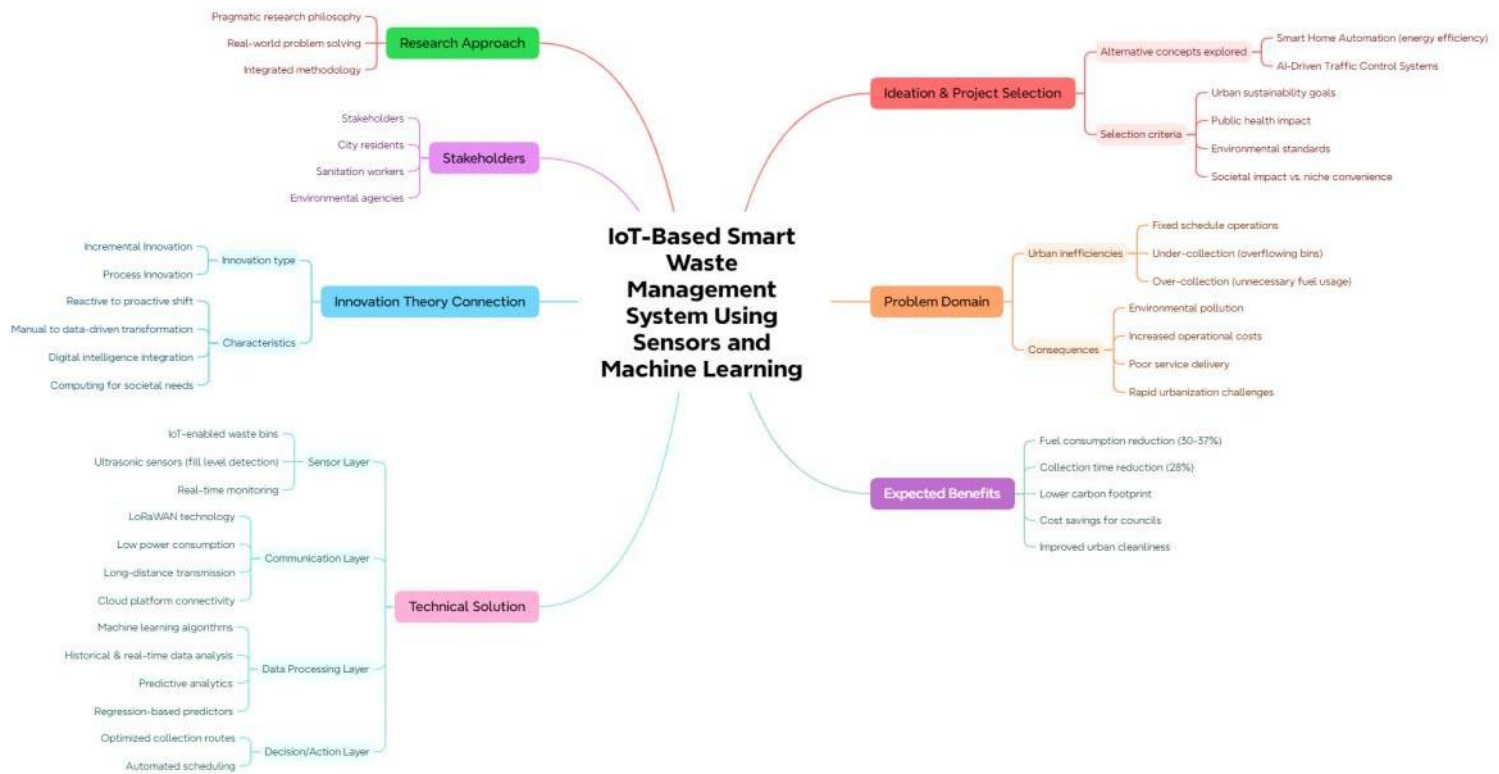
BSC APPLIED COMPUTING

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TASK 1:Ideation & Mind Map



IoT-Based Smart Waste Management System Using Sensors and Machine Learning

Project Selection & Ideation Process.

