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Quantifying Reliability Indices of Garbage Data Collection IOT-based Sensor Systems using Markov Birth-death Process

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Abstract
The aim of this paper is to analyze the performance of a Garbage data collecting sensor network system (GDCSNS) through mathematical modelling and a reliability approach. The reliability assessment of such a system is essential to ensuring that it can collect data related to garbage at different locations consistently and accurately. After the determination of the reliability measures of the system, the next aim is to identify the weakest sensors of the system so that a timely maintenance strategy for the weakest sensor can be planned to avoid disruption in the collection of data from the sensor systems. In the considered system, three sensors have been installed at various location in the city that send the information to the center office (hub point) and then from the center office to the person who is responsible for collecting the garbage from the location and dumping it at some predefined places. These sensors collect data related to garbage level, weight, and other information and send it to computers at the city's central office. Markov modelling has been used to model the system. Based on the mathematical model, a state transition diagram and a set of Kolmogorov time-dependent differential equations have been obtained. The various state probabilities (explicit expressions) related to the performance of the system, namely, Reliability, Mean time to failure, have been obtained to understand the different maintenance policies that can be used. A sensitivity analysis has also been performed to determine the weakest sensor among the sensors.

Keywords- Reliability indices, Garbage data, IoT, Sensor systems, Markov modelling, Multi-state system.

1. Introduction

Due to the increase in population and urbanization, solid waste in the world is increasing at a rapid rate. This increasing waste is a cause of greatest concern for society. Due to this waste, many deadly diseases spread, and thousands of people lose their lives every year. Therefore, it is mandatory to manage solid waste properly so that the environment remains clean and green. These days, many different types of sensors are being used, like ultrasonic sensors, infrared sensors, gas sensors, etc., in IoT-based devices. These sensors help us collect data from different environments. These sensors also help in collecting data on the waste level and weight of the dustbins. In today's world, technology and communication systems have evolved a lot, making it easy for mankind to get data on others' activities at their desired locations. This is helping people save on travel time, costs, etc. by getting the required data without actually visiting those particular locations. It has become possible to collect far-away data using sensors. A sensor is a device that is used to detect changes in the environment or the presence of objects, calculate the weight of the object, and send the information to other electronic devices using a microcontroller. Sensors are always used in conjunction with another electronic device.

To begin the reliability assessment, we first need to identify the different states that garbage-collecting IOT-based sensor systems can be in. For example, the system can be in a "working" state, where it is collecting data accurately, or in a "faulty" state, where it is not collecting data at all. We can also define additional states, such as a "partially working" state, where the system is collecting some data but not all. Firstly, the authors have identified the different states and then created a Markov chain diagram that shows the transitions (Figure 2) between the states over time. The diagram will include transition probabilities that represent the likelihood of moving from one state to another.

In this paper, the focus has been given to the reliability of garbage data collection sensor systems that have been installed at various locations in the city. As the garbage is increasing day by day due to the increase in population in rural and urban areas. Therefore, proper management of garbage collection has become very important with technological advancements. Various researchers are predicting that the world’s population will be around 9.7 billion by 2050. More population means more generations of garbage in the near future. This garbage may include items like metal, wood, cartons, vegetable peels, debris, papers, plastic, etc. This garbage comes from homes, hospitals, schools, industries, etc. Few garbage items produce a bad odour, but some items produce toxic gases that are harmful to humans, animals, soil, water, and the air. It also leads to the spread of diseases and bacteria. Due to this, many people die every year, despite the many good medical facilities available these days. Therefore, proper disposal of garbage is mandatory. For the proper disposal of waste, mainly humans and vehicles are being used in India. Somewhere, technological devices are also available for the proper management of garbage. For city garbage management, landfilling and incineration techniques are being used. If garbage is properly managed and separated, then it can be used for recycling, which ultimately saves the country's natural resources. For the separation of garbage, various tools are available, like robotic arm systems, trammels, etc. These techniques are very fast and efficient for sorting garbage. The entire task is done by machines, which ultimately increases the safety of humans as they don’t have to touch any hazardous garbage objects that may cause skin disorders or other types of infections.

Various tools and techniques are available for the proper management of garbage these days, but still, it is desirable to get garbage-related data using the sensor system at the desired location as it is cost-effective and time-saving. If the bins get full, then a message is sent to the center that the bin at this location is full, so empty this bin. The authority sends the vehicle so that overflow of the garbage from the bin can be avoided and the spread of the garbage on the road can be properly managed. There are some research questions that need to be answered through this research.

1.1 Research Questions

(i) What is the status of the IoT devices’ usage in the garbage management of a city?
(ii) If IoT devices are being used, then are they fully reliable to capture all the data related to the garbage level?
(iii) Is the municipal corporation of each city utilizing its resources efficiently and effectively?
(iv) How do Municipal Corporation identify the weakest sensors among many sensors installed at the various locations of the city?
(v) After identification of the weakest sensor, how does the authority plan its maintenance strategies?

1.2 Existing System of Garbage Picking in India

In India, garbage is lifted mainly by the municipal corporation from various sites in each city. Every day, employees deputed by the municipal corporation come in their vehicles and visit each site one by one and empty the garbage bins one by one. Some municipal corporations have installed smart dustbins at various sites and monitor the status of each bin on the computer screen installed in their offices. Once the garbage reaches a certain height, a message is sent by the microcontroller to the system, and employees of the municipal corporation reach the desired site and empty the bin. This process is cost-effective and saves many resources for the municipal corporation.

1.3 Proposed System's Reliability Analysis

In the existing system, if smart garbage bins are installed at the various sites of the city, it becomes a costly decision compared to traditional bins; therefore, it is of the utmost importance that all the components of the system be protected from harm and failures so that they remain available for a longer duration. Keeping this in mind, the authors have decided to analyze the performance of the sensor systems of the smart dustbins installed at three different locations in a city.

1.4 Problem Statement

For municipal corporations, data related to garbage levels and the weight of smart trash bins is very important. For this purpose, the sensors used in the smart trash bin should be very reliable in their operation. Any failure in the sensors leads to the loss of very important information, and the garbage lifter will not be able to reach that particular site. This will result in the spread of garbage on the roads, and many deadly diseases may spread in the locality or area. Therefore, the authors in this paper intend to analyze the performance of the sensor systems of the three smart dustbins installed at the three locations in the city. The aim of this paper is to determine the various reliability measures of the system. After reliability determination, the next aim is to find the weakest sensor or sensors of the system so that timely maintenance activity can be planned to avoid the failure of the system.

2. Related Works

In this section, the authors present the studies carried out by various researchers to help society properly manage the garbage in cities and countries. The various authors have presented their views on how to deal with garbage management problems. The authors (Sasikumar and Krishna, 2009; LaGrega et al., 2010; Pariatamby et al., 2014) presented their views on how solid waste and municipal corporations can be managed without using technological solutions. But these days, to handle the increasing garbage capacity of the world, many authors have given technologically based solutions like IoT-based systems and RFID-based garbage systems. Firstly, we present the work done in the field of IoT-based solutions. Anitha (2017) developed an IoT-based trash bin. In this bin, a sensor was placed on the top of the bin to gauge the level of garbage inside the bin. When the garbage reaches a certain level, a message is sent to the municipal corporation authority to send the employees to empty the bin. This system helps the garbage lifter not manually check each bin. Thole et al. (2019) developed an IoT-based trash bin that sends a message to the authority when garbage reaches the maximum level, and this system automatically calculates the exact location of the bin from where the garbage has to be lifted. Geethamani et al. (2021) designed a web-based and an IoT-based application for managing garbage. This application displays all the garbage-related data. This application is mainly designed for five types of users, namely This application has the advantage that if anybody needs a waste item, he or she can purchase it online at a cheap rate. Bhor et al. (2015) developed a smart dustbin using a sensor system that measures the level of garbage in the bin. Once the bin is completely filled, the Infrared sensor (IR) sends the message to the microcontroller, which in turn uses the GSM to send the message to the authority. A graphical user interface was also developed to look for the desired information on the screen. If garbage is not lifted in the stipulated time period, a record of this is sent automatically to the authority, which can take action against the contractor. Hence, this system may help reduce corruption. Chakraborty et al. (2021) developed an Android application that has three interfaces. The first interface is for the user. The user needs to register first. After the registration, the user can log in to the application page, where he can track the municipal corporation vehicle's location. Users can book garbage collection from their house, and they can also file a complaint using the interface. In the second interface, the garbage collector can accept the booking, and he can easily track the location of the site where the garbage has to be picked up. The third interface is for the administrator, who can check the functioning of the garbage collector and any serious issues faced by the people of the locality. Chadha et al. (2019) presented a sensor-based smart bin with a compressor plate that is connected to a motor. Once the bin gets full, the plate compresses the garbage in the bin and makes space in the bin so that more garbage can be thrown into it. Their research helps reduce the frequency with which municipal staff lift garbage. Cai et al. (2022) developed an IoT-based application called "Garbage Manager". This is a very low-cost application that displays garbage bin-related data in real-time. In their research, it was found that this application reduces manpower by 24.07% and garbage overflow time by 83.33%. Asyikin and Syahidi (2020) developed two types of smart dustbins, namely mini-smart dustbins and super-smart dustbins, for college campuses. Mini-smart dustbins are placed on the lecturer's and academic staff's tables. They throw candy wrappers and tissues in these dustbins. Super smart dustbins are placed outside the classroom, prayer room, and canteens. Students and other staff members throw snack wrappers, cold drink bottles, and others in these dustbins. In their research, they concluded that the usage of smart dustbins on the campuses creates interest among the students to throw the garbage in the bins only. Vamsi et al. (2021) developed an IoT-based application called "Smart garbage monitoring and disposable support system". This application gives the real-time status of each trash bin. Once it is fully filled, a message is sent to the worker. All the data can be accessed and stored in the cloud.

