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Implementation of Finite State Automata to Optimize the Waste Collection Process in the Greenify Application

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Abstract

Efficient waste management is a major challenge in urban life. One promising solution is the use of Finite State Automata (FSA) to optimize the waste containment process within the Greenify application. This study aims to explore the application of FSA in designing the logical flow for waste management, which includes identifying waste types, collection locations, and pick-up schedules. The methodology employed is a theoretical approach that implements the FSA model to regulate statuses and transitions between different steps in the waste management process. The results demonstrate that FSA can improve operational efficiency, reduce management errors, and enhance the user experience. The application of FSA in Greenify facilitates a more structured and automated waste management system, while also improving the accuracy of scheduling and waste collection. This conclusion highlights the significant potential of FSA as a technological solution for environmentally friendly waste management, with the goal of optimizing the performance of the Greenify application and advancing urban waste management practices.

Keywords: *Automata Theory, Finite State Automata, Green Technology, Waste Management.*

1. Introduction

Effective and efficient waste management remains a significant challenge in modern life, particularly in rapidly growing urban areas where population density and waste generation rates continue to increase exponentially [1][2]. Improperly managed waste not only contributes to environmental degradation such as pollution of land, water, and air but also poses serious health risks to communities and exacerbates social problems, including reduced quality of life and increased economic burdens[3][4][5]. Consequently, there is a pressing need for advanced technologies that enable more structured, automated, and intelligent waste management systems to address these multifaceted challenges[6] .

One promising approach to achieving this is the use of Finite State Automata (FSA), a mathematical and computational model extensively utilized in fields such as computer science, formal language theory, and systems engineering [7]. FSA models systems as a finite number of distinct states, with well defined transitions between these states triggered by specific inputs or events. This capability makes FSA particularly suitable for modeling and controlling processes that involve sequential decision-making and state-dependent behavior, such as waste collection and sorting operations.

In the context of waste management, FSA can be employed to represent the various stages of the waste collection process such as waste detection, segregation, transportation,

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and disposal each corresponding to a unique state within the automaton. Inputs such as sensor data, user interactions, or environmental conditions can trigger transitions between these states, enabling the system to respond dynamically and efficiently to real-time conditions. For example, an FSA-based system can automatically switch from a "waiting" state to a "collection" state when a sensor detects that a waste bin is full, thereby optimizing collection routes and schedules[8].

The Greenify application leverages the FSA concept to enhance the automation and accuracy of waste management tasks. As a technology driven platform, Greenify integrates sensors, user interfaces, and backend algorithms modeled on FSA principles to streamline the entire waste management workflow[9]. By clearly defining operational states and transitions, Greenify can reduce human error, improve resource allocation, and ensure timely waste collection and processing. This results in increased operational efficiency, reduced environmental impact, and a more user-friendly experience for individuals and municipalities alike.

Moreover, the use of FSA in Greenify facilitates scalability and adaptability. As urban environments evolve and waste management requirements change, the FSA model can be easily updated or extended to incorporate new states and transitions, such as integrating recycling incentives or handling hazardous waste[10]. This flexibility makes Greenify a robust and future-proof solution for sustainable urban waste management.

The waste container process in the Greenify application requires a system capable of recognizing specific conditions, such as waste type, collection location, and collection schedule. In this context, Finite State Automata (FSA) can be employed to design a logical flow that regulates the management process, optimizes collection timing, and ensures that each step in the waste management workflow is executed correctly[11]. This study aims to explore the application of FSA in optimizing the waste container process within the Greenify application. By integrating FSA, it is expected that waste management will become more efficient, operational errors will be minimized, and the overall user experience will be enhanced. Additionally, this study seeks to provide deeper insights into the potential of FSA as a technological solution for addressing challenges in automated waste management systems.

