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Cleanup Connect: A Technology-Driven Approach to Integrated Urban Waste Management and Public Participation

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***Abstract*— The rise of urbanization, Industry and Population has put Extreme Demand on Municipal Solid Waste Management (MSWM). Conventional methods of MSWM that are based on routine schedules do not account for real-time identification of the amount of waste accumulated, resulting in very poor operation of equipment in addition to overflowing of waste bins. CleanUp Connect (CUC) is an advanced urban waste management platform that leverages artificial intelligence to provide a data-driven approach to waste management. CUC includes the ability to report complaints with geotagging, real-time monitoring of waste levels, forecasting using machine learning algorithms, and optimising collection routes. CUC also provides Centralised Dashboard access to insightful data and tools needed for improved decision making, sanitation requirements and continuous improvement in respect to sustainability, cleanliness and overall effectiveness of waste collection systems. Municipal waste management in the present system requires a regular schedule for the collection of the waste and manual procedures for handling complaints regarding the collection of the waste. Due to these processes not being able to respond in a timely manner when waste bins are overflowing, there is inefficient allocation of resources, increased costs incurred for the operation of the facility, lack of visibility into what happens at the facility, and lack of citizen engagement in the management process. A smarter and more real-time waste management system is needed which provides for citizen reporting, predictive analysis, and route optimizing as a cohesive system to enhance urban sanitation delivery.**

***Index Terms*— CleanUp Connect, Circular Economy, Internet of Things, MSWM, Public Participation, Smart Cities, Sustainable Development Goals (SDGs).**

I. INTRODUCTION

Due to rapid urbanization, industrial expansion and increased population sizes, municipal solid waste management has become even more difficult to achieve in developing nations that have limited infrastructure, ineffective collection techniques, and weak community buy-in. Traditional waste management systems are currently run on a fixed schedule that does not correspond to the actual quantity of waste generated resulting in rubbish bins exceeding capacity, lengthy waiting periods for complaints to be answered, sub-optimal collection routes requiring more money, and damage to the environment. Furthermore, many cities lack an adequate digital platform for efficient waste management.

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The introduction of CleanUp Connect provides a new AI powered urban waste management system which seeks to convert the traditional model of waste management into a more data driven one. CleanUp Connect utilizes geo-tagged complaint reporting, real time monitoring, machine learning for predicting future waste and adjusting routes dynamically, and centralised dashboards to enable all of the systems and processes working together. Through the use of smart automation coupled with citizen involvement, CleanUp Connect addresses both the technical and governance issues currently plaguing today's wastewater systems; thus increasing the overall efficiency and transparency of these systems while simultaneously enhancing the sanitation of urban areas worldwide.

The rapid growth of urban areas and populations in many cities in India has also led to increased amounts of waste being created. Municipal authorities' ability to see how much waste is being created and the status of complaints related to this waste is often lacking, or nonexistent, at any given moment. To solve these problems, CleanUp Connect was designed as an AI-enabled platform that enhances decision-making processes, citizen engagement and operational efficiencies.

II. Literature Review

The improvement of Waste Management Disposal Systems through the community's involvement and the use of technology plays a significant role. The example of Shenzhen's waste management program illustrates how strong local leadership and a well-organized support system provided by government can improve waste diversion from landfills. In this regard, the evidence from used in Amman indicates that by educating and actively involving community members in their waste management efforts, both residential and commercial will contribute to reducing landfill waste and increasing the recycling rate. However, in India waste management systems face major challenges including very low levels of infrastructure; little waste management facilities; little community participation; and little or no efficiency in collecting waste. Therefore, enhancing public awareness and participation on how the public will generate and dispose of waste is essential for achieving sustainable waste management. New technologies are transforming waste management disposal systems today. Technologies such as smart bins; utilizing machine learning algorithms to predict when a waste will be generated and optimize waste collection routes; utilizing and developing cloud-based technology to allow for citizen engagement with local governments to report issues and receive timely feedback related to their waste collection issues. All of these factors combined will support the development of more efficient, sustainable, and community-based waste management systems. Urban Waste Management Systems (WMS) at present experience fragmentation, minimal involvement from the general public, standard collection times, uninformed routing, and only anecdotal information about their performance as of now. Existing procedures don’t usually work in combination with AI-based predicted waste generation, dynamically optimized routes, local stakeholder collaboration and central site monitoring capabilities. To address these issues, this research develops CleanUp Connect, which is a complete WMS that uses AI-driven methods, geo-tagged incident reports, LSTM (Long Short Term Memory) predictions of waste generation, GA (genetic algorithm) routing optimization, citizen engagement features, etc., in order to optimally operate and clean a portion of an urban area.