Next, we present some RFID-based systems. Ranjana et al. (2021) developed a smart bin using an RFID reader and sensors that open the lid automatically when they detect a garbage bag. In this bin, they used a gas sensor and a humidity sensor to measure the gases and humidity in the bin. Each person is given an RFID tag to throw the garbage in the bin. The person who throws the most garbage is also given the most points, and the user can use these points to get the gift from the municipal corporation. In this way, people throw garbage only in the bin to get the maximum number of points. Parikh et al. (2017) developed an RFID reader-based dustbin that senses the presence of a human and shows the name of the registered user on the LCD screen when the RFID tag is read by the RFID reader. After this, it opens its lid automatically, and this lid stays open until a human remains present near the bin. The presence of humans is detected by an ultrasonic sensor. When this bin gets filled, it shows a red light on the LCD screen, and the microcontroller sends a message to the authority that the bin is completely full. Tripathi et al. (2018) proposed an RFID-based smart dustbin for railway stations. As in railway stations, conventional dustbins can be easily used by terrorists to place bombs. Here, they proposed to issue RFID tags that store all the user's information. When an RFID reader reads the RFID tag, all the information about the user is saved in the database. If anybody tries to put the bomb in the bin, then his personal information can be accessed from the database, and the culprit can be traced very easily.

A few other authors also presented their views on garbage management, and some of them also conducted a survey to gauge the curiosity of the people about using the smart dustbin. Chandra and Tawami (2020) conducted a survey of 30 randomly selected people to know whether people prefer to use conventional dustbins or smart dustbins. They concluded that people are more inclined to use smart dustbins than conventional dustbins. Amasuomo and Baird (2016) clarified which should be treated as waste and which should not be treated as waste. According to the authors, waste is what is collected, transported, and disposed of in such a manner that its harmful effects are properly eliminated. Gundupalli et al. (2017) presented recent advances in waste sorting systems using sensors and actuators. They also presented the challenges of the automatic waste sorting systems. They presented the view that the cost of these machines is too much; hence, for the developing nation, it is mandatory to develop a low-cost automatic waste sorting system. Geetha et al. (2019) used a hesitant fuzzy multimodal method to assess the healthcare waste disposal method.

In the above discussion, we have seen that for smart bins, the sensor is the main component that measures the weight and height of the garbage in the bin. This has been observed in the above research: nobody has ever tried to assess the reliability of the sensor systems of the smart dustbins. In the present paper, we have modelled three garbage-collecting data sensors located at three different locations in the city using Markov modelling. Markov modelling is a state-based system that describes the various states that a system can be in. Various authors have already used Markov modelling to model the different systems. Kumar and Kumar (2020, 2021, 2022) used Markov modelling to model wireless communication systems, Automatic ticket vending machine (ATVM), and Turnstile system. Yeh et al. (2022) proposed an all-multiterminal BAT algorithm by revising the binary-addition-tree algorithm (BAT) and the layered-search algorithm (LSA) and calculating all multi-terminal reliabilities. The AMP-based-approximation approach was developed by Forghani-Elahabad et al. (2019) to reduce the computing cost that occurs in solving different reliability problems. Also, different reliability models through the concept of uncertainty were discussed by Dhiman and Kumar (2020) and Kumar and Dhiman (2020, 2021, 2023).

The remainder of the paper is organized as follows: In section 3, a system description and the system's various states are given. In section 4, mathematical modelling of the system is given. In section 5, the system's various reliability measures, like reliability and MTTF, are given. In section 6, results and discussion are given. In section 7, a conclusion is given. In section 8, the future direction for the researchers is given.

3. System Description and System States

3.1 System Description

The Garbage Data Collecting Sensor Network System (GDCSNS) is an Internet of Things (IoT)-based system designed to collect and manage data related to garbage collection in a city. The system is composed of various sensors placed at garbage sites. These sensors are capable of detecting items and collecting data such as the amount of garbage in a container, the location of the container, and the time of the last pickup. The data collected by these sensors is transmitted to a central server via a wireless network, where it is processed and analyzed to optimize garbage collection routes and schedules. The system can also provide alerts to waste management personnel when containers are full. In the present study, the authors have considered three sensors that are collecting data from three different locations in the city and sending the information to the center. These sensors measure the height and weight of the trash bin. The systematics diagram of a GDCSNS is shown below in Figure 1. Due to the nature of the proposed problem, failure and repair rates follow the exponential distribution, which is also known as constant failure and repair rates. Failure rates and repair rates are actually the frequencies with which an engineering system or component fails or repairs, respectively. They are expressed per unit of time. In the Markov model, to make a transition from one state to another, only the previous state's knowledge is required. There is no need to remember the history of the previous states. These days, TPM (total product maintenance) is being used by many industries to avoid breakdowns, slow-running production capacity, and defects. Yet the failure of the system is random in nature and may occur at any time during its operation. Therefore, it is mandatory to check the performance of the system from time to time so that failures can be avoided by planning proper maintenance strategies.

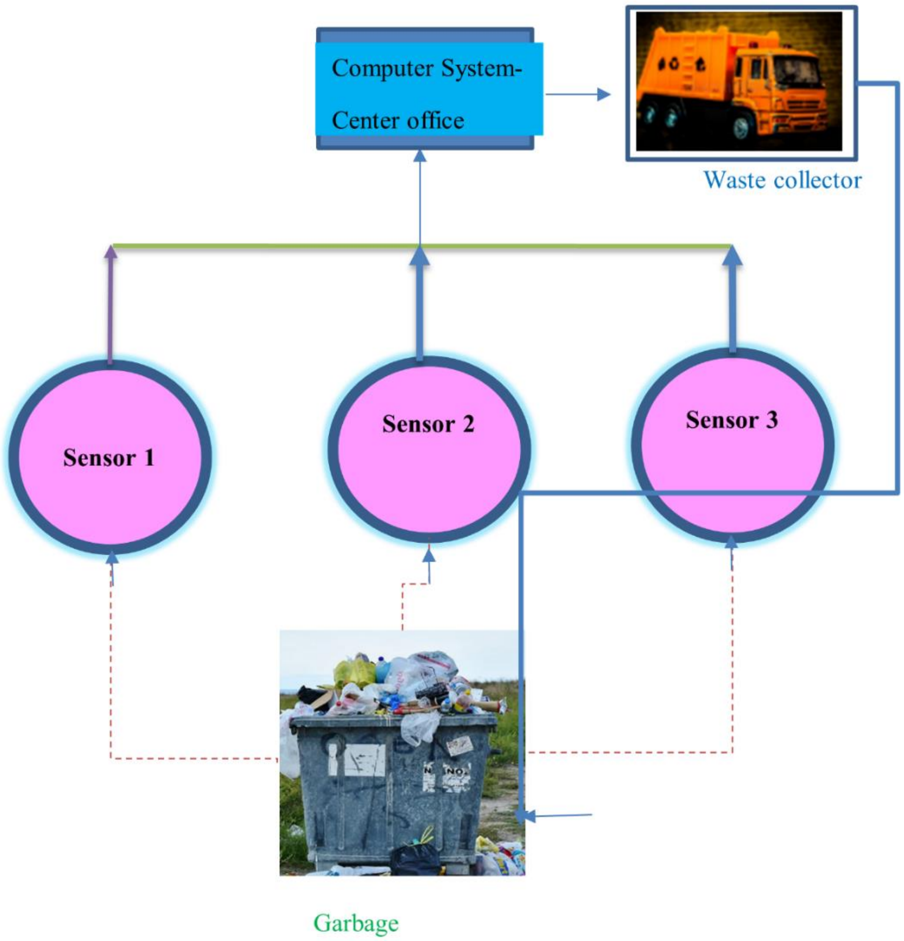

Figure 1. Garbage data collecting sensors network system.