2. Related Work

Various studies have extensively explored the implementation and utilization of Finite State Automata (FSA) across diverse fields, demonstrating its versatility and effectiveness in modeling sequential processes and decision-making systems. For example, one notable study titled *"Implementation of Finite State Automata on Vending Machines in Carrying Out Book Return Transactions in Libraries"* investigates how FSA can be applied to automate the process of book returns via vending machines in libraries[12]. This research highlights how FSA can model the states and transitions involved in user interactions, ensuring smooth and error-free transactions by clearly defining each step in the process—from book insertion, verification, to confirmation of return. The study emphasizes how FSA's structured approach helps in managing complex user inputs and system responses, reducing the likelihood of errors and improving overall system reliability.

Similarly, another study, *"Implementation of Finite State Automata (FSA) with Vending Machine Simulation on Android Applications,"* focuses on simulating vending machines on Android platforms using FSA. This study aims to provide users with a clear understanding of vending machine operations by modeling the system's states and transitions, thereby facilitating practical applications tailored to user needs [13].By breaking down the vending machine's operation into discrete states such as idle, selection, payment, and dispensing, the study demonstrates how FSA can simplify the design and implementation of interactive systems. This approach not only aids developers in creating more intuitive applications but also enhances user experience by providing predictable and consistent system behavior.

Beyond these specific applications, these studies collectively underscore the broader potential of FSA to simplify complex processes by breaking them down into manageable states and transitions, which can be systematically controlled and optimized. The ability of FSA to represent real-world processes as a series of well-defined states makes it an invaluable tool in automation, where precision and reliability are paramount. Moreover, FSA's mathematical foundation allows for formal verification and validation, ensuring that systems behave as intended under all possible conditions.

In the context of waste management, these principles are particularly relevant. Waste container processes often involve multiple stages such as detecting container status, user interaction for waste disposal, and scheduling collection. Applying FSA to model these stages allows for clear definition of each state and the conditions that trigger transitions, enabling automation systems like the Greenify application to operate more efficiently and accurately. This structured approach helps in minimizing human error, optimizing resource allocation, and improving overall system responsiveness.

Furthermore, the adaptability of FSA means it can be customized to accommodate various scenarios and user behaviors, making it a flexible solution for dynamic environments like urban waste management. By leveraging insights from previous research and the inherent strengths of FSA, this study aims to contribute to the development of smarter, more sustainable waste management systems that can be integrated into broader smart city initiatives.

Automata Language Theory

Automata Language Theory, a foundational area in theoretical computer science, provides a rigorous framework for modeling and analyzing systems that process sequences of inputs through abstract machines known as automata. These models, including Finite State Automata (FSA), Pushdown Automata, and Turing Machines, are instrumental in recognizing formal languages by transitioning between defined states based on input symbols[14]. In the context of waste management, particularly within smart and automated systems, this theory offers powerful tools to model complex sequential processes such as waste detection, sorting, user interaction, and scheduling. By representing these processes as states and transitions, automata enable systematic control, error handling, and decision-making automation, which are critical for efficient and reliable waste management operations[15]. For instance, a smart waste container system can be modeled using FSA to manage states like idle, waste detection, sorting, full container, collection scheduling, and error handling, ensuring smooth transitions and robust performance. Moreover, the formal verification capabilities inherent in automata theory guarantee that system behaviors adhere to intended specifications, enhancing reliability[16]. The scalability and flexibility of automata models allow for easy adaptation to evolving waste types, user behaviors, and integration with broader smart city infrastructures. Consequently, automata-based approaches not only improve operational efficiency but also contribute to the development of intelligent, user-friendly, and environmentally sustainable waste management solutions. As waste management systems increasingly incorporate IoT and machine learning technologies, the combination with automata theory promises even greater adaptability and optimization, positioning it as a cornerstone for future smart waste management innovations.

