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Real-time smart garbage bin mechanism for solid waste management in smart cities

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ABSTRACT

Unprecedented urbanization and rapid population growth have increased waste generated annually posing challenges to cities globally. The annual World Health Organization reports indicate that many people die from preventable diseases as a result of improper waste disposal and management. The provision of garbage bins is inadequate in the management of solid waste in smart cities. The major problem is that garbage bins fill up quickly, and it takes time for the municipal workers to empty the bins. This paper focuses on a real-time smart garbage bin mechanism for solid waste management in smart cities. Conventional garbage collection and management systems have many shortcomings, including inaccessibility to actual data required, lack of throughput, and late unloading. The mechanism proposed accesses real-time information of any smart garbage bin deployed across the city and helps to resolve the problem of waste overflow from garbage bins and keep the smart cities clean. Fuzzy logic is applied in the strategic deployment of smart garbage bins across the smart cities. The system is implemented on Net-logo which is widely used in multi-agent modelling environments. The significant advantage of the system is its novelty in real-time decision-making and real-time monitoring using the fuzzy logic process.

1. Introduction

Waste management in cities has been a critical challenge to city engineers and urban planners for a long time (Das et al., 2019). The significant causes of waste generation in the cities are industrialization, increased household incomes, changing consumer patterns due to taste and preferences, economic growth, development, and exponential population growth (Silva, Khan & Han, 2018). Also, an increase in the human population has led to an increase in waste production, posing a challenge to waste management and control for smart cities (Zhu et al., 2015). It is well known that there is a significant generation of waste from households as well as industries . The local authorities collect this generated waste and subsequently take it to the dumping sites for disposal or recycling.

In order to keep the environment hygienic, clean, and green, the monitoring of waste and its disposal is vital. The improper disposal of waste can result in numerous health hazards (De & Debnath, 2016). Over the last decade, many cities worldwide have faced significant challenges such as small parking slots for vehicles, overcrowding, waste management, unemployment, housing, traffic jams, and water and sewerage problems (Monzon, 2015). These challenges have severely affected the livelihood of city residents. In the recent past, Internet of Things (IoT) has helped resolve some of these challenges. For example, in smart cities based on IoT, physical devices interact over the internet and provide ease to human beings based on their intelligence (Mehmood et al., 2017; Srinivasan, Rajesh, Saikalyan, Premsagar & Yadav, 2019).

The rapid growth in urban population and the voluminous generation of waste have made the cities unclean and dirty, which poses a health challenge to urban residents (Thakuriah, Tilahun & Zellner, 2017). The generated waste can be classified into solid and wet waste. The main focus of this paper is to suggest novel methods of solid waste management and the associated control mechanism for smart cities coherently making a Smart Garbage Bin Mechanism(SGBM). The control mechanism is aimed at cleaning and sanitizing the smart city environment more intelligently. The process of waste management and the associated control mechanism is broken down into five steps: garbage collection, transportation of garbage, analysing and processing garbage, recycling garbage, and the disposal of garbage (Mahajan, Kokane, Shewale, Shinde & Ingale, 2017). The proposed SGBM is novel in the aspect

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of real-time monitoring of solid waste deposited in garbage bins, and it employs fuzzy expert system in decision making that helps in strategic deployment of garbage bins across the smart city. Besides, the proposed mechanism will be of great benefit in the near future where all communication will be established through the internet without human interference.The proposed system is implemented using Netlogo which provides a multi-agent modelling environment.

The following are the contributions of this paper.

a The proposed system will improve the environmental and hygiene quality of smart cities, leading to reduction in health hazards by providing timely collection of garbage.
b The proposed model will help reduce traffic jams because the garbage collecting trucks will be using optimal paths to reach the garbage bins.
c The system will provide real-time solid waste collection framework to city municipalities.

The rest of the paper is organized as follows; Part II presents the literature review, part III discusses the details of the methodology employed, PartIV covers the results and discussion and Part V has the conclusion and future work.