3.2 Nomenclature and State Description
In this section, various notations used in the paper are given in Table 1, and the system's various states are described in Table 2. The state transition diagram of the system is given in Figure 2.

3.2.1 Notations
The following notations will be used in this paper for building the mathematical model.

Table 1. Notations.

t	Time variable
s	Laplace transformation variable
λ_i	Failure rate of the i^{th} sensor
μ_i	Repair rate of the i^{th} sensor
$P_i(t)$	Probability of the system being in the i^{th} state
$\overline{P}_i(s)$	Laplace transformation of $P_i(t)$

3.2.2 State Description
The following table gives all the possible states of the system.

Table 2. State narrative.

S_0	All the sensors of the system are in good condition.
S_1	The first sensor of the system fails and the system is in a degraded state.
S_2	The second sensor of the system fails and the system is in a degraded state.
S_3	The third sensor of the system fails and the system is in a degraded state.
S_4	The first and second sensors of the system fail and the system is in a degraded state.
S_5	The second and third sensors of the system fail and the system is in a degraded state.
S_6	The first and third sensors of the system fail and the system is in a degraded state.
S_7	All the sensors of the system fail and the system fails completely.

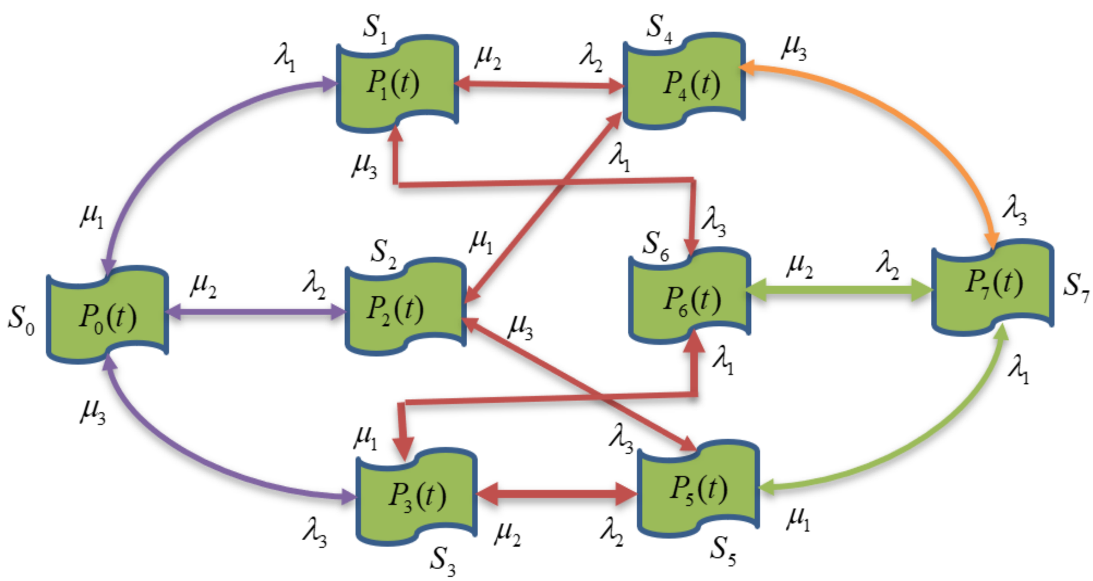

Figure 2. State transition diagram of the system.

4. Kolmogorov Differential Equations Generation from State Transition Diagram
In this section, we develop the Chapman-Kolmogorov differential equation for the proposed system. These equations are developed for a repairable system. On the failure of any component, the system makes a transition from one state to another, and after the repair is offered, the system is again brought back to the previous state. Initially, the system makes the transition at time $t+\Delta t$ and then, letting $\Delta t \to 0$, we obtain the following system of differential equations for the garbage data collecting sensor systems:

$$\left[\frac{d}{dt}+\lambda_1+\lambda_2+\lambda_3\right]P_0(t)=\mu_1 P_1(t)+\mu_2 P_2(t)+\mu_3 P_3(t) \tag{1}$$

$$\left[\frac{d}{dt}+\mu_1+\lambda_2+\lambda_3\right]P_1(t)=\lambda_1 P_0(t)+\mu_2 P_4(t)+\mu_3 P_6(t) \tag{2}$$

$$\left[\frac{d}{dt}+\mu_2+\lambda_1+\lambda_3\right]P_2(t)=\lambda_2 P_0(t)+\mu_1 P_4(t)+\mu_3 P_5(t) \tag{3}$$

$$\left[\frac{d}{dt}+\mu_3+\lambda_2+\lambda_1\right]P_3(t)=\lambda_3 P_0(t)+\mu_2 P_5(t)+\mu_1 P_6(t) \tag{4}$$

$$\left[\frac{d}{dt}+\lambda_3+\mu_2+\mu_1\right]P_4(t)=\mu_3 P_7(t)+\lambda_2 P_1(t)+\lambda_1 P_2(t) \tag{5}$$

$$\left[\frac{d}{dt}+\lambda_1+\mu_3+\mu_2\right]P_5(t)=\mu_1 P_7(t)+\lambda_3 P_2(t)+\lambda_2 P_3(t) \tag{6}$$

$$\left[\frac{d}{dt}+\lambda_2+\mu_3+\mu_1\right]P_6(t)=\mu_2 P_7(t)+\lambda_3 P_1(t)+\lambda_1 P_3(t) \tag{7}$$

$$\left[\frac{d}{dt}+\mu_3+\mu_1+\mu_2\right]P_7(t)=\lambda_3 P_4(t)+\lambda_1 P_5(t)+\lambda_2 P_6(t) \tag{8}$$

$$P_i(0)=\begin{cases}1 & i=0\\ 0 & i\neq 0\end{cases} \tag{9}$$

Taking inverse Laplace transformation of the equations from (1)-(9), we get the following equations,

$$[s+\lambda_1+\lambda_2+\lambda_3]\overline{P_0}(s)=1+\mu_1\overline{P_1}(s)+\mu_2\overline{P_2}(s)+\mu_3\overline{P_3}(s) \tag{10}$$

$$[s+\mu_1+\lambda_2+\lambda_3]\overline{P_1}(s)=\lambda_1\overline{P_0}(s)+\mu_2\overline{P_4}(s)+\mu_3\overline{P_6}(s) \tag{11}$$

$$[s+\mu_2+\lambda_1+\lambda_3]\overline{P_2}(s)=\lambda_2\overline{P_0}(s)+\mu_1\overline{P_4}(s)+\mu_3\overline{P_5}(s) \tag{12}$$

$$[s+\mu_3+\lambda_2+\lambda_1]\overline{P}_3(s)=\lambda_3\overline{P}_0(s)+\mu_2\overline{P}_5(s)+\mu_1\overline{P}_6(s) \tag{13}$$

$$[s+\lambda_3+\mu_2+\mu_1]\overline{P}_4(s)=\mu_3\overline{P}_7(s)+\lambda_2\overline{P}_1(s)+\lambda_1\overline{P}_2(s) \tag{14}$$

$$[s+\lambda_1+\mu_3+\mu_2]\overline{P}_5(s)=\mu_1\overline{P}_7(s)+\lambda_3\overline{P}_2(s)+\lambda_2\overline{P}_3(s) \tag{15}$$

$$[s+\lambda_2+\mu_3+\mu_1]\overline{P}_6(s)=\mu_2\overline{P}_7(s)+\lambda_3\overline{P}_1(s)+\lambda_1\overline{P}_3(s) \tag{16}$$

$$[s+\mu_3+\mu_1+\mu_2]\overline{P_7}(t)=\lambda_3\overline{P_4}(s)+\lambda_1\overline{P_5}(s)+\lambda_2\overline{P_6}(s) \tag{17}$$