The ideation phase was used to brainstorm on some of the possible digital solutions to urban challenges before selecting the final project. First of all, a mind map was developed to brainstorm other ideas, such as Smart Home Automation to be energy efficient and AI-Driven Traffic Control Systems to decrease congestion. However, the **IoT-Based Smart Waste Management System** was chosen after considering these alternatives in comparison with the current sustainability objectives in the world. This move was necessitated by the fact that the city had to deal with the much-needed reform of the “persistent inefficiencies” in urban sanitation that have a direct effect on the overall health of the population as well as the environmental standards. While the smart home solutions are more convenient in a specific niche, the efficient waste management gives a broader impact on society and the environment, which fits the scope of the module focus on, “How Innovation Shapes the world.”

Problem Domain & Context

Contemporary cities still have severe inefficiencies in conventional waste collection. Traditional systems use fixed schedules rather than real waste levels, leading to overflows and wasted fuel. These issues have the effect of polluting the environment, high operations costs, and service delivery. High urbanization in developing countries has only increased those problems and thus created the need to have scalable and technology-driven frameworks (Atofarati *et al.*, 2025). This project suggests an intelligent system that combines machine learning analytics and real-time sensor monitoring to make urban waste collection optimal.

Technical Solution & System Concept

The proposed system will be built around IoT-based waste bins that have ultrasonic sensors to monitor real-time fill-up of garbage on waste bins. These sensors send the information to a central cloud platform through the technology of the Long Range Wide Area Network (LoRaWAN) which is chosen due to its low power consumption and capability to transmit information across large distances in the densely populated urban areas (Najikethus *et al.*, 2024).

The Data Processing Layer applies ML to compare historical and real-time data. This system will be predictive with analytics on how soon a certain bin is going to be full, unlike the static model (Adekoya and Ogbolumani, 2025). The system can be used to automatically create optimized collection routes using models like a regression-based predictor (Wang *et al.*, 2025). Recent industry research indicates that optimization of routes using AI model will help to save about 30-37% of fuel, almost 28% of collection time, which will significantly decrease the carbon footprint of sanitation fleets (Market.us, 2024).

Besides prediction and routing, the system will have smart decision-support dashboard that will show real time bin location, projected fill cycles and recommended routes that will be used by the city managers. At the bin level, edge computing also could be added to pre-process sensor data to avoid network

congestion and enhance responsiveness when the network was busy. The cloud platform will also have automated anomaly detection to indicate sensor errors, abnormal fill patterns or vandalism to increase the reliability of the system. End-to-end encryption and authenticated device registration will be given the top priority to ensure the integrity of the data. Through this extended architecture, it is scalable, and can support thousands of smart bins over the increased urban metropolitan regions.

Connection to Innovation Theory

This project is a kind of Incremental Innovation developed into Process Innovation in the context of the online section “How Innovation Shapes The World”. It does not create a brand new product, but rather transforms the method of service delivery, radically improving on the reactive, manual approach of service delivery into a proactive, data-driven one. The project, through the incorporation of digital intelligence into the existing physical infrastructure (waste bins and collection trucks), is an example showing the application of computing technology in society. This correspondence indicates the contribution of creativity, i.e., applying ML to mundane logistics, to bringing actual value to society, particularly, to minimizing the costs of local councils and maximizing the cleanliness of residents.

Stakeholders & Objectives

The project includes such key stakeholders as local councils, city residents, sanitation workers and environmental agencies. Ideally each group will gain access to a lower pollution level, improved service delivery, and an improved operational planning process. The conceptual framework will be arranged into four layer: The Sensor Layer, The Communication Layer, The Data Processing Layer and the Decision / Action Layer . The general project follows a pragmatic research philosophy, which promotes methodological integration to solve the real-life problems in a practical manner (Atofarati *et al.*, 2025).

