Efficient Waste Management Models for Smart Cities: A Case Study

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Abstract. Waste management is a matter of the greatest concern in the modern world. We do not have an efficient waste management system in India. Developing a comprehensive network of waste management is the biggest challenge that we are facing today. Research on smart cities brings together the advances in the field of science and technology to ensure sustainable development of cities ensuring a healthy, wealthy, and peaceful life for all. In this paper, we discuss a mathematical modelling method that can effectively be implemented to build a network of waste management in which human being, organizations, institutions, and government agencies play their role. We discuss the waste management system of Thiruvananthapuram, the capital city of Kerala, as an example. We show that the waste management system of the city is not and sufficient and efficient. We also give suggestions to improve the system.

1. Introduction

The smart city is a modern concept, which is a contribution of the technologically advanced world. New research in smart cities aims at improving personal and social life using advanced digital technologies and artificial intelligence. Using machine learning techniques we capture data, process, inspect, and analyze the collected data, which are related to human life, and then applied to manage the system efficiently [1].

The objects and materials that we possess in our life have some value for us. When its value becomes null the object becomes waste in the judgment of an individual. But for a different person, the same thing may be valuable. So the meaning of the word “waste” is highly subjective. We do not go much deep into this philosophic aspects of the meaning of the word because it requires a detailed discussion and hence it is set aside for another occasion. Many objects are commonly called waste by all. In this study, we mainly focus on such things.

If an object has some reuse value in the evaluation of some people, that object could be given to them. This is called waste reuse. Many objects labeled waste can be recycled to produce similar kinds of objects or different kinds of new objects. Some waste materials are very rich sources of energy. If an object cannot be used in any one of the forms mentioned so far, it should be disposed of permanently. The general approach to the concept of waste management has three components. Waste Reuse Management (WReuM), Waste Recycle Management (WRecM), and Waste Disposal Management (WDM). An efficient waste management system must effectively handle all the three components. The first component consists of the marketing or free transfer of second-hand materials from the owner to the needy person. The percentage of the third component in the waste management system must be reduced to zero. Unfortunately in India, the percentage of the third component is much
higher than the first two. The percentage of the second component is extremely low. In the following section we discuss the problems that prevail in the waste management system in India.

2. Waste Management in India

Mathematical modelling is an important method that can effectively be used to represent real-life problems. It can help us to find some solution to the problem. In this section, we briefly review the mathematical modelling techniques used by researchers for modelling waste management problems. The majority of the municipal waste management models identified in the literature are decision support models. Morrissey et al. [2] divided the models into three categories. First type is based on cost-benefit analysis. The second type is based on life cycle assessment and the last is based on multi-criteria decision making. In his view, the current models have many shortcomings. Some models emphasize the refinement of evaluation steps, instead of addressing the decision-making process itself. A waste management model must consider environmental, economic, and social aspects together to be sustainable. Many of these models do not consider all the three important factors together in their model.

Mathematical modelling of waste management systems is not a new concept. The period 1970 – 90 mathematical modelling techniques were applied in the waste management problems. An outline of these models is given by Morrissey et al. [2]. The approach to the problem of waste management in India is extremely different from that of other countries in the world. We do not have a centralized and collaborative system for waste management. Ours waste management system is highly localized and not networked. We are backward in applying modern technology and scientific advancements to improve the efficiency of the system of waste management. Planning and implementation of waste management techniques completely rest on the local authorities. State Government and Central Government are devoid of their responsibilities in building a network of waste management system. We have underestimated the scope and opportunities of a well networked WMS. An efficient WMS can make the country self sufficient in many ways. Generation of energy, recycling and reuse of used materials, creation of new job opportunities, control over the scarcity of materials for the development etc are the main issues that can be addressed by an efficient waste management system. The most pathetic condition of Indian waste management systems is discussed by Sunil Kumar et al. [3] and Reji Kumar et al. [5] as well as the opportunities associated with it. In this paper, the authors initiate a study of WMS based on network analysis. Our waste management system is a complete failure due to inadequate waste collection, transport, treatment, and disposal. Waste generation in India is growing fast due to fast growth in population, rapid urbanization, and indifferent behaviour of citizens. The diverse culture of India is making the situation extremely dangerous and impossible to get corrected naturally.