2. Literature review

In the last few years, there have been many proposals on smart systems by researchers to deal with numerous challenges faced by the cities globally. Some proposals have focused on smart waste collection process (Kamm, Gau, Schneider & Vom Brocke, 2020) and smart waste management systems (Baldo, Mecocci, Parrino, Peruzzi & Pozzebon, 2021;Guerra, Bolea, Gamiz & Grau, 2020;Pardini et al., 2020;Rutqvist, Kleyko & Blomstedt, 2019). According to (Balakrishna,2012), a smart city is an advanced infrastructure that incorporates Information Communication Technologies(ICT) and in which, everything or every device is interconnected with one another and can interact without any interference. One fundamental requirement in a smart city environment is that everything is supposed to be intelligent and mart in making decisions. With advancements in technology, a smart city requires many applications for providing services to the residents. The major applications include: smart health (Pramanik, Lau, Demirkan & Azad, 2017), smart surveillance and security (Eldrandaly, Abdel-Basset & Abdel-Fatah, 2019), smart traffic management and control (Rizwan, Suresh & Babu, 2016), smart environment monitoring (Ullo & Sinha, 2020), smart farming (Dagar et al., 2018) and many other many applications (Guerra et al., 2020;Javadzadeh et al., 2020). From the smart cities applications and literature review, big data and data analysis is required in development of these applications (Ahmad et al., 2020; Melakessou, Kugener, Alnaffakh, Faye & Khadraoui, 2020). In this section on literature review, research on solid waste collection and management mechanisms is reviewed.

Mamun, A., Hannan, Hussain & Basri, 2016, developed a real-time intelligent garbage bin level monitoring system coupled with rule-based decision algorithms used in solid waste collection and the management. The decision-based algorithms would sense the waste-data through a wireless sensor network (WSN). The architecture had three modules, namely the control station, smart garbage bin and gateway. The concept of this system was that the garbage bins can collect the status of solid waste in them. In an event where a small change occurs, they would transmit the status of the data collected to a central server through an intermediate coordinator (Cerchecci et al., 2018). An array of applications in the central server provided the updated garbage bin status in real-time. The advantage of the proposed system was its design and development, which resulted in an automated garbage bin status checking system that is novel in that it uses decision-based algorithms. However, the system also had several challenges, in that it lacked GPS for position detection, errors in the output data readings of the sensors, and lack of citizen interaction with the system.

Sanjeevi and Shahabudeen (2016), introduced optimal pathfinding in the transportation of solid waste for city municipalities, which involved using the Dijkstra's algorithm and Geographical Information System (GIS). The system aimed at reducing the distance travelled by waste trucks to reach the garbage bins by 9.93%. This optimal pathfinding also reduced the time spent on the roads and fuel costs. Nevertheless, the authors did not expound on how all the stakeholders (the city residents and the garbage collectors) will be involved and how the proposed system could be used by municipal authorities to improve waste management and reduce the cost of waste collection.

Ramson, Vishnu, Kirubaraj, Anagnostopoulos & Abu-Mahfouz, 2021, developed an effective control mechanism to measure the filling levels of the solid waste garbage bins. The system was developed to use Infrared (IR) sensor, transmitter, microcontroller and Radio Frequency (RF) module to gather the information of any waste in the garbage bins right on time. The sensors have been employed sense the exact level of solid waste in the garbage bins and send any alert to the central controller. The microcontroller then encodes all these alerts and sends them to the Central Processing Unit (CPU).

Lozano, Caridad, De Paz, Villarrubia Gonzalez and Bajo (2018), introduced a new method of checking the levels of SGB and subsequently determines an optimal path in the state of Philadelphia, USA based on genetic algorithm and logistic regression. However, the authors did not provide the technology to transmit the data from the SGB to other arrays of the devices in the system.

Yusof, Zulkifli, Yusof & Azman, 2018, introduced an innovative way of collecting waste information from the garbage bins. The authors suggested an integration of the GSM module and the ultrasonic sensors. The ultrasonic sensors were aimed at detecting the current level of waste in the garbage bins and compare it with the threshold limit provided. If the detected level exceeds the threshold, the sensor issues a notification of an update to the Arduino UNO responsible for the general communication of the system. Further, the Arduino UNO sends an alert signal to the GSM module.The GSM module is wirelessly linked to Personal Digital Assistant (PDA), and the information is shared with the municipal authorities.

Pant, Saurkar and Sarvaiya (2019), proposed a system that would obtain information on solid and liquid waste from the smart garbage bins. The mechanism incorporated both IoT and WSN. An array of sensors were attached to the SGB, and the communication between the SGB and the central server was through WSN. The personnel involved in garbage collection played a significant role because they would receive all the alerts that are generated by the various sensors. The authors stated that, one of the cities in India, Asansol, has proposed using GIS in planning for the collection, transportation and storage of all the waste generated intelligently.The SGBM system proposed in this paper for solid waste management for smart cities is better compared to the existing systems in the terms of its flexibility and optimal route finding.