Finite State Automata

Finite State Automata (FSA), is a fundamental mathematical model in computational theory used to represent and analyze systems characterized by a finite number of distinct states[17]. This model operates by transitioning between these states in response to a sequence of inputs, thereby enabling the recognition of formal languages sets of strings that adhere to specific syntactic rules. FSAs are particularly valuable in modeling systems where the behavior can be described as a series of discrete states and transitions, making them highly applicable in various fields including computer science, linguistics, and engineering. In practical applications such as waste management, FSAs provide a structured framework to design automated processes that require precise control and decision-making based on input conditions[18]. By defining states such as idle, detection, sorting, and error handling, FSAs facilitate the development of intelligent systems capable of managing complex workflows efficiently and reliably[19]. The simplicity and rigor of FSAs also allow for formal verification, ensuring that system behaviors conform to expected patterns, which is critical in safety-sensitive and resource-optimized environments. Consequently, FSAs serve as a powerful tool for both theoretical analysis and practical implementation in systems requiring deterministic and predictable state-based operations[20].

Finite State Automata (FSA) are formally defined as a 5-tuple (Q,Σ,δ,S,F), which provides a precise mathematical framework for modeling systems with a finite number of states. Here, Q represents the finite set of states or positions that the automaton can occupy during its operation. The set Σ denotes the input alphabet, comprising all possible input symbols that the automaton can process[21]. The transition function δ is a critical component that maps a pair consisting of a current state and an input symbol to a subsequent state, effectively governing the state transitions based on inputs[22]. The initial state $S \in Q$ specifies the starting point of the automaton before any input is processed. Finally, the set $F \subseteq Q$ contains the final or accepting states, which determine whether the input string is accepted by the automaton after processing[23]. This formalism allows FSAs to recognize formal languages by systematically transitioning through states in response to input sequences, making them indispensable in computational theory and practical applications such as language parsing, protocol design, and automated control systems[24]. The clarity and rigor of the 5-tuple definition facilitate both theoretical analysis and implementation, ensuring that system behaviors can be precisely modeled, verified, and optimized[25].

3. Methodology

This study employs a formal computational modeling approach based on Finite State Automata (FSA) to analyze and design automated systems with discrete state transitions. The methodology begins with the formal definition of the FSA model as a 5-tuple (Q,Σ,δ,S,F), where Q represents the finite set of states, Σ denotes the input alphabet, δ is the transition function mapping state-input pairs to subsequent states, S is the initial state, and F is the set of accepting or final states[26][27]. The research process involves identifying and defining the relevant states and inputs specific to the system under study, such as waste detection, sorting, and error handling in smart waste management applications[28]. Subsequently, the transition function δ is constructed to model the system's behavior in response to various inputs, ensuring that all possible state transitions are accounted for. The model is then implemented and simulated to verify its correctness and efficiency in managing sequential processes[29]. Formal verification techniques are applied to ensure that the automaton adheres to desired specifications, preventing undesirable states or transitions. Data collection includes system logs and performance metrics during simulation or real-world deployment, which are analyzed to evaluate the model's effectiveness. This methodological framework allows for systematic design, testing, and optimization of state-based automated systems, providing a robust foundation for developing intelligent and reliable applications in domains such as waste management, vending machines, and user-interactive systems[30].

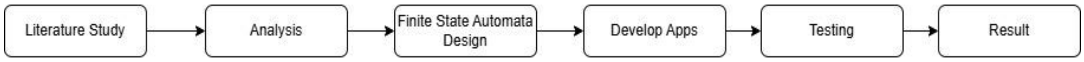

Figure 1. Research Methodolgy

Figure 1 shown at this stage, the research primarily focuses on an extensive exploration of relevant literature to establish a solid theoretical and conceptual foundation concerning finite state automata (FSA), with particular emphasis on their application in automation systems. This phase involves a comprehensive review of previous studies, technological advancements, and methodological approaches related to the implementation of finite state automata, especially those based on Non-Deterministic Finite Automata (NDFA). By systematically analyzing existing research and technological developments, the study aims to identify key principles, challenges, and best practices that inform the design and development of FSA-based systems. The collected references and insights serve as a critical basis for shaping the system architecture and guiding the development process, ensuring that the proposed solutions are grounded in established knowledge and current innovations. This literature-driven approach not only enhances the rigor and relevance of the research but also facilitates the integration of proven techniques and novel ideas, ultimately contributing to the advancement of intelligent automation systems.