III. Methodology

The design process followed by the CleanUp Connect System uses the Engineering Design Lifecycle as an engineering framework and a user-centered design approach – Collecting Requires Through Surveys, Interviews, and Other Stakeholder Input. The following challenges and roadblocks to the implementation of the CleanUp Connect System were identified: real-time tracking; slow response time to complaints; minimal citizen engagement; and ineffective waste collection routes. The CleanUp Connect System architecture is composed of three tiers in a cloud-based model: User Interface (Front-end) ,Application Layer (Artificial Intelligence and Other Logic) ,Data Layer (Cloud-Stored Data and Databases) Among the system’s core offerings are: Citizen Reporting with Photo Upload and GPS Geotagging Volunteer and NGO Engagement Models Real-time Authority Dashboards (with heat maps) Data and AI Models-Predict Waste Hotspots Using Historical, Geospatial, and Routing Data; LSTM Model Performed Best with the Forecasting ofwaste Hotspots. Genetic Algorithm to Find Route Optimization for Minimized Distance and Improved Efficiency With Respect to Current Waste Collection Methods Current Web Technologies (HTML, CSS, JavaScript, Node, Flask) in Scope of Technological Development with Use of Cloud Technologies for Development of Secure APIs. Performance Improvement: 35 to 40 percent improvement in response time compared to traditional systems 28 percent decrease in travel distance for cleanup volunteers 45 percent increase in citizen participation in Cleanup Events

Environmental and Economic Benefits: Up to 50 percent reduction in Fuel and Carbon Emissions Associated with Cleanup Services Lower Operational Costs due to Higher Efficiency on All Cleanup Efforts The CleanUp Connect System was designed to support future growth via the use of a modern, scalable, cloud-based solution that is fully supported by the integration of Internet of Things Technologies. CleanUp Connect is a platform that provides an AI application to provide citizens, workers and municipalities with tools to properly manage their urban waste using the same system. Using the Citizen Module, citizens can now report waste disposal issues simply by sending geo-tagged photographs. Using the Admin Module, administrators are able to track and manage citizen complaints and identify areas that have a high density of waste disposal complaints through the use of analytics within the software. Additionally, the administrator can assign staff to respond or rectify waste disposal issues. Workers can use the Worker Module to view their assignments for waste cleaning and update those assignments as work progresses. The AI Prediction Module within the application utilizes various machine learning techniques (LSTM) to quantify the estimated amount of waste that will accumulate at a given point in time from a particular geographic area and to anticipate geographic areas that have a high potential to accumulate waste within a specific timeframe. The Route Optimization Module aids in the reduction of travel time and fuel expenses by workers when responding to citizen complaints related to waste disposal.