For the calculation of reliability set all the repair rates equal to zero, *i.e.*, $\mu_1=\mu_2=\mu_3=0$ in (10)-(17), we obtain the following equations.

$$[s+\lambda_1+\lambda_2+\lambda_3]\overline{P_0}(s)=1 \tag{18}$$

$$[s+\lambda_2+\lambda_3]\overline{P_1}(s)=\lambda_1\overline{P_0}(s) \tag{19}$$

$$[s+\lambda_1+\lambda_3]\overline{P_2}(s)=\lambda_2\overline{P_0}(s) \tag{20}$$

$$[s+\lambda_2+\lambda_1]\overline{P}_3(s)=\lambda_3\overline{P}_0(s) \tag{21}$$

$$[s+\lambda_3]\overline{P}_4(s)=\lambda_2\overline{P}_1(s)+\lambda_1\overline{P}_2(s) \tag{22}$$

$$[s+\lambda_1]\overline{P}_5(s)=\lambda_3\overline{P}_2(s)+\lambda_2\overline{P}_3(s) \tag{23}$$

$$[s+\lambda_2]\overline{P}_6(s)=\lambda_3\overline{P}_1(s)+\lambda_1\overline{P}_3(s) \tag{24}$$

$$[s]\overline{P_7}(s)=\lambda_3\overline{P_4}(s)+\lambda_1\overline{P_5}(s)+\lambda_2\overline{P_6}(s) \tag{25}$$

where, $T_0=(s+\lambda_1+\lambda_2+\lambda_3)$, $T_1=(s+\lambda_2+\lambda_3)$, $T_2=(s+\lambda_1+\lambda_3)$, $T_3=(s+\lambda_2+\lambda_1)$, $T_4=(s+\lambda_3)$ $T_5=(s+\lambda_1)$, $T_6=(s+\lambda_2)$, $T_7=(s)$.

Substituting these values in Equations (18)-(25), we can obtain the state probabilities of the system as given below:

$$\overline{P_0}(s)=\frac{1}{T_0} \tag{26}$$

$$\overline{P_1}(s)=\frac{\lambda_1}{T_1\,T_0} \tag{27}$$

$$\overline{P_2}(s)=\frac{\lambda_2}{T_2\,T_0} \tag{28}$$

$$\overline{P_3}(s)=\frac{\lambda_3}{T_3\,T_0} \tag{29}$$

$$\overline{P_4}(s)=\frac{\lambda_1\lambda_2}{T_0\,T_1\,T_4}+\frac{\lambda_1\lambda_2}{T_0\,T_2\,T_4} \tag{30}$$

$$\overline{P_5}(s)=\frac{\lambda_2\lambda_3}{T_0\,T_2\,T_5}+\frac{\lambda_2\lambda_3}{T_0\,T_3\,T_5} \tag{31}$$

$$\overline{P_6}(s)=\frac{\lambda_1\lambda_3}{T_0\,T_1\,T_6}+\frac{\lambda_1\lambda_3}{T_0\,T_3\,T_6} \tag{32}$$

$$\overline{P_7}(s)=\frac{\lambda_3}{T_7}\left[\frac{\lambda_1\lambda_2}{T_0\,T_1\,T_4}+\frac{\lambda_1\lambda_2}{T_0\,T_2\,T_4}\right]+\frac{\lambda_1}{T_7}\left[\frac{\lambda_2\lambda_3}{T_0\,T_2\,T_5}+\frac{\lambda_2\lambda_3}{T_0\,T_3\,T_5}\right]+\frac{\lambda_2}{T_7}\left[\frac{\lambda_1\lambda_3}{T_0\,T_1\,T_6}+\frac{\lambda_1\lambda_3}{T_0\,T_3\,T_6}\right] \tag{33}$$

The system's upstate is the sum of those states in which either the system is working at full capacity or working at partial capacity but has not failed completely. The system's upstate is given in equation (34) below. The system's downstate is the sum of the system's failed states, which are the completely failed states of the system. The system downstate is given in equation (35) below.

$$\overline{P_{up}}(s)=\overline{P_0}(s)+\overline{P_1}(s)+\overline{P_2}(s)+\overline{P_3}(s)+\overline{P_4}(s)+\overline{P_5}(s)+\overline{P_6}(s)$$
$$=\frac{1}{T_0}+\frac{\lambda_1}{T_1T_0}+\frac{\lambda_2}{T_2T_0}+\frac{\lambda_3}{T_3T_0}+\frac{\lambda_1\lambda_2}{T_0T_1T_4}+\frac{\lambda_1\lambda_2}{T_0T_2T_4}+\frac{\lambda_2\lambda_3}{T_0T_2T_5}+\frac{\lambda_2\lambda_3}{T_0T_3T_5}+\frac{\lambda_1\lambda_3}{T_0T_1T_6}+\frac{\lambda_1\lambda_3}{T_0T_3T_6} \quad (34)$$
$$+\frac{\lambda_3}{T_7}\left[\frac{\lambda_1\lambda_2}{T_0T_1T_4}+\frac{\lambda_1\lambda_2}{T_0T_2T_4}\right]+\frac{\lambda_1}{T_7}\left[\frac{\lambda_2\lambda_3}{T_0T_2T_5}+\frac{\lambda_2\lambda_3}{T_0T_3T_5}\right]+\frac{\lambda_2}{T_7}\left[\frac{\lambda_1\lambda_3}{T_0T_1T_6}+\frac{\lambda_1\lambda_3}{T_0T_3T_6}\right]$$

$$\overline{P}_{down}(s)=\overline{P_7}(s) \quad (35)$$

5. System's Performance Indicator of Garbage Data Collecting Sensor System

5.1 Reliability of the System

The reliability of the technical object is its probability of performing the required operation successfully without any failure for a specified period under prescribed conditions. Mathematically, the reliability of the system can be expressed as

$$R(t)=P(T>t) \quad (36)$$

It implies that the system cannot fail before the time period T. The reliability of a system is entirely depending on parameter t. In order to obtain the reliability of the proposed system, take the inverse Laplace transformation of equation (34), the following expression of the reliability can be obtained:

$$R(t)=e^{-\lambda_3 t}+e^{-\lambda_1 t}+e^{-\lambda_2 t}-e^{-(\lambda_1+\lambda_2)t}-e^{-(\lambda_1+\lambda_3)t}-e^{-(\lambda_2+\lambda_3)t}+e^{-(\lambda_1+\lambda_2+\lambda_3)t} \quad (37)$$

$(\lambda_1,\lambda_2,\lambda_3)$ as shown in the following Table 3.

Table 3. Reliability of the system versus time.

	R_1	R_2	R_3
Time (In Month)	$\lambda_1=0.0500\ per/month$ $\lambda_2=0.0345\ per/month$ $\lambda_3=0.0270\ per/month$	$\lambda_1=0.0714\ per/month$ $\lambda_2=0.0435\ per/month$ $\lambda_3=0.0333\ per/month$	$\lambda_1=0.1250\ per/month$ $\lambda_2=0.0588\ per/month$ $\lambda_3=0.04167\ per/month$
0	1.00000	1.00000	1.00000
2	0.99967	0.99928	0.99804
4	0.99761	0.99505	0.98733
6	0.99275	0.98550	0.96530
8	0.98455	0.97009	0.93276
10	0.97283	0.94902	0.89191
12	0.95767	0.92291	0.84526
14	0.93929	0.89259	0.79514
16	0.91806	0.85897	0.74347
18	0.89433	0.82291	0.69176
20	0.86854	0.78521	0.64110

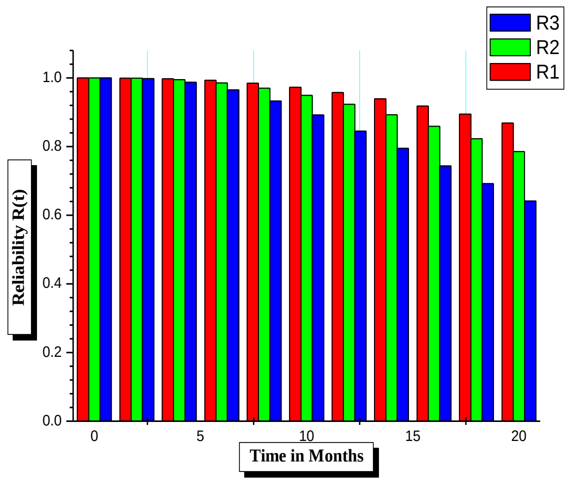

Figure 3. Reliability of the system versus time.