3. Methodology

3.1. System design

The proposed SGBM has three modules: the SGB, garbage collecting vehicle (GCV) and a centralized database (CDB). The SGB is an intelligent node and is used in the storage of waste from all public and private places within the city. It provides critical information to the centralized database that is the smart garbage bin level (SGBL) which are pegged on percentage, the smart garbage bin colour (SGBC) with green colour at $= \langle$ 50%, yellow colour $=<$75% and when $\rangle$ 75% it turns to red.

The GCV is deployed to help transport SGB across the smart cities following optimal paths. This GCV will be in complete coordination with the database, such that the GCV will receive information about the SGBs that have exceeded the threshold of 75% indicating that they areready to

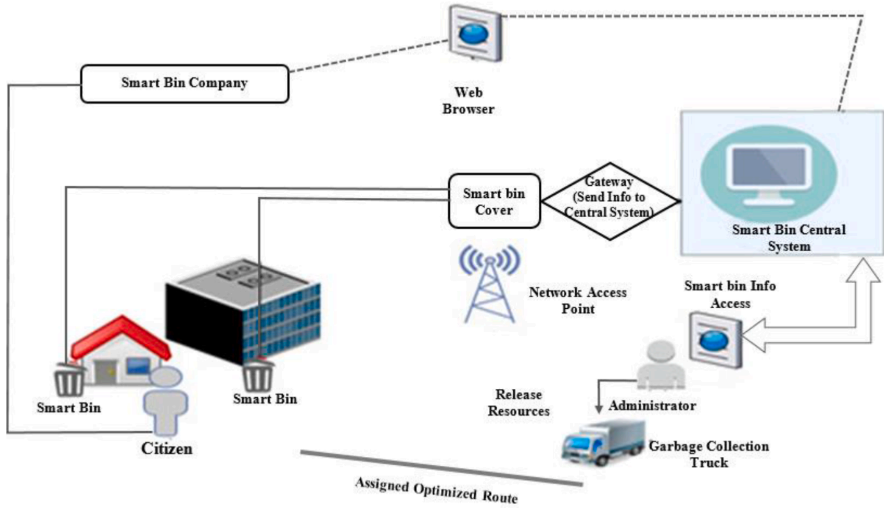

Fig. 1. The General Architecture of SGBM.

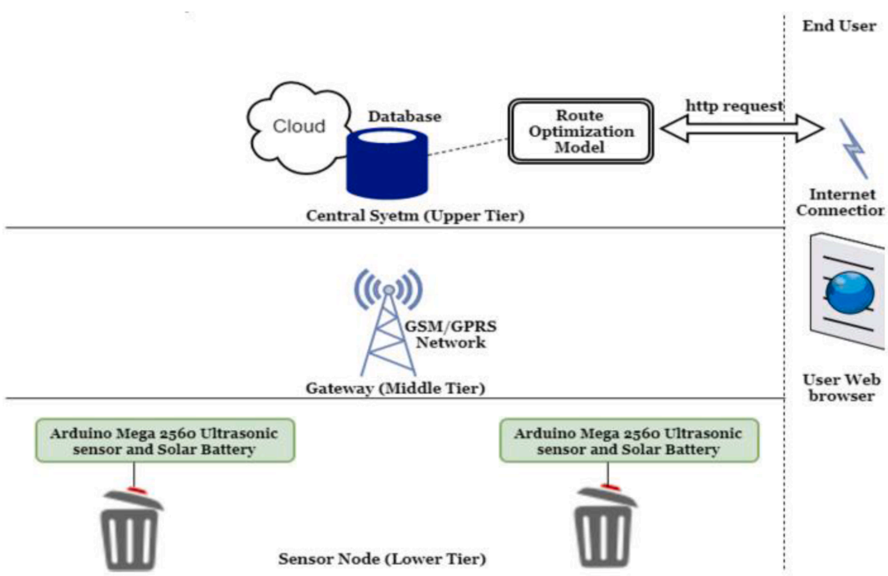

Fig. 2. Smart garbage bin mechanism and the central system architecture.

be offloaded. Following the receipt of this message, the GCV will take the SGBs to the dumping sites for recycling.

According to the system, the central database also serves as the information centre. All the details of SGB like levels, colour, weight, and SGB identification can be accessed from the CDB.