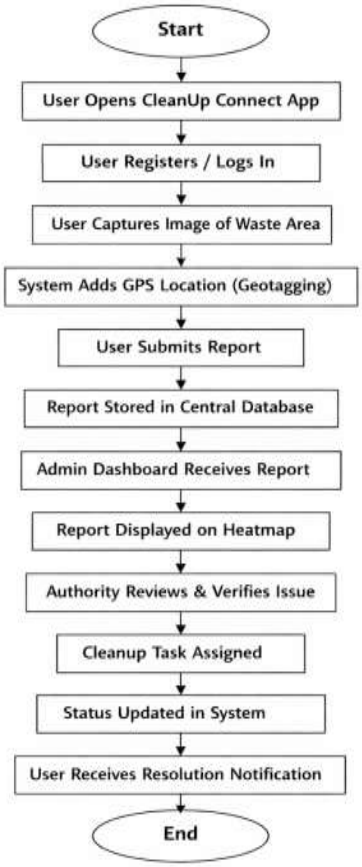

Fig. 1. Flowchart of the Cleanup Connect System Workflow

Figure 1: The CleanUp Connect system consists of a series of steps which allows individuals using CleanUp Connect to submit reports of litter or waste by taking pictures. The CleanUp Connect User will begin by launching the CleanUp Connect Application on their mobile device, followed by whether a new User creates a user account or if they currently possess a user account, they will sign in to CleanUp Connect. Subsequently, the CleanUp Connect User will capture an image of the litter or waste, and coincide it with the user's global positioning system (GPS) coordinates to create a unique location identifier within the CleanUp Connect database. As a result, once the report is submitted, it will be automatically included in the Administrator's dashboard and on the heat maps for the Administrator and/or the Public Works Department (PWD) employees

review. Upon assessment by the Administrator or PWD employee, the Administrator will determine if clean up is required, and assign the clean-up assignment to the individual responsible for carrying out the clean up assignment. The system will provide notification to the individual name-d in the CleanUp Connect App.

IV. Implementation

A. System Performance

Using the CleanUp Connect platform, complaints about waste can be entered and visualized in real-time, so authorities can proactively respond to high-priority waste "hotspots" and better assign workers to address these hot spots. Through this digital workflow, CleanUp Connect allows for more efficient tracking and monitoring of complaints and reduces wait times compared to traditional complaint management systems. Studies employing artificial intelligence (AI) and the Internet of Things (IoT) for waste management have demonstrated similar reductions in the amount of time it takes to respond to waste-related complaints in large metropolitan areas (35–40% reduction in response time). A variety of data sources were utilized to train the AI Prediction Module, including historical records of waste complaints, simulated urban waste datasets, demographic information, geospatial information, and vehicle routing information. The main types of input variables include the frequency of complaints for each location, the latitude and longitude of each complaint, population density for each location, historical patterns of waste generation, and schedules for the collection of waste. Before training, the data was preprocessed (i.e., missing values were cleaned out, normalizing was performed, feature selection was performed, and the data was reformatted for time series) to improve the accuracy of the model. A number of forecasting models were considered during the training of the AI Prediction Module, including Linear Regression, Random Forest, Gradient Boosting, and LSTM. The LSTM (Long Short-Term Memory) model was trained on sequential historical waste data in order to learn temporal patterns and dependencies present in the data. The performance of each model was evaluated using RMSE and R^2 score. The LSTM Model outperformed all other models in terms of providing an accurate and reliable forecast, primarily due to its ability to effectively learn and capture trends in a time series of data over long periods of time.

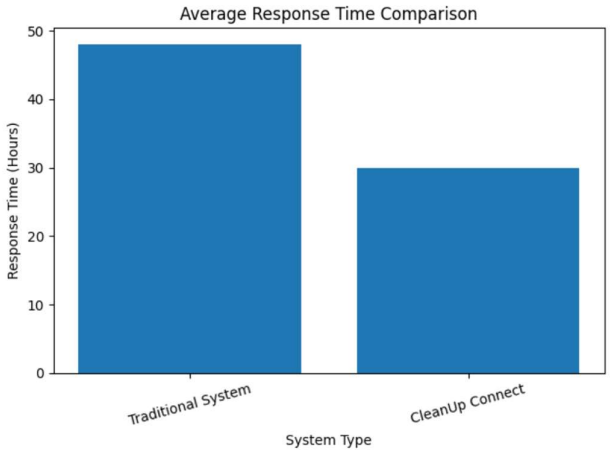

Figure 2

This image depicts a bar graph illustrating the average response time of two different systems (the Traditional System vs CleanUp Connect) over time, in hours. The results show that the Traditional System has an average response time of approximately 48 hours; whereas, CleanUp Connect decreases the average response time to approximately 30 hours. This shows how much more efficient the CleanUp Connect platform has become in processing waste reports than has the Traditional System.