5.2 Mean Time to Failure (MTTF) of the Data Collecting Sensor System

The Mean time to failure of the system is defined as the average time that a system takes to fail for the first time. From any organization's point of view, which is using the devices or machines, and from a safety point of view, the MTTF of the device should be higher. In order to calculate the MTTF of the purposed system in this paper, set $s \to 0$ in Equation (34), the obtained function is dependent on the failure rates of the system, as shown below.

$$MTTF = \begin{bmatrix} \frac{1}{(\lambda_1+\lambda_2+\lambda_3)} + \frac{\lambda_1}{(\lambda_2+\lambda_3)(\lambda_1+\lambda_2+\lambda_3)} + \frac{\lambda_2}{(\lambda_1+\lambda_3)(\lambda_1+\lambda_2+\lambda_3)} + \frac{\lambda_3}{(\lambda_1+\lambda_2)(\lambda_1+\lambda_2+\lambda_3)} \\ + \frac{\lambda_1\lambda_2}{(\lambda_2+\lambda_3)(\lambda_1+\lambda_2+\lambda_3)\lambda_3} + \frac{\lambda_1\lambda_2}{(\lambda_1+\lambda_3)(\lambda_1+\lambda_2+\lambda_3)\lambda_3} + \frac{\lambda_3\lambda_2}{(\lambda_1+\lambda_3)(\lambda_1+\lambda_2+\lambda_3)\lambda_1} \\ + \frac{\lambda_2\lambda_3}{(\lambda_1+\lambda_2)(\lambda_1+\lambda_2+\lambda_3)\lambda_1} + \frac{\lambda_1\lambda_3}{(\lambda_2+\lambda_3)(\lambda_1+\lambda_2+\lambda_3)\lambda_2} + \frac{\lambda_3\lambda_1}{(\lambda_1+\lambda_2)(\lambda_1+\lambda_2+\lambda_3)\lambda_2} \end{bmatrix} \quad (38)$$

Now one can see the variation in the MTTF of the whole system when the failure rate of each sensor is increased while keeping the failure rates of other sensors fixed. The following Table 4 and Figure 4 demonstrate it quite clearly.

Table 4. MTTF of the system with respect to variation in the failure rates.

MTTF (Variation in failure rates)	$\lambda_2 = 0.0345\ per/month$ $\lambda_3 = 0.0270\ per/month$	$\lambda_1 = 0.0500\ per/month$ $\lambda_3 = 0.0270\ per/month$	$\lambda_1 = 0.0500\ per/month$ $\lambda_2 = 0.0345\ per/month$
0.01	114.2494	111.8506	108.5946
0.02	72.4071	68.7969	64.0862
0.03	60.9769	56.6853	51.2142
0.04	56.2664	51.5605	45.6494
0.05	53.9096	48.9370	42.7518
0.06	52.5832	47.4307	41.0653
0.07	51.7740	46.4958	40.0066
0.08	51.2501	45.8813	39.3042
0.09	50.8950	45.4592	38.8179
0.1	50.6454	45.1590	38.4696

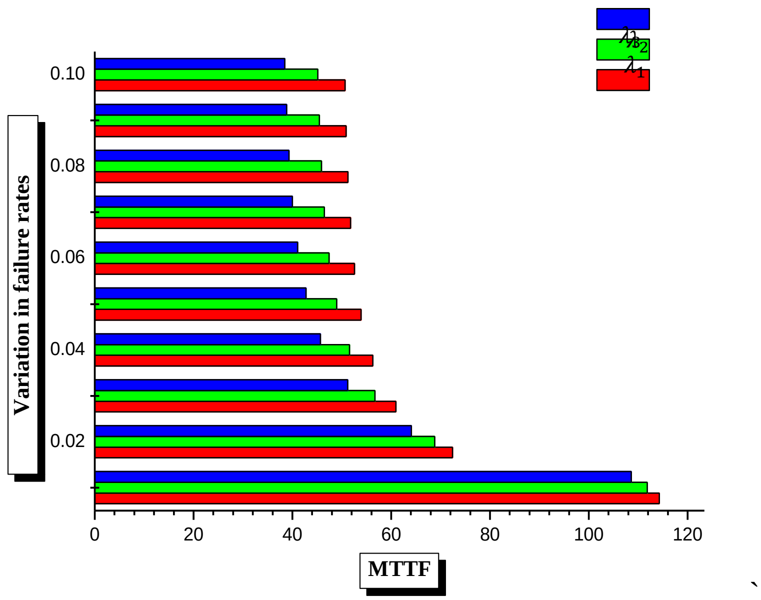

Figure 4. MTTF of the system with respect to variation in the failure rates.

5.3 Sensitivity of MTTF of the Data Collecting Sensor System

A Sensitivity analysis is performed to determine the most critical component/ components of the system. It actually determines how the system's MTTF is affected by changing the failure rate of a single component while keeping the failure rates of the other system's components fixed. Here, the authors perform a sensitivity analysis of the MTTF of the data-collecting garbage sensor systems. For this, differentiate equation (39) with respect to all the failure rates one by one and set the failure rates as follows.

$\lambda_1 = 0.0500\, per/month,\ \lambda_2 = 0.0345\, per/month,\ \lambda_3 = 0.0270\, per/month$.

and then varying each failure rate from 0.01 to 0.1 in these derivatives while keeping other failure rates values fixed. In this way, one can easily obtain Table 5 and the corresponding Figure 5 for the sensitivity of the MTTF of the data-collecting sensor systems.

Table 5. Sensitivity of MTTF with respect to variation in the failure rates.

Variation in failure rates	$\frac{\partial(MTTF)}{\partial\lambda_1}$	$\frac{\partial(MTTF)}{\partial\lambda_2}$	$\frac{\partial(MTTF)}{\partial\lambda_3}$
0.01	-8960.16165	-9123.87988	-9392.21442
0.02	-1861.18587	-1949.50606	-2050.81936
0.03	-683.39613	-734.41797	-790.76713
0.04	-319.12734	-351.82780	-385.88623
0.05	-171.72233	-193.33761	-215.27727
0.06	-101.42133	-116.29464	-131.04634
0.07	-64.05679	-74.63298	-84.95734
0.08	-42.57436	-50.30412	-57.75677
0.09	-29.45905	-35.24145	-40.76174
0.10	-21.06173	-25.47473	-29.65414

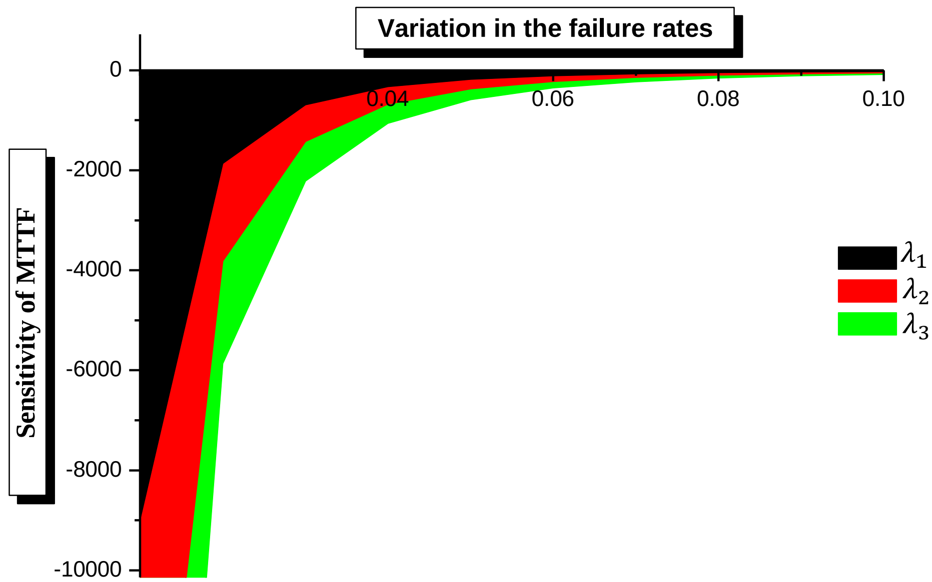

Figure 5. Sensitivity of MTTF with respect to variation in the failure rate.