This stage represents the initial step aimed at thoroughly analyzing the primary requirements of the waste recycling machine automation system as a whole. The analysis is conducted by identifying existing problems, determining the system's needs, and designing appropriate solutions. Data collection is carried out through both primary and secondary methods. Primary data is gathered via direct observation and interviews with relevant stakeholders, while secondary data is obtained from reliable sources such as scientific journals, reference books, previous research reports, and other pertinent documents. The comprehensive data collected during this phase serves as the foundational basis for the subsequent system design, ensuring that the developed solution is well-informed, relevant, and effectively addresses the identified needs.

Design process of a finite state automaton model based on Non-Deterministic Finite Automata (NDFA), specifically tailored to meet the operational requirements of an automatic waste recycling machine. The design process involves a thorough analysis of system conditions, the formulation of state transitions, and the implementation of the corresponding algorithm. The NDFA model is subsequently implemented within a system prototype to evaluate its capability and efficiency in autonomously managing waste recycling tasks. This approach ensures that the model is rigorously tested in a practical context, providing valuable insights into its performance and potential for real-world application.

4. Result and Disscusion

In this study, automata theory serves as the foundational logic for designing the waste management process within the Greenify application. The system is engineered to offer multiple options that users can select based on their specific waste management needs. The application of Finite State Automata (FSA) enables the waste container process to be executed in a structured and systematic manner through clearly defined stages represented as states. Transitions between these states occur in response to specific inputs, such as the type of waste, collection location, or pick-up schedule. The design process leverages the well-organized mathematical framework of FSA to delineate the sequential steps in the waste management workflow. Each state in the system corresponds to a particular condition for example, "waiting for waste type input," "determining collection location," and "pickup confirmation." The transition logic ensures that the system advances to the next step only when the preceding conditions are satisfied, thereby minimizing the risk of operational errors. The effectiveness of this FSA-based waste container logic design is illustrated in Figure 2 below.

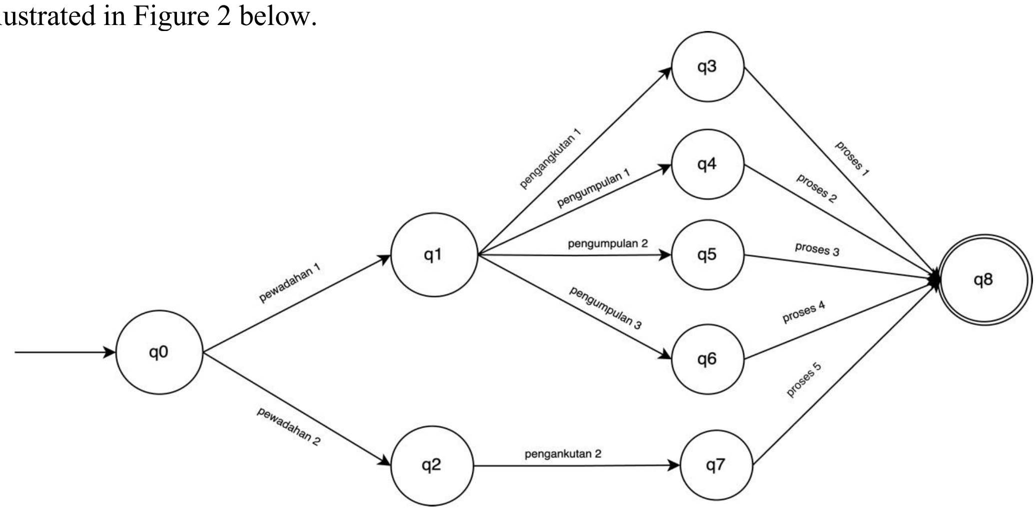

Figure 2. Design Finite State Automata for Collecting Waste

Q = {q0, q1, q2, q3, q4, q5, q6, q7, q8}
E = {Pe1, Pe2, Pg1, Pn1, 2, Pn3}
S = {q0}
F = {q8}