Reference

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Task 2: Aim, Objectives, and Research Area

Topic: IoT-Based Smart Waste Management System Using Sensors and Machine Learning

Project Aim and Objectives (Q1)

Project Aim

This project aims to design, develop, and to conceptually assess a prototype Smart Waste Management System, which is an Internet of Things (IoT) sensor-based system that merges machine learning (ML) analytics with the sensor. The objective is to overcome the inefficiency of the traditional standard static waste-collection schedules that tend to make unnecessary trips, raise the costs of operation, and have environmental effects. The research aims to present how urban centres can decrease fuel consumption, enhance their waste-collection and minimise carbon emissions by illustrating a system that can monitor real-time fill-level and the dynamic route optimisation (Sarker, 2021).

Project Objectives

The study will use the following SMART objectives in order to meet the aim:

- To review existing issues in the field of urban waste management through the analysis of literature released between 2020 and 2025, in particular, sensor constraints and communication standards, including Wi-Fi and LoRaWAN.
- To create a conceptual architecture with the real-time visualisation of a cloud-based dashboard, integration of ultrasonic sensors, (HC-SR04), and ESP32 microcontroller.
- To build a predictive ML model, using algorithms like the Random Forest or LSTM to predict the level of bin fill based on past patterns.
- To evaluate the system by the use of simulated data and test the accuracy of the optimisation of routing in various situations of waste generation.
- To assess the ethical and environmental concerns related to the implementation of the distributed sensor networks, consideration on the data privacy, energy usage, and longterm sustainability.

Research Philosophy (Q2)

This project employs *Pragmatic research philosophy*, which is suitable in applied engineering and computing research is focused on finding possible solutions and does not follow one perspective of the world (Saunders et al., 2023). Pragmatism is moderate in methodology and has the ability to accommodate the technical and human-centric aspects of the problem.

Flexible reasoning is often needed in solving technological problems as described in Unit 1 Topic 2. Strict interpretivism, focusing on the perceptions of the users, does not have the empirical rigour required in sensor-network design. Pure positivism that focuses on scientific measurement may ignore behavioural patterns that determine garbage disposal. Pragmatism fills these shortcomings in that it enables the research to co-exist with quantitative experimentation; to measure sensor accuracy and network latency; and to conduct qualitative evaluation to measure the usability and feasibility of the system. The current information systems literature also emphasizes pragmatism as a useful paradigm in artefact-focused research in the sense that it gives importance to practical results and context-sensitive knowledge (Goldkuhl, 2020).

Research Tools, Databases and Search Strategy.

A search strategy has been created systematically to provide access to valid and up-to-date evidence to support the system architecture and methodological choices.

Databases and Search Tools

The following repositories will be prioritised:

- The IEEE Xplore: To research on the sensors, embedded systems, and wireless protocols.
- ACM Digital Library: ML applications, system-architecture research, and design of algorithms.
- ScienceDirect: To access more literature of the environmental engineering and smart-city development.
- Google scholar: To track citations and do additional searches.

Search Strategy and Keywords.

Efficient search strings will be generated using the following Boolean operators:

- (IoT" or "Internet of Things") AND “waste management” and “optimization.”
- “Machine Learning” OR "Deep Learning" AND “Smart City” and “Sensors.”

Inclusion and Exclusion Criteria.

So as to be academically accurate:

- Inclusion: Peer-reviewed articles and conference papers published in 2020-2025 and that include the empirical data on the smart-city or sensor-based system.
- Exclusion: Blogs, uncited white papers, older sources before 2020, and the studies that did not concentrate on the logistics of waste collection but on the treatment of biological wastes.

This is a systematic method of ensuring that the research is based on the current technological standards and is not dependent on the obsolete methodology.

To extend the credibility of the literature search, one more screening process will be introduced to estimate the quality of the methods used by each of the selected sources. Research will be evaluated by its lucidity in regard to research design, openness in data gathering, and applicability to the IoT architecture or machine learning optimisation in waste systems. The use of citation chaining will also enable the identification of the influential works, which are often mentioned in various publications. In cases where contradictory evidence is found in the literature, e.g. varying interpretations of LoRaWAN bandwidth efficiency or ML accuracy, a comparative analysis will be conducted to find the most technically plausible results. This is an improvement that secures a stricter evidence base on system design decisions

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Task 3: Research Strategies

Topic: IoT-Based Smart Waste Management System Using Sensors and Machine Learning

Strategies for Validity, Reliability, Generalisability, and Ethical Considerations

Ensuring methodological rigour is essential for maintaining the academic and practical integrity of this IoT-based study (Saunders et al., 2023).