5.4 Sensitivity of Reliability of the Data Collecting Sensor System

The sensitivity of reliability determines how the whole system's reliability is affected by changing the failure rate of a single system component while keeping the other failure rates fixed. Differentiate equation (37) w.r.t. failure rates and set failure rates as follows:

$$\lambda_1 = 0.0500\, per/month,\ \lambda_2 = 0.0345\, per/month,\ \lambda_3 = 0.0270\, per/month.$$

and then varying the time unit. In this way, one can easily obtain Table 6 and the corresponding Figure 6 for the sensitivity and reliability of the data-collection sensor systems. Here, the authors perform a sensitivity analysis of the reliability of the data-collecting sensor systems.

Table 6. Sensitivity of reliability with respect to variation in time.

Time (In Months)	$\frac{\partial(R(t))}{\partial\lambda_1}$	$\frac{\partial(R(t))}{\partial\lambda_2}$	$\frac{\partial(R(t))}{\partial\lambda_3}$
0	0	0	0
2	-0.00634	-0.00933	-0.01202
4	-0.04321	-0.06465	-0.08389
6	-0.12429	-0.18909	-0.24728
8	-0.25125	-0.38878	-0.51254
10	-0.41875	-0.65937	-0.87640
12	-0.61756	-0.99044	-1.32747
14	-0.83828	-1.36861	-1.84998
16	-1.06980	-1.77962	-2.42644
18	-1.30309	-2.20960	-3.03930
20	-1.53014	-2.64584	-3.67206

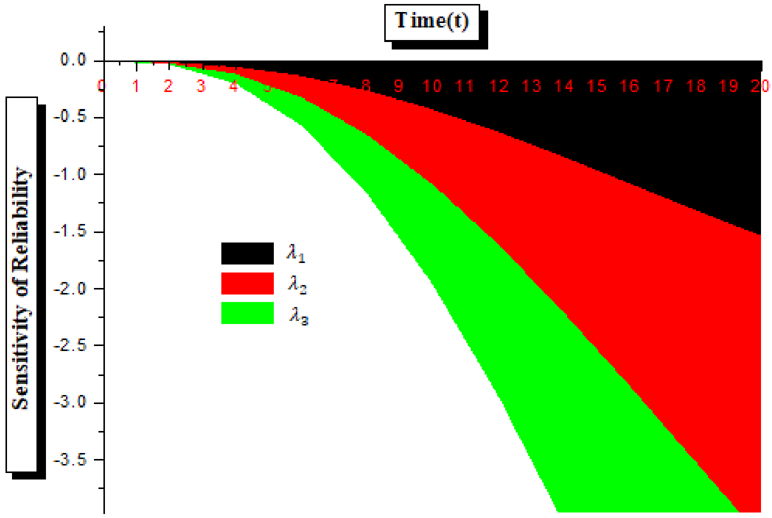

Figure 6. Sensitivity of reliability with respect to variation in time.

6. Results and Discussion

In this paper, the performance of the data-collecting sensor systems has been analyzed with the help of the Markov model. This model is a state-based model, and using this model, possible system states can be shown very easily. The Markov model helps in modelling a real-life situation or an engineering problem. This model can help the municipal corporations of the various cities assess the performance of the data-collecting sensor systems and identify the weakest sensors in the city after the analysis. Thus, this model may help the municipal corporation use its resources effectively and efficiently. From the transition state diagram, Kolmogorov differential equations have been obtained and solved with the help of the Laplace transformation for obtaining state probabilities of the system. Various reliability measures, like reliability and MTTF, have been determined for the proposed system. The authors have also performed a sensitivity analysis of the system to identify the critical sensor(s) of the system. The following results have been obtained:

(i) Table 3 and Figure 3 represent the reliability of the proposed model for various sets of failure rates. It is quite obvious from the graph that as the time unit increases, the reliability of the system keeps on decreasing. Initially, at t=0, the reliability of the system for three sets of failure rates is 1. After 20 months, the reliability for the first set of failure rates is 0.86854. When failure rates are increased, then reliability is 0.78521 for the second set of failure rates after 20 months. The reliability is 0.64110 after 20 months for the third set of failure rates. Hence, there is a decline in the reliability of the system due to increasing the failure rates of the sensors. Sometimes, cost also plays an important role, due to which authorities start using low-quality products or products with higher failure rates. As discussed above, the authority should avoid using low-quality and higher-failure-rate sensors so that the system remains available and reliable for a long duration, and maintenance costs will also be low for this type of system.

(ii) Table 4 and Figure 4 represent the MTTF (mean time to failure) of the system. The Mean failure time helps in estimating the average time when a system fails for the first time. A high value of the MTTF of the system indicates that it may be more reliable to use, and a low value of the MTTF indicates that the system may be less reliable to use. From Table 4 and Figure 4, it is quite obvious that by varying the failure rate of the third sensor, the MTTF of the whole system reduces drastically when compared with the MTTFs of the first and second sensors. Hence, among all sensors, sensor 3 is the weakest sensor on the basis of its MTTF.

(iii) Table 5 and Figure 5 represent the sensitivity of the MTTF with respect to the variation in failure rates. It is quite obvious that the system's MTTF is more sensitive to variations in the failure rate of the third sensor. This means that any slight increase in the failure rate of the third sensor decreases the system's MTTF too much. This implies that the third sensor is very sensitive to the system's MTTF when compared with the other two sensors' MTTF.

(iv) Table 6 and Figure 6 represent the sensitivity of the reliability of the system. It can be observed from the figure that the system's reliability is more sensitive with time for the third sensor of the system. This implies that increasing the time unit reliability of the third sensor decreases drastically in comparison to the other two sensors' reliability.

7. Conclusion

In this paper, we have presented data-collecting sensor systems. These sensors are used in the smart trash bin. Sensors help measure the weight and height of the garbage in the trash bins. Therefore, proper functioning of these sensors is required to obtain the desired information related to the garbage. In this model, we model the system using Markov modelling. The various states of the system have been shown in the transition state diagram. Kolmogorov-Chapman differential equations have been formulated and solved using the Laplace transformation to obtain the various state probabilities of the system. From the above result and discussion section, it is quite clear that "sensor 3" has a very low MTTF. Also, the system's MTTF is very sensitive to the failure rate of the third sensor. The system's overall reliability is also very sensitive to variations in the time unit for the third sensor. Therefore, the authority handling these smart bins in the city is given the advice to take proper care of the third sensor, as the third sensor is the weakest sensor in the city, so that the reliability of the overall system can be improved. This model has helped identify the weakest sensor in the city. For this sensor, the authority may plan timely repair and maintenance. This analysis will definitely help the authority improve the garbage management strategies of the city by planning the timely repair and maintenance of the weakest sensor.

8. Future Direction of the Research

In this paper, the authors have taken only three locations in the city to identify the weakest sensor of the smart trash bins. But some cities are quite big, and they may be using hundreds and thousands of smart trash bins. Therefore, this study may be further extended to determine the weakest sensors in the whole city so that data from these sensors may be obtained by municipal corporations to keep the city clean and green.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

The probability of the structure to be in the state S_0 in the interval $(t, t + \Delta t)$ is given by (on the basis Figure 2).

$$P_0(t + \Delta t) = (1 - \lambda_1\, \Delta t)(1 - \lambda_2\, \Delta t)(1 - \lambda_3\, \Delta t)P_0(t) + \mu_1 \Delta t\, P_1(t) + \mu_2 \Delta t\, P_2(t) + \mu_3 \Delta t\, P_3(t)$$

$$\frac{P_0(t+\Delta t)-P_0(t)}{\Delta t}+(\lambda_1+\lambda_2+\lambda_3)P_0(t)=\mu_1\,P_1(t)+\mu_2\,P_2(t)+\mu_3\,P_3(t)$$

Now taking $\lim\limits_{\Delta t\to 0}$ we get

$$\lim_{\Delta t\to 0}\frac{P_0(t+\Delta t)-P_0(t)}{\Delta t}+(\lambda_1+\lambda_2+\lambda_3)P_0(t)=\mu_1\,P_1(t)+\mu_2\,P_2(t)+\mu_3\,P_3(t)$$

$$\left[\frac{d}{dt}+\lambda_1+\lambda_2+\lambda_3\right]P_0(t)=\mu_1\,P_1(t)+\mu_2\,P_2(t)+\mu_3\,P_3(t) \tag{1}$$