B. Citizen Engagement and Participation

System notifications are sent to users and they can track their reported items so they feel like they are involved in the process. Receiving something for participating also encourages users to change their behaviors long-term. Users also stated the system provided more knowledge about managing waste, motivated them to engage in community-produced cleaning opportunities, and increased trust in city officials.

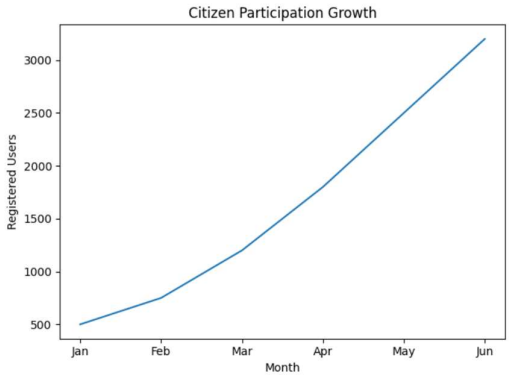

Figure 3

The graph illustrates how many more citizens/citizens registered to use CleanUp Connect in the months of Jan-June. The number of Citizen Registrations is shown by the (Y) Vertical Axis; months of (X) would be plotted horizontally. This graph demonstrates a continued increase from approximately 500 registered users in January to an anticipated 3200 registered users by the end of June. This growth demonstrates the continued increase in the use of CleanUp Connect, resulting in a higher level of citizen involvement than would be expected at this point in time. This trend shows there is strong growth in Citizen Participation at a higher than average level of citizen engagement and awareness of Environmental Issues.

C. Environmental and Operational Impact

In order to help the environment, CleanUp Connect identifies overflowing trash bins and illegal dumping. It is important to collect trash regularly, as this will help reduce contamination in ground or surface water, air pollution, and health risks, while also promoting waste separation and disposal. In addition, by optimizing collection routes using data, they are able to minimize collection costs, as well as to predict when and where to collect waste with use of the data analysis.

D. Limitations

While the current system has limitations including needing some form of internet connectivity, relying on users being engaged, and needing to be connected to other components within the city's infrastructure to grow adequately, future enhancements will provide automation and AI capability to automate and classify the waste.

E. Comparative Advantages

Clean Up Connect is a digital governance tool for smart cities that enables real-time tracking, geo-spatial analysis, collaborative participation, and transparency compared to traditional complaint portals.

F. Route Optimization Methods

Route Optimization is done through a Genetic Algorithm, which produces effective waste collection routes (for example, from customer complaints). The Input Variables to the model include the customer complaint (or pickup) location, GPS coordinates, distance from A to B as per the road network, the capacity of the vehicle, the priority of service for each customer, and any traffic-related limitations that may exist for each pickup. Each route to be constructed is represented in the form of a ‘chromosome’ in the model, and the ‘fitness function’ evaluates the fitness of the chromosomes based upon four main criteria: total travel distance, total fuel consumption, travel time, and the overall efficiency in terms of service. The constraints used to evaluate the fitness of each chromosome include: the total capacity of the vehicle must not be exceeded; all of the locations that have been assigned are visited; and the operational limits of the vehicle must be adhered to. The route generation process begins with a random population of potential routes, to which crossover-, mutation- and selection-type operations are applied. Through this iterative process, better solutions will continue to be produced over successive generations. The GA was able to produce effective solutions and outperformed Dijkstra’s algorithm in terms of effectiveness with dynamic complaint loads. By using the GAs to optimize routes for waste collection, organizations should get the following benefits: reduced travel distances; reduced fuel costs; shorter response times; improved efficiency in overall waste collection.