Table 1. Table Transition FSA for Collecting Waste

Q	Pe1	Pe2	Pg1	Pn1	Pn2	Pn3	Pr1	P2	Pr3	Pr4
q_0	q_1	q_2	-	-	-	-	-	-	-	-
q_1	-	-	-	-	-	-	-	-	-	-
q_2	-	q_3	q_4	q_5	q_6	-	-	-	-	-
q_3	-	-	-	-	-	q_7	-	-	-	-
q_4	-	-	-	-	-	-	q_8	-	-	-
q_5	-	-	-	-	-	-	-	q_8	-	-
q_6	-	-	-	-	-	-	-	-	q_8	-
q_7	-	-	-	-	-	-	-	-	-	q_8
q_8	-	-	-	-	-	-	-	-	-	-

Description:
1. Process q0 to q1/q2 = container process from waste source
2. Process q1 to q3 = direct transportation from medium container
3. Process q1 to q4/q5/q6 = waste collection from container
4. Process q2 to q7 = direct transportation from large container
5. Process q3 to q8 = waste process from transportation to landfill
6. Process q4 to q8 = waste process from collection to landfill
7. Process q5 to q8 = waste process from collection to landfill
8. Process q6 to q8 = waste process from collection to landfill
9. Process q7 to q8 = waste process from transportation to landfill

The design of the Finite State Automata (FSA) provides a comprehensive overview of the application under development, which is intended to facilitate user understanding of the system's operational workflow. Specifically, this design is applied to the waste container process within the Greenify application, illustrating how the system transitions through various states to manage waste effectively. By visually and logically mapping the states and transitions, the FSA model helps clarify the sequence of operations, making it easier for users and developers alike to comprehend the underlying mechanics of the application. This structured approach not only enhances transparency but also supports the development of a robust and user-friendly waste management system.

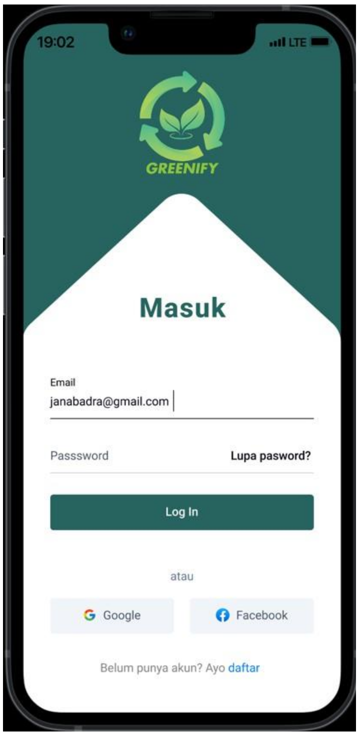

Figure 3. Greenify App Login

The login page of the Greenify application, as shown in Figure 3 above, prominently displays the application's logo and name at the top, emphasizing its commitment to environmentally friendly waste management. Below this header, the login form includes fields for users to enter their email and password, accompanied by a "Forgot password?" option to assist users in recovering their accounts if necessary. A clearly labeled "Log In" button allows users to access their accounts after entering their credentials. Additionally, alternative login options are provided through Google and Facebook accounts, each represented by distinct buttons for ease of use. For new users, a "Don't have an account? Let's register" link is positioned at the bottom, directing them to the registration page. This clean, simple, and intuitive design ensures ease of access and promotes an optimal user experience by catering to both returning and new users effectively.

Figure 4. Main Dashboard Greenify

The Greenify application homepage, as illustrated in Figure 4 above, is thoughtfully designed to provide users with essential information and quick access to key features that facilitate the waste collection process. At the top of the page, a personalized greeting welcomes the user by name and displays their profile photo, fostering a sense of connection and engagement. Directly below, the current month's bill is prominently displayed, enabling users to easily monitor their service costs. An achievement indicator follows, showcasing the total amount of waste successfully recycled, which serves to motivate users and raise awareness of their positive environmental impact.