Validity and Reliability

Validity determines the effectiveness of the research in measuring the targeted constructs. To ensure content validity, the questions in the survey concerning the interaction of the users with the smart waste bins will be formulated in accordance with the constructs of Technology Acceptance Model (TAM). Triangulation will be implemented based on the comparison of quantitative data on the frequency of bin overflow with qualitative information by maintenance personnel and aligning the reported problems with the functional realities (Creswell & Creswell, 2023).

The reliability or the consistency of the results will be enhanced by the application of a standardised questionnaire to reduce the differences in interpretation by respondents. In the qualitative part, coding decisions will be documented in the audit trail to provide the transparency and allow an external review.

Generalisability

Even though the implementation is based in a particular institutional or community setting, analytical generalisability will be sought. Results will be contrasted with using larger literature on smart-city infrastructure to justify usage in other settings (Bell et al., 2022). The transferability of results is further increased by inclusion of various stakeholders-students, administrators, and waste collectors.

Ethical Considerations

- Informed Consent: Before their participation, the participants will be given detailed information on the purpose of the study, procedures, and rights to withdraw.
- Data privacy: The data will be anonymised and kept safely as per the principles of GDPR.
- IoT Ethics: Ethical risks of data security and potential surveillance existing with sensor-based systems will also be evaluated as part of the project (Stahl et al., 2023).

Pilot Data Collection and Research Strategies.

Mixed Methods Sequential Explanatory Design will be used with the initial approach to quantitative data to find the general tendencies, followed by qualitative data to contextualise and explain those trends.

Data Collection Methods

1. Quantitative Surveys: A sample of more than 50 users will receive an online questionnaire aimed at gauging the views on the existing waste-management inefficiencies and willingness to adopt smart-bins.
2. Qualitative Interviews: Semi-structured interviews with staff of facility and waste-managers will offer operating data that is not available in surveys.
3. System Testing: Simulations of ultrasonic sensors will be created that will be used to test the precision of the machine-learning model that predicts the level of bin-fill.

Telemetry logs will also be generated by the system and will be used during sensor simulations. The logs will capture network transmission periods, lost packets, latency bursts, and abnormal activities within the IoT network. The comparison between technical performance and user-reported experiences enhances internal validity with the help of the analysis of such logs. Situational factors that were noted through observational field notes in the process of testing the prototype will include the interference of the environment, misalignment of sensors, or network congestion. The integration of user-centred, system-centred and observational data allow the research to engage in deeper methodological triangulation and generate a more detailed picture of system behaviour and interaction between the user.

Pilot Study

Pilot questionnaire was conducted in relation to three participants, three potential users and two IT specialists. Another meta-evaluation of clarity and time taken to complete was also done. Clarification on terminologies like *ultrasonic latency* was brought up, and they were changed to easier terms (e.g., *sensor response time*) to make the terms easier to understand and achieve more accurate results.

Quantitative and Qualitative Analysis.

Quantitative Analysis

Data will be analysed with the use of SPSS or Python data analysis programs via surveys and sensor simulation data.

- Descriptive Statistics: The frequency distributions and the measures of central tendency will be used to summarise the demographic data and the waste-management concerns.
- Inferential Statistics: T-tests will be used to compare the level of acceptance where relevant to include students and staff among others.
- Predictive Modelling: Sensor data will be predicted with regression algorithms and measured against MAE and R-squared indicators (Sarker, 2021).

Qualitative Analysis

It will be based on a Thematic Analysis approach (Braun and Clarke, 2021).

- Coding: Primary codes will be created from transcripts review (e.g., "route inefficiency," vandalism concerns).
- Theme Development: Codes will be narrowed down to larger themes like Operational Feasibility and User Trust in Automation that will provide a context in which the quantitative findings will be interpreted.

References

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