The probability of the structure to be in the state S_1 in the interval $(t,t+\Delta t)$ is given by

$$P_1(t+\Delta t)=(1-\mu_1\,\Delta t)(1-\lambda_2\,\Delta t)(1-\lambda_3\,\Delta t)P_1(t)+\lambda_1\Delta t\,P_0(t)+\mu_2\Delta t\,P_4(t)+\mu_3\Delta t\,P_6(t)$$

$$\frac{P_1(t+\Delta t)-P_1(t)}{\Delta t}+(\mu_1+\lambda_2+\lambda_3)P_1(t)=\lambda_1\,P_0(t)+\mu_2\,P_4(t)+\mu_3\,P_6(t)$$

Now taking $\lim\limits_{\Delta t\to 0}$ we get

$$\lim_{\Delta t\to 0}\frac{P_1(t+\Delta t)-P_1(t)}{\Delta t}+(\mu_1+\lambda_2+\lambda_3)P_1(t)=\lambda_1\,P_0(t)+\mu_2\,P_4(t)+\mu_3\,P_6(t)$$

$$\left[\frac{d}{dt}+\mu_1+\lambda_2+\lambda_3\right]P_1(t)=\lambda_1\,P_0(t)+\mu_2\,P_4(t)+\mu_3\,P_6(t) \tag{2}$$

The probability of the structure to be in the state S_2 in the interval $(t,t+\Delta t)$ is given by

$$P_2(t+\Delta t)=(1-\mu_2\,\Delta t)(1-\lambda_1\,\Delta t)(1-\lambda_3\,\Delta t)P_2(t)+\lambda_2\Delta t\,P_0(t)+\mu_1\Delta t\,P_4(t)+\mu_3\Delta t\,P_5(t)$$

$$\frac{P_2(t+\Delta t)-P_2(t)}{\Delta t}+(\mu_2+\lambda_1+\lambda_3)P_2(t)=\lambda_2\,P_0(t)+\mu_1\,P_4(t)+\mu_3\,P_5(t)$$

Now taking $\lim\limits_{\Delta t\to 0}$ we get

$$\lim_{\Delta t\to 0}\frac{P_2(t+\Delta t)-P_2(t)}{\Delta t}+(\mu_2+\lambda_1+\lambda_3)P_2(t)=\lambda_2\,P_0(t)+\mu_1\,P_4(t)+\mu_3\,P_5(t)$$

$$\left[\frac{d}{dt}+\mu_2+\lambda_1+\lambda_3\right]P_2(t)=\lambda_2\,P_0(t)+\mu_1\,P_4(t)+\mu_3\,P_5(t) \tag{3}$$

The probability of the structure to be in the state S_3 in the interval $(t,t+\Delta t)$ is given by

$$P_3(t+\Delta t)=(1-\mu_3\,\Delta t)(1-\lambda_2\,\Delta t)(1-\lambda_1\,\Delta t)P_3(t)+\lambda_3\Delta t\,P_0(t)+\mu_2\Delta t\,P_5(t)+\mu_1\Delta t\,P_6(t)$$

$$\frac{P_3(t+\Delta t)-P_3(t)}{\Delta t}+(\mu_3+\lambda_2+\lambda_1)P_3(t)=\lambda_3\,P_0(t)+\mu_2\,P_5(t)+\mu_1\,P_6(t)$$

Now taking $\lim\limits_{\Delta t\to 0}$ we get

$$\lim_{\Delta t \to 0} \frac{P_3(t+\Delta t) - P_3(t)}{\Delta t} + (\mu_3 + \lambda_2 + \lambda_1) P_3(t) = \lambda_2\, P_0(t) + \mu_2\, P_5(t) + \mu_1\, P_6(t)$$

$$\left[\frac{d}{dt} + \mu_3 + \lambda_2 + \lambda_1\right] P_3(t) = \lambda_3\, P_0(t) + \mu_2\, P_5(t) + \mu_1\, P_6(t) \tag{4}$$

The probability of the structure to be in the state S_4 in the interval $(t, t+\Delta t)$ is given by
$P_4(t+\Delta t) = (1-\lambda_3\, \Delta t)(1-\mu_2\, \Delta t)(1-\mu_1\, \Delta t)P_4(t) + \mu_3 \Delta t\, P_7(t) + \lambda_2 \Delta t\, P_1(t) + \lambda_1 \Delta t\, P_2(t)$

$$\frac{P_4(t+\Delta t) - P_4(t)}{\Delta t} + (\lambda_3 + \mu_2 + \mu_1) P_4(t) = \mu_3\, P_7(t) + \lambda_2\, P_1(t) + \lambda_1\, P_2(t)$$

Now taking $\lim_{\Delta t \to 0}$ we get

$$\lim_{\Delta t \to 0} \frac{P_4(t+\Delta t) - P_4(t)}{\Delta t} + (\lambda_3 + \mu_2 + \mu_1) P_4(t) = \mu_3\, P_7(t) + \lambda_2\, P_1(t) + \lambda_1\, P_2(t)$$

$$\left[\frac{d}{dt} + \lambda_3 + \mu_2 + \mu_1\right] P_4(t) = \mu_3\, P_7(t) + \lambda_2\, P_1(t) + \lambda_1\, P_2(t) \tag{5}$$

The probability of the structure to be in the state S_5 in the interval $(t, t+\Delta t)$ is given by
$P_5(t+\Delta t) = (1-\lambda_1\, \Delta t)(1-\mu_3\, \Delta t)(1-\mu_2\, \Delta t)P_5(t) + \mu_1 \Delta t\, P_7(t) + \lambda_3 \Delta t\, P_2(t) + \lambda_2 \Delta t\, P_3(t)$

$$\frac{P_5(t+\Delta t) - P_5(t)}{\Delta t} + (\lambda_1 + \mu_3 + \mu_2) P_4(t) = \mu_1\, P_7(t) + \lambda_3\, P_2(t) + \lambda_2\, P_3(t)$$

Now taking $\lim_{\Delta t \to 0}$ we get

$$\lim_{\Delta t \to 0} \frac{P_5(t+\Delta t) - P_5(t)}{\Delta t} + (\lambda_1 + \mu_3 + \mu_2) P_5(t) = \mu_1\, P_7(t) + \lambda_3\, P_2(t) + \lambda_2\, P_3(t)$$

$$\left[\frac{d}{dt} + \lambda_1 + \mu_3 + \mu_2\right] P_5(t) = \mu_1\, P_7(t) + \lambda_3\, P_2(t) + \lambda_2\, P_3(t) \tag{6}$$

The probability of the structure to be in the state S_6 in the interval $(t, t+\Delta t)$ is given by
$P_6(t+\Delta t) = (1-\lambda_2\, \Delta t)(1-\mu_3\, \Delta t)(1-\mu_1\, \Delta t)P_6(t) + \mu_2 \Delta t\, P_7(t) + \lambda_3 \Delta t\, P_1(t) + \lambda_1 \Delta t\, P_3(t)$

$$\frac{P_6(t+\Delta t) - P_6(t)}{\Delta t} + (\lambda_2 + \mu_3 + \mu_1) P_6(t) = \mu_2\, P_7(t) + \lambda_3\, P_1(t) + \lambda_1\, P_3(t)$$

Now taking $\lim_{\Delta t \to 0}$ we get,

$$\lim_{\Delta t \to 0} \frac{P_6(t+\Delta t) - P_6(t)}{\Delta t} + (\lambda_2 + \mu_3 + \mu_1) P_6(t) = \mu_2\, P_7(t) + \lambda_3\, P_1(t) + \lambda_1\, P_3(t)$$

$$\left[\frac{d}{dt} + \lambda_2 + \mu_3 + \mu_1\right] P_6(t) = \mu_2\, P_7(t) + \lambda_3\, P_1(t) + \lambda_1\, P_3(t) \tag{7}$$

The probability of the structure to be in the state S_7 in the interval $(t, t+\Delta t)$ is given by

$$P_7(t+\Delta t) = (1-\mu_3\,\Delta t)(1-\mu_1\,\Delta t)(1-\mu_2\,\Delta t)P_7(t) + \lambda_3 \Delta t\,P_4(t) + \lambda_1 \Delta t\,P_5(t) + \lambda_2 \Delta t\,P_6(t)$$

$$\frac{P_7(t+\Delta t) - P_7(t)}{\Delta t} + (\mu_3+\mu_1+\mu_2)P_7(t) = \lambda_3\,P_4(t) + \lambda_1\,P_5(t) + \lambda_2\,P_6(t)$$

Now taking $\lim_{\Delta t \to 0}$ we get,

$$\lim_{\Delta t \to 0} \frac{P_7(t+\Delta t) - P_7(t)}{\Delta t} + (\mu_3+\mu_1+\mu_2)P_7(t) = \lambda_3\,P_4(t) + \lambda_1\,P_5(t) + \lambda_2\,P_6(t)$$

$$\left[\frac{d}{dt} + \mu_3 + \mu_1 + \mu_2\right] P_7(t) = \lambda_3\,P_4(t) + \lambda_1\,P_5(t) + \lambda_2\,P_6(t) \tag{8}$$

Initial condition

$$P_i(0) = \begin{cases} 1 & i = 0 \\ 0 & i \neq 0 \end{cases} \tag{9}$$

References

Amasuomo, E., & Baird, J. (2016). The concept of waste and waste management. *Journal of Management & Sustainability*, 6(4), 88-96. https://doi.org/10.5539/jms.v6n4p88.