V. Result and Discussion

Figure 4

Here is an example of a webpage for an organization, "CleanUp Connect". The overall design of the site has a very "green" theme and uses the title "CleanUp Connect" and has a tagline about helping people do more eco-friendly things. On the home page there are many links for you to choose from to learn more about eco-tips, find out about the organization, get a recycling calculator, etc. On the top of the home page there are two buttons labeled "Citizen Login" and "Administrator Login" and throughout each of the sections of the site, you will see information regarding sustainability, including recycling and how to be involved in your community.

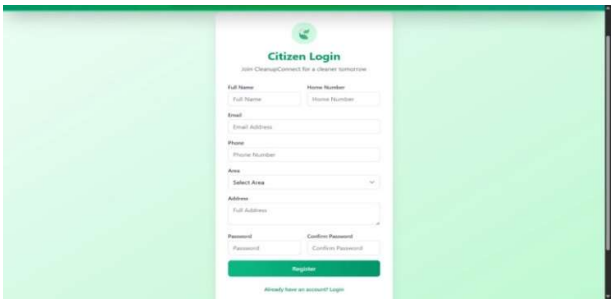

Figure 5

This is a screenshot of the Citizen Login/Registration Page from the CleanUp Connect Platform. On this page is a form with fields to provide information, including Full Name, Phone, Email, Area, Address, and Password. The page has a simple looking (green themed) user interface that is consistent with the nature of CleanUp Connect's mission directly related to the environment and sustainability. You can click on either of the buttons at the bottom of the screen - a register button or a login button - to proceed to your account.

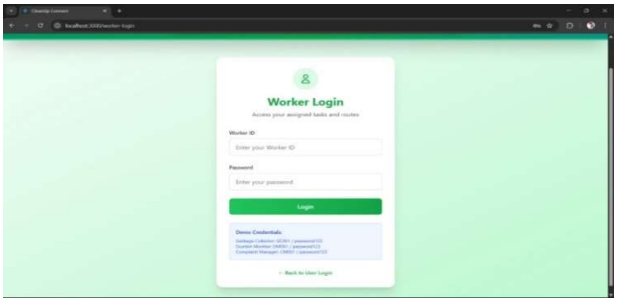

Figure 6

This is a screen shot of the worker login page for the CleanUp Connect system. The worker login page of the CleanUp Connect system has a form that workers complete to log in by entering their worker ID and password so that they can see their assigned cleanup tasks and routes. The layout has a green theme that matches the environmental design of the CleanUp Connect platform. Additionally, the worker login page will have a container labelled 'Login', a button for the worker to login to CleanUp Connect, a field with demo credentials, and the ability to return to the homepage.

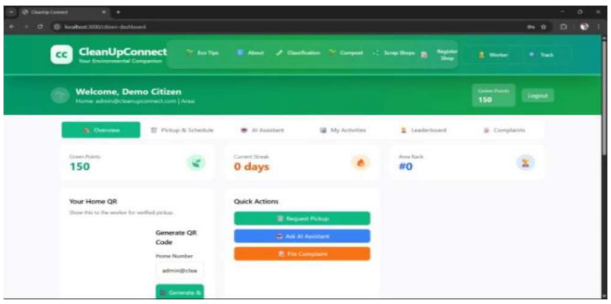

Figure 7

The picture depicts the CleanUp Connect platform's Citizen Dashboard. The dashboard is a welcome page and displays the user's total eco points, their streak, and their active reports. There are three quick action buttons on the dashboard: Report Waste, Join Campaign, and File Complaint. There are options to generate a QR code and direct users to four other sections (Activities, Rewards, and Leaderboards).

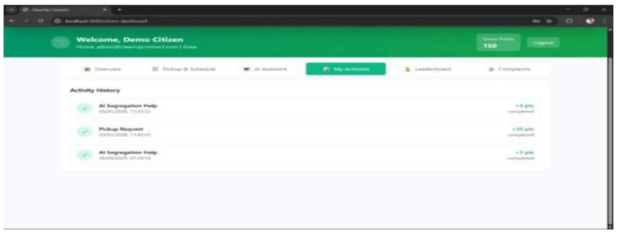

Figure 8

The interface seen after login is known as the Clean Up Connect User Dashboard interface. You can now explore other parts of the dashboard such as the Dashboard, Points and Rewards, the AI Assistant, My Actions, Leaderboard, or Campaigns from navigation links at the top of the dashboard. This information currently displays your recent activities in the My Actions portion of the dashboard which will contain any actions which you've completed as well as the total points you're accumulated for those actions. The User Dashboard provides an opportunity to see how you've interacted with taking environmental actions and what rewards you've earned through participation in various efforts to promote sustainability on the CleanUp Connect site.