3.2. Conceptual design

The conceptual design is an overview of the proposed system architecture and the general architecture implementation. Fig. 1 is the general architecture with three main factors; the GCV driver,the city resident and the system administrator. The city resident has to buy the SGB from the waste management company contracted by the city municipality and register it. The company then deploys the SGB to the destination specified. The residents of the city can also access any information and pay electronically to the waste collection company through the web. The covers of the SGBs are embedded with IC (Integrated Circuit) boards which provide real-time and continuous monitoring of waste levels in the SGB. Together with GSM/GPRS, Arduino Wi-Fi is used as a gateway to transmit solid waste data into CDB. The system administrator is able to manage the registration of the city residents and update the payment information. Also, the system administrator is able to allocate the optimal routes that would be taken by the GCV drivers.

Fig. 2 shows the system central architecture. It is made up of a three-tier system consisting of lower, middle and upper tiers. In the lower tier, there are sensor nodes such as Arduino Mega 2560 Ultrasonic sensor, Ultrasonic sensors (HC-SR04), and weight sensors (SEN-10245SEN-10,245). The gateway is located in the middle tier, and the upper tier contains the CDB, which is allied to optimizing the system. The CDB receives continuous updates from the SGB and stores the solid waste status through different gateways after establishing a stable connection with the server. Data stored is analysed, and optimal paths to be used by GCV are established through the linked optimization model. A restricted Graphic User Interface (GUI) is provided to the city residents and the system administrator depending on their respective roles.

3.3. Functional flow chart diagram of SGBM

The flow chart diagram in Fig. 3 describes the working principle of

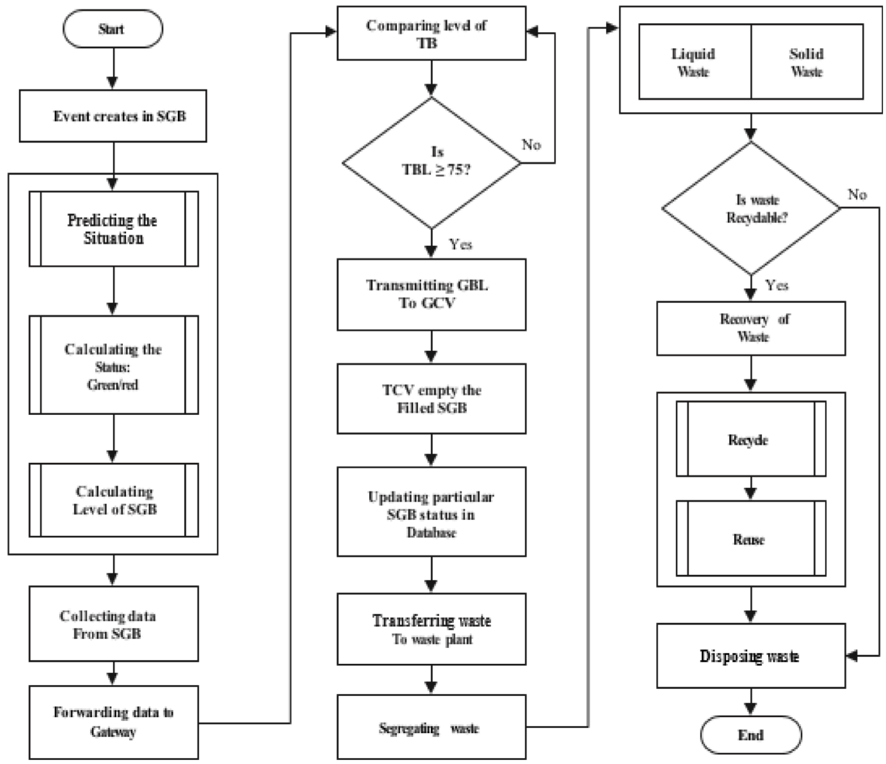

Fig. 3. Functional flow chart diagram of SGBM.

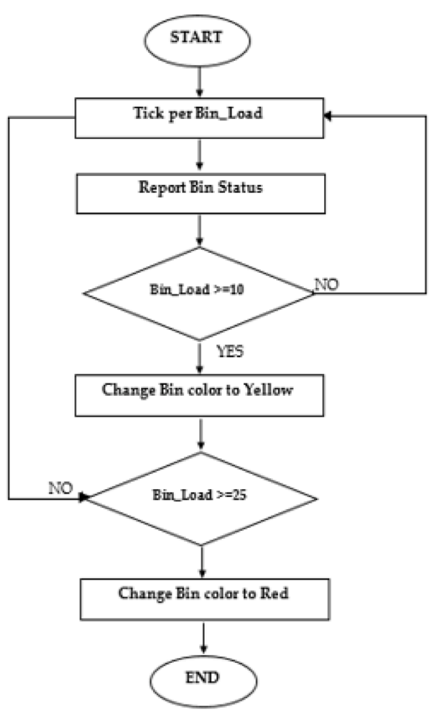

Fig. 4. Flow chart smart garbage bin decision logic .