Anitha, A. (2017). Garbage monitoring system using IoT. *In IOP Conference Series: Materials Science and Engineering*, *263*(4), 042027(1-12). https://doi.org/10.1088/1757-899X/263/4/042027.

Asyikin, A.N., & Syahidi, A.A. (2020). Design and implementation of different types of smart dustbins system in smart campus environments. *International Joint Conference on Science and Engineering*, 1-7. https://doi.org/10.2991/aer.k.201124.001. (In press).

Bhor, V., Morajkar, P., Gurav, M., Pandya, D., & Deshpande, A. (2015). Smart garbage management system. *International Journal of Engineering Research & Technology*, *4*(3), 1117-1120.

Cai, H., Hu, J., Li, Z., Lim, W.H., Mokayef, M., & Wong, C.H. (2022). An IoT garbage monitoring system for effective garbage management. In *International Conference on Computer Engineering, Network, and Intelligent Multimedia* (pp. 203-206). Surabaya, Indonesia. https://doi.org/10.1109/cenim56801.2022.10037387.

Chadha, A., Gupta, R., Rai, P.K., & Abrol, S. (2019). SUNBIN: A cleaner technology for better waste management. *International Journal of Science & Research*, *8*(6), 1620-1624.

Chakraborty, S., Mehta, A., Sheikh, S., & Jha, A.K. (2021). Smart waste management system. *Journal of Emerging Technologies & Innovative Research*, *8*(5), 250-254.

Chandra, R.P., & Tawami, T. (2020). Design of smart trash bin. In *IOP Conference Series: Materials Science and Engineering* (Vol. 879, No. 1, pp. 1-6). Bandung, Indonesia. https://doi.org/10.1088/1757-899x/879/1/012155.

Dhiman, P., & Kumar, A. (2020). Reliability and sensitivity assessment of a thermal power plant using Boolean function technique. *Journal of Physics: Conference Series. 1531*(1), 012075. https://doi.org/10.1088/1742-6596/1531/1/012075.

Forghani-Elahabad, M., Kagan, N., & Mahdavi-Amiri, N. (2019). An MP-based approximation algorithm on reliability evaluation of multistate flow networks. *Reliability Engineering & System Safety*, *191*, 106566. https://doi.org/10.1016/j.ress.2019.106566.

Geetha, S., Narayanamoorthy, S., Kang, D., & Kureethara, J.V. (2019). A novel assessment of healthcare waste disposal methods: Intuitionistic hesitant fuzzy MULTIMOORA decision making approach. *IEEE Access*, *7*, 130283-130299. https://doi.org/10.1109/access.2019.2940540.

Geethamani, R., Rakshana, P., Raveena, P., & Ragavi, R. (2021). Garbage management system. In *2021 7th International Conference on Advanced Computing and Communication Systems* (Vol. 1, pp. 1190-1192). IEEE. Coimbatore, India. https://doi.org/10.1109/ICACCS51430.2021.9441922.

Gundupalli, S.P., Hait, S., & Thakur, A. (2017). A review on automated sorting of source-separated municipal solid waste for recycling. *Waste Management*, *60*, 56-74. https://doi.org/10.1016/j.wasman.2016.09.015.

Kumar, A., & Dhiman, P. (2020). Reliability range through upgraded operation with trapezoidal fuzzy number. *Fuzzy Information and Engineering*, *12*(4), 452-463. https://doi.org/10.1080/16168658.2021.1918039.

Kumar, A., & Dhiman, P. (2021). Reliability estimation of a network structure using generalized trapezoidal fuzzy numbers. *Journal of KONBiN*, *51*(1), 225-241. https://doi.org/10.2478/jok-2021-0015.

Kumar, A., & Dhiman, P. (2023). Comparative analysis of two fuzzy modeling through investigation of condensate system. *International Journal of Fuzzy Systems*. https://doi.org/10.1007/s40815-023-01532-y. (In press).

Kumar, A., & Kumar, P. (2020) Application of Markov process mathematical modelling in analyzing communication system reliability. *International Journal of Quality & Reliability Management*, *37*(2), 354-371. https://doi.org/10.1108/ijqrm-05-2019-0160.

Kumar, A., & Kumar, P. (2022). Reliability assessment for multi-state automatic ticket vending machine (ATVM) through software and hardware failures. *Journal of Quality in Maintenance Engineering*, *28*(2), 448-473. https://doi.org/10.1108/JQME-08-2020-0089.

Kumar, P., & Kumar, A. (2021). Tripod turnstile machines performance analysis for the system safety and security without considering simultaneous failures using reliability approach. *International Journal of Mathematical, Engineering and Management Sciences*, *6*(1), 383-395. https://doi.org/10.33889/ijmems.2021.6.1.024.

LaGrega, M.D., Buckingham, P.L., & Evans, J.C. (2010). *Hazardous waste management*. Waveland Press. Long Grove, Illinois.

Pariatamby, A., Tanaka, M., Islam, A., Rasul, G., Manandhar, P., Parveen, J.A., & Ahmed, N. (2014). *Municipal solid waste management in Asia and the Pacific Islands*. Springer, Singapore.

Parikh, P.A., Vasani, R., & Raval, A. (2017). Smart dustbin—an intelligent approach to fulfill Swatchh Bharat Mission. *International Journal of Engineering Research in Electronic Communication Engineering*, *4*(10), 6-9.

Ranjana, P., Varsha, S., & Eliyas, S. (2021). IoT based smart garbage collection using RFID and sensors. *In Journal of Physics: Conference Series, 1818*(1), 012225. https://doi.org/10.1088/1742-6596/1818/1/012225.

Rhyner, C.R., Schwartz, L.J., Wenger, R.B., & Kohrell, M.G. (1995). *Waste management and resource recovery*. CRC Press. https://doi.org/10.1201/9780203734278.

Sasikumar, K., & Krishna, S.G. (2009). *Solid waste management*. PHI Learning Pvt. Ltd.

Thole, P.A., Kalbhor, K.D., Gole, A.D., & Dhage, N.J. (2019). Smart waste management system for industry. *International Journal of Scientific Research and Engineering Development, 2*(5), 1-9.

Tripathi, A., Pandey, C., Narwal, A., & Negi, D. (2018). Cloud based smart dustbin system for metro station. In *2018 3rd International Conference on Internet of Things: Smart Innovation and Usages (IoT-SIU)* (pp. 1-4). IEEE. Bhimtal, India. https://doi.org/10.1109/iot-siu.2018.8519845.

Vamsi, T.M.N., Chakravarthi, G.K., Lanka, P., & Divakar, B. (2021). An IoT based smart garbage monitoring and disposal support system. In *2021 5th International Conference on Computing Methodologies and Communication* (pp. 438-442). IEEE. Erode, India. https://doi.org/10.1109/iccmc51019.2021.9418289.

Yeh, W.C., Tan, S.Y., Forghani-Elahabad, M., El Khadiri, M., Jiang, Y., & Lin, C.S. (2022). New binary-addition tree algorithm for the all-multiterminal binary-state network reliability problem. *Reliability Engineering & System Safety*, *224*, 108557. https://doi.org/10.1016/j.ress.2022.108557.