The homepage also features intuitive navigation icons that provide rapid access to critical functions such as location information, customer service (CS), problem reporting, and waste collection schedules. Additionally, users can view details of their current service package, including the specific plan they are subscribed to, along with a convenient button to upgrade their service if desired. At the bottom of the screen, a navigation bar offers access to supplementary features such as the main dashboard, transaction history, QR code scanning, notifications, and profile settings.

With its clean, organized layout and user-centric design, the Greenify homepage is optimized to help users efficiently manage their waste collection services while promoting ease of use and a seamless user experience.

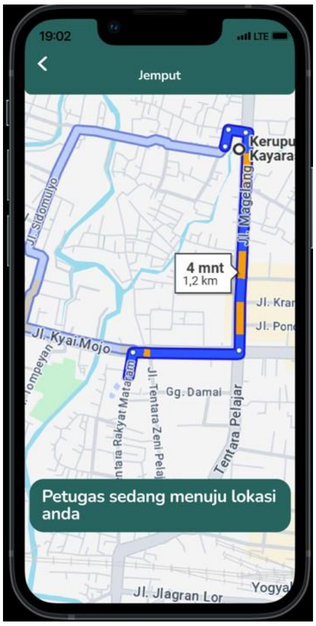

Figure 5. Map Waste Collect

The waste pick-up process page on the Greenify application, as illustrated in Figure 5 above, features an interactive map that displays the officer's route to the user's location in real time. This map includes an estimated distance and arrival time, providing users with clear and timely information. The route is visually marked with a blue line, enhancing the user's ability to track the officer's progress. Additionally, a notification stating, "The officer is on his way to your location," is prominently displayed to keep users informed about the current status of the pick-up process. The design of this page prioritizes transparency and ease of access, thereby supporting operational efficiency and significantly improving the overall user experience in waste management.

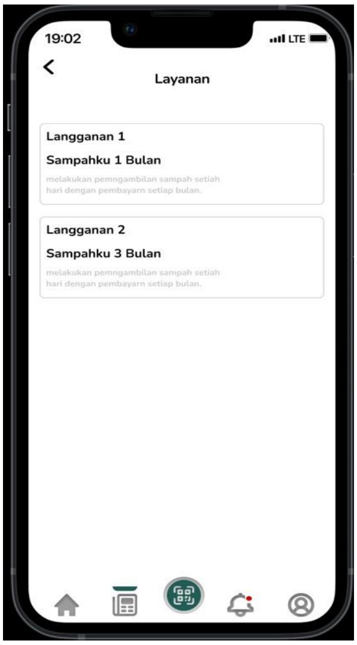

Figure 6. Services Greenify Apps

The service type page on the Greenify application, as shown in Figure 6 above, allows users to select a waste management subscription plan tailored to their needs. This page presents two service options: Subscription 1: My Waste 1 Month and Subscription 2: My Waste 3 Months. Each subscription includes a description indicating that the service provides routine daily waste collection, with payments made on a monthly basis. The design of this page is simple and minimalist, enabling users to easily understand the available options and choose the package that best fits their requirements.

5. Conclusion

Based on the results of this study, it can be concluded that the application of Finite State Automata (FSA) in the waste container process within the Greenify application provides a robust logical framework for structuring the waste management system. By segmenting the process into distinct states ranging from waste type recognition and collection location identification to scheduling pick-ups FSA facilitates an automated and well-organized workflow. This structured approach not only enhances the efficiency and accuracy of waste management operations but also significantly improves the user experience by offering a clear, intuitive, and easy-to-navigate system. Overall, the integration of FSA in the Greenify application demonstrates its potential as a powerful tool for optimizing sustainable waste management practices through technology-driven solutions.

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