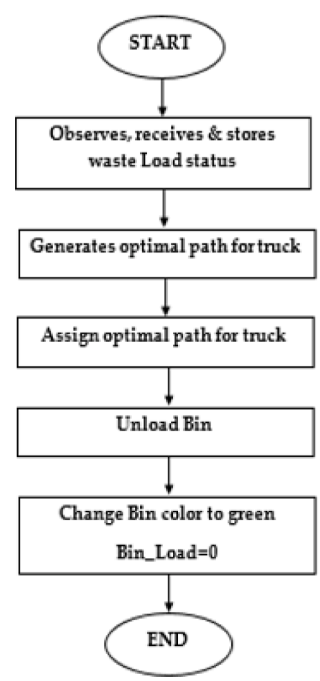

Fig. 5. Flow chart for waste collection optimization.

the smart garbage bin. The fundamental function of the proposed system is disposal of waste while generating revenue. The 3R concept of Reduce-Reuse-Recycle represents a sequence of steps that are used in proper management of waste in smart cities. The reduce concept fundamentally minimizes the volume of solid waste generated, the recycle concept aims at reprocessing or recovering of waste material that has been extracted from the SGB and the re-use concept aims at utilizing the waste material after the completion of the recycling process. The processing in the SGBM system begins immediately after an event has been created in the SGB. Each SGB has a threshold limit that is set, which helps in easy access of the SGB and the cleaning process starts once the threshold limit has been exceeded.

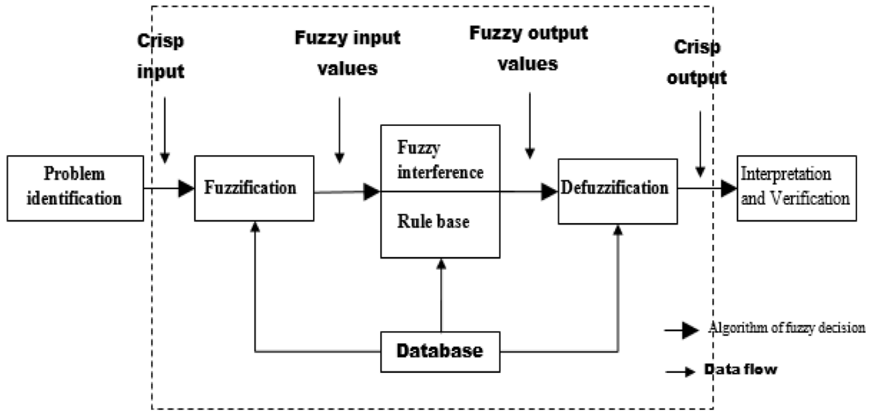

Fig. 6. Fuzzy Expert System (The dotted Region).

Table 1
The corresponding level ratings, colour ratings and status ratings of SGB.

SGB Level Ratings	Category	SGB Colour Ratings	Category	SGB Weight Ratings	Category	SGBStatus Ratings	Category
0.1 to 0.5	Low	0 to 0.2	Red	0 to 10	Light	0–33%	Bad
0.5 to 1.0	Medium	0.2 to 0.4	Yellow	10 to 25	Medium	34–66%	Average
1.0 to 1.5	High	0.4 to 1.0	Green	> 25	Heavy	67–100%	Good

3.4. Decision logic

Figs. 4 and 5 represent the logical decision and the building blocks that are involved in the recording of the status of the SGB to the emptying of the SGB. The flow-chart diagrams below provide an illustration on how the SGB (multi-agent model) will achieve both the aspect of real-time monitoring of solid waste and the collection of the solid waste. The flowcharts can also be used in modelling the dynamic aspect of the SGBM system.