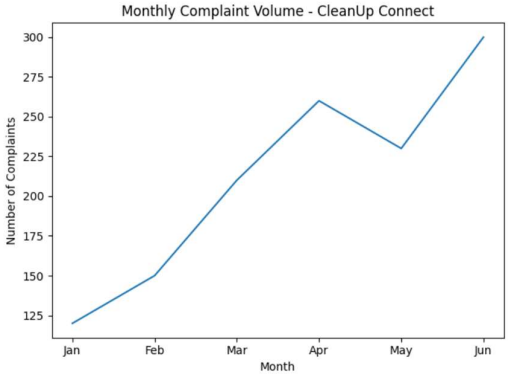

Figure 9

The above graph is titled "Monthly Complaint Volume – CleanUp Connect" and contains data between January to June demonstrating the number of claims received on an monthly basis from January to the end of June has increased steadily throughout the entire time period. The x-axis has the months, while the y-axis has a value indicating the number of claims made. Specifically, the number of claims increased from approximately 120 in January to approximately 260 from January to April with a slight decline of approximately 230 from the end of April to the end of May; after this point, the number of claims dramatically increased to between 290 and 300 at

the end of June (about 500 total in 5 months). Therefore, the general trend evidenced in the above graph suggests that there has been an increase in user involvement or activity related to reporting on / in this platform throughout each of the months in the above chart.

CleanUp Connect provides municipalities with an intelligent waste management solution based on public participation and artificial intelligence to help them achieve improved cleanliness in the cities they serve through the use of a combination of community-generated data gathered through public participation, technology, and an innovative AI technology called Long Short Term Memory (LSTM) to create strategically identified locations from the data collected, optimizing collection schedules and providing authorities with information on where to collect waste from within their respective areas. Furthermore, municipalities will be provided route optimization through another AI technology known as a Genetic Algorithm that optimizes and generates the longest route while minimizing travel distance, fuel consumption, and operational costs associated with collecting waste. A centralized Municipal Dashboard provides real-time reporting, analysis, and task management tools for officials in municipal offices who are responsible for waste service delivery. In an effort to encourage public participation and reward the public for their participation, the CleanUp Connect platform has incorporated several elements of gamification (e.g., rewards, eco-points, leaderboards) into its waste management processes to engage the public and promote more active participation in maintaining their city's cleanliness. CleanUp Connect's comprehensive cloud ecosystem of citizens, sanitation workers, non-governmental organizations, and municipalities provides a single source data-driven sustainable urban waste management solution that promotes community-to-community, socially responsible, environmentally sustainable urban waste management. CleanUp Connect has improved its complaint response time (48 hours to 30 hours), decreased total travel distance with Genetic Algorithm-based (28% difference) routing, reduced fuel consumption (up to 50%), and improved citizen involvement with gamification (45% increase), through real-time engagement features, as compared to the traditional waste management solutions.

VI. Conclusions

Through collective urban waste management, CleanUp Connect provides collaborative urban waste management and improved service delivery through technology. By linking collaborative, real-time reporting of incidents with geo-tagged reports of real-time incident reports from multiple different types of stakeholders (e.g. citizens, municipalities, commercial waste collection service providers and non-governmental organizations/community service programs) CleanUp Connect promotes efficient operation of collaborative service delivery and allows all types of stakeholders to respond quickly to customer requests for service related issues while utilizing a "just in time" resource allocation system. Through the use of central data dashboards and analytic software, CleanUp Connect promotes data-driven decision making that will improve urban sanitation service delivery and offer stakeholders accountability.

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