3.5. Smart garbage bin mechanism using fuzzy expert system

Fuzzy logic plays a fundamental role in decision making for real-time world situations. Fuzzy logic was introduced in 1965 by Lofti Zadeh, a mathematician at the University of California (Abdallah et al., 2020). He published his work on Fuzzy sets, which laid a foundation for the present day fuzzy logic and fuzzy set theory. Lofti observed that computer logics were not sufficient in manipulating data that had vague and subjective ideas. So he came up with Fuzzy logic that allowed conventional computers to determine the distinct nature of data with shades of grey similar to human reasoning (Zadeh, 2015). The fuzzy logic is of significance because it helps in dealing with uncertainties and vagueness in monitoring the physical environment in real-time (Abdallah et al., 2020).

3.5.1. The architecture of fuzzy expert system

The fuzzy expert system has three fundamental modules; Fuzzifier, Defuzzifier and Fuzzy Inference Engine or Inference Rules (Din et al., 2018). The Fuzzifier performs Fuzzification, which is converting crisp input or real variables into linguistic variables. The Defuzzifier performs defuzzification, which reconverts the fuzzy output into numerical values (Bublyk & Rybytska, 2017). The inference rules apply the appropriate if-then rules, conditional statements are used to validate the state of a particular variable (Sacks et al., 2017). The fuzzy expert system is shown in Fig. 6.

Fuzzy logic is utilized in making decisions to enable the smart garbage bins to be deployed strategically across the city. Fuzzy logic enhances an efficient way of reading SGB in real-time and monitoring the external environment by using various linguistic variables (Abdallah et al., 2020; Sharma, Shamkuwar & Singh, 2019). The linguistic variables have various categories (Table 1).

Table 2
Showing the values of the inputs used for the selection of location for the SGB.

Criteria	Location A	Location B	Location C
The distance from the collection points	Small	Medium	Large
Level of accessing GCV	Medium	Difficult	Large

Fuzzy Expert System helps in decisions making, while making an appropriate selection of locations where the SGB is installed. In this case, only two attributes are used to select suitable places to install garbage bins: distance from the collection points and the level of accessing GCV. Considering these two attributes, the proposed system makes decisive decisions, as illustrated in Table 2.

The parameters in table 2 are essential when selecting the best location to deploy SGBs for the city residents. The proposed system is more efficient in providing cleaning services to the metropolitan or municipal authorities and monitoring waste deposited to the SGB in real-time. In the event of decision-making, the fuzzy sets are fundamental for the generation of fuzzy rules (such as the if-then rule). The (if then) rules are integrated to produce the required output values (Bano, Ud Din & Al-Huqail, 2020). Finally, the (if then) rules are integrated to produce the required output, as illustrated in Fig. 7. From Fig. 7, only 2 input variables are selected to determine a strategic place for the deployment of SGB. By applying an inference rule, only one output is generated.

4. Results and discussion

4.1. Simulation setup

For the purpose of simulation, the following terminologies are used; the agent bins represents the SGBs, the agent truck represents the GCV and the agent citizen represents the city residents (Table 3).

4.1.1. Agent bins

In the simulation, 25 agent bins are distributed randomly across the city using the fuzzy expert system decision. At the initial stage, the agent bins are green because the level of the agent bin[bin_load = 0]. The

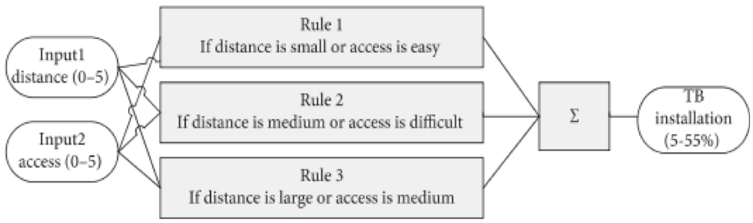

Fig. 7. The if-then rule that is used for the deployment of SGB.

Table 3
Simulation Parameters.

Bin Parameters	
Maximum capacity of the bins	25
Truck Parameters/Garbage Collecting Vehicle	
Number of trucks	5
Cost per waste unit	500 UC
Maximum Capacity of trucks	100

agent bin levels are increased per tick as soon as the simulation time kicks off [bin_load = bin_load + 1].

When the SGB level [bin_load >= 10], its colour automatically changes to yellow which is considered as the first alert. When the SGB level [bin_load >= 25], its colour automatically changes to red because the agent bin has reached the threshold and it has achieved the maximum capacity.The levels of the agent bins are continuously reported and transmitted for analysis. The simulation monitor provides the total number of agent bins that are distributed randomly. Each time the number of full agent bins is reported, it should decrease automatically once a truck is assigned to their path for collection, or else a delay will be observed.

4.1.2. Agent trucks

The agent truck follows an optimal route for waste collection once [bin_load >= 25] and the colour of the agent bin has turned red. The maximum capacity for the agent truck for simulation is [Truck_load >= 100] waste units. Once the collected agent bins have been unloaded, they automatically change the colour to green, and their level becomes zero. Also, when [Truck_load >= 100] has been emptied, the truckload returns to zero.

4.1.3. Agent citizen

Agent citizen is another agent defined in the model. The movement of citizens across the city portrays the activities undertaken resulting in the production of waste. In the simulation system, the citizens are involved because they have to pay for solid waste collection in the smart city. The total amount of revenue generated from solid waste collected is given by;

$$R_T = N_i \times p$$

R_T is the total revenue generated, N_i represents the weight of the SGB collected and P represents the price per unit of waste weight collected in terms of Units of Currency (UC).

4.2. Discussion

The system was implemented on a NetLogo platform, and this was done by running several simulations at different simulation times. At the initial stage, 25 agent bins were randomly deployed across the city. The initial condition of the agent bin[bin_load = 0].

At simulation $T_1 = 0$ mins. The Go button icon runs the simulations, and the SGB levels are increased every 1 tick. The agent bins with [bin_load >= 10] have their colour turning to yellow, showing that it is almost full. The SGB with [bin_load >= 25] has its colour automatically turning to red, which means it is full.

At simulation T_2 =53 mins .Out of the 25 distributed SGBs, the following 8 SGBs were full $\{1, 5, 6, 10, 18, 19, 20, 24\}$ as shown in the Fig. 8. It also shows the continuous and periodic recording of waste levels of each agent bin per tick.

The optimal route for the collection of waste by the agent trucks is as shown in Fig. 9. The figure shows changes in colour (Green, Yellow & Red) for different agent bins according to the amount of garbage in them. Fig. 9, also indicates optimal paths used to access agent bins that have exceeded the threshold (agent bins that have turned the colour to red).

At simulation time T_3= 93 mins, the periodic recording of the different waste levels for each agent bin per tick is shown in the Fig. 10. The number of uncollected agent bins increased to 12 at T_3.

At the simulation time (T_2), 8 agent bins were full, but 4 other agent bins had a delay. Identification of the position of vertices for the different 4 full agent bins that had delays during the collection time of T_2 is shown in Fig. 11.

5. Conclusion and future work

The paper has presented real-time smart garbage bin mechanism for solid waste management in smart cities. The system is implemented

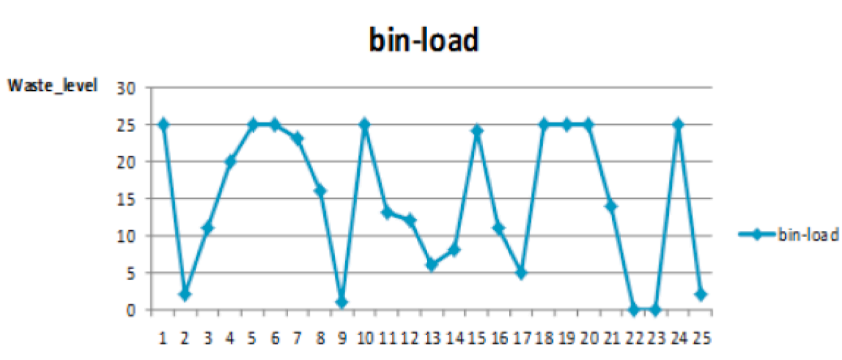

Fig. 8. Smart Garbage bins showing different levels at T_3.

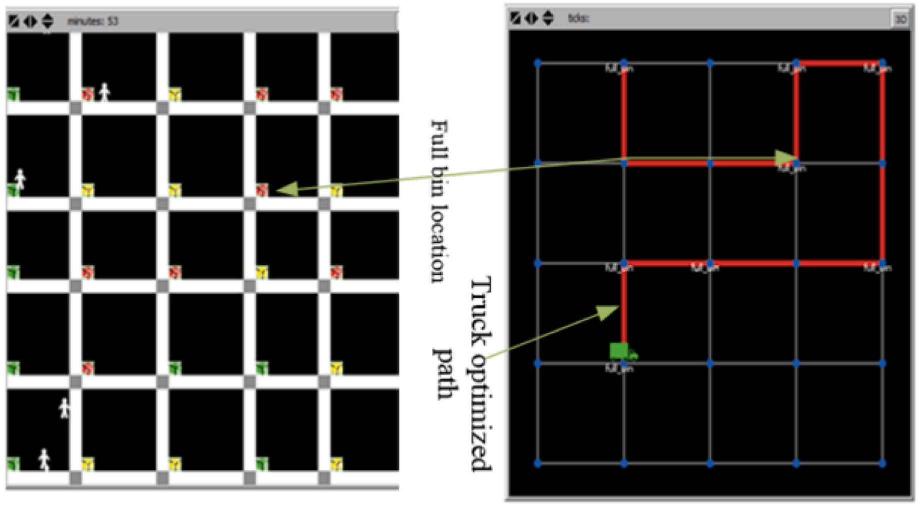

Fig. 9. Showing colour changes of agent bins and optimal paths used by agent trucks for garbage collection.

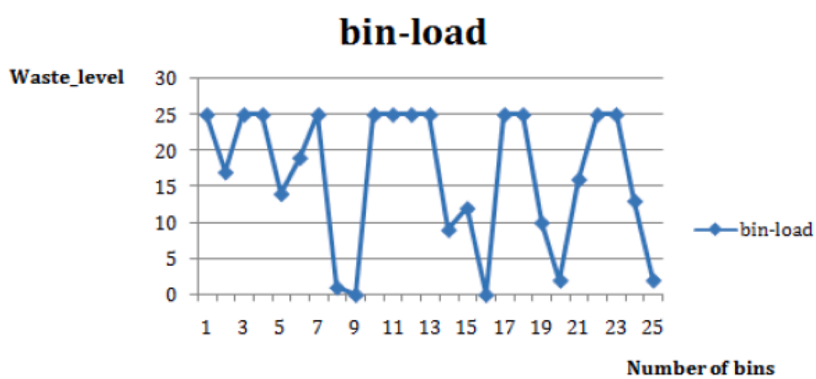

Fig. 10. Agent bins with different levels of waste at T_3=93 mins.

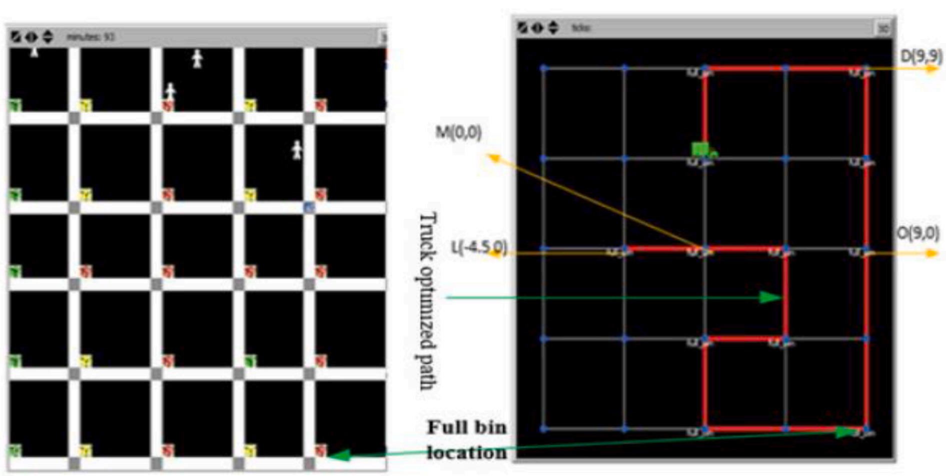

Fig. 11. Identification of vertices for agent bins that had delay during T_2 and finding their optimal paths.

using Netlogo, which provides a real-time multiagent modelling environment, and the SGBM results show that the mechanism is responsive, adaptable and effective to any smart city environment. Existing solid waste collection and management systems have several drawbacks: less accessibility to the actual data, late or delayed unloading of waste from the garbage bins, lack of throughput, and hindrance in embracing new techniques. Therefore, a more pragmatic and advanced approach must be designed and developed to overcome the existing systems' challenges. In general, waste monitoring and collection takes a significant amount of money from the municipal budget. The method proposed in this paper can access real-time data from the smart garbage bins; hence, it can appropriately implement the waste collection procedure. The proposed waste monitoring and collection mechanism is achieved by using both architectural and theoretical models. Future work should consider using WSN in the real-time waste collection and management by integrating the GIS maps into the system for precise location identification of the nodes. In addition, the future work may consider applicability of IoT in the implementation of the proposed system.

Declaration of competing Interest

The authors report no declaration of interest

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