The quantity of waste generated varies from place to place. It is very high in megacities and very low in rural areas. It is almost proportionate to the total population that inhabits in an area. The Ministry of Environment and Forest (MoEF) has issued MSW (Management and Handling) Rule 2000 which intends to ensure proper waste management in India [4]. According to this Rule municipal authorities are responsible for implementing the law and developing infrastructure for solid waste management. This is the main drawback of this Rule. Waste management is not a simple task that can be effectively planned and implemented by local bodies. It needs national-level planning the strategy and centralized control over its implementation. All activities must be monitored and reviewed for their effectiveness at different levels. At the grass-root level, every citizen of the country must take part effectively in the process. Duties and responsibilities of an ordinary individual must be defined in clear terms and the same must be done at all levels in the system.

The waste management in India is mainly the informal sector. The informal sector consists of small-scale, labor-intensive, largely unregulated and unregistered agents who use outdated methods for collection and processing of waste. The informal sector is run by the contribution of waste pickers, who collect household, commercial, and industrial waste. Hundreds of thousands of waste pickers and
waste collecting agents in India depend on waste for an income. These waste pickers and collection agents do not have any training in waste management. The existing network of waste management systems in India consists of waste pickers, waste collectors, and waste recycling centres. This is a natural network in which the nodes are the waste pickers, waste collectors, and collection centres. Waste pickers collect only those waste materials which have some monetary value. They leave the other kind of waste in the environment. The waste materials that have no monetary value are usually sent to landfills. Landfills are not an acceptable solution to the problem. Complete recycling of all materials in the form of waste is the ultimate aim of a sustainable waste management system.

This situation leads to an inefficient and incomplete waste management system. Thus we need a new efficient network of waste management, in which each individual discharges his predetermined duties to the maximum possible extent for the effective management of waste materials. In the following section, we describe how to change the current system by applying the techniques of social network analysis.

Social network is a network of individuals together with the relations existing among them. World Wide Web, Internet, friendship network, collaboration network etc are examples of social networks. Social network analysis is the scientific study of the role and importance of the members of the network along with the characteristics of the relation among the members using the methods of graph theory. Importance of some actors in spreading information in complex networks is studied in [7, 8].

Centrality measure of a network is a well studied parameter which helps us to understand the importance of nodes in the network. According to the relative importance of actors in a network the members are ranked. Degree centrality, Closeness centrality, Betweenness centrality, K-core decomposition, Mixed degree decomposition method etc are some important centrality measures that can be used to find rank of the members according to their importance in the network. Improved k-shell decomposition method is a modified version of the k-shell decomposition method proposed by Kumar et al. [13]. A new measure of centrality named the m-ranking method was proposed by Kumar et al. [6]. This method is modified to handle the situation of directed network [10] and the influence in the network due to personal variations [9]. A method to find the m-ranking approximately is discussed in [14]. The methods are applied to find the ranking of nodes in two real world networks [11, 12].

3. Mathematical Modelling of Waste Management Systems

The system of waste management in a country can be modeled using graph theoretic networks and its efficiency and effectiveness can be studied using the techniques in social network analysis. Mathematical modeling techniques are not effectively being used in the field of waste management. Researchers in the field have turned their attention to apply mathematical modeling techniques to solve the problems of waste management only in the recent past [5]. So application of social network in the field is completely new and offers a wide spectrum of openings.

A network representing the WMS can consist of all the members of the society at the root level. These members can be connected to various collection centers located in the neighborhood. The local collection centers play an important role in the management of waste. The centers must be strengthened by providing sufficient workers and technological knowhow to separate and collect the waste materials according to the future use the procedure through which it passes. Separation and collection must start at the point of the generation of the waste. So a very pleasant relation between the members of the society and the first level collection centers are essential for the proper functioning of the entire system of waste management. We propose a two way relation between the first level collection centers and the members of the society. First level centers must be connected to the second level collections centers or waste processing and recycling centers. The responsibility of building and maintaining of the second level centers rests mainly on the state and central government. Currently in India the task of establishing the second level centers is done by local self government. This is one of the main reasons of inefficient system of waste management in India. The entire system and all levels
of waste management must be monitored and policy for decision making and evaluation for continuous improvement of the system must be done by department of the state and central government.

From the above discussion it is clear that the state and central government must act as center of all activities that control the entire system. In other words they are the hubs in the network. So the centrality measure of the nodes representing the state government and the central government in the network must be high when compared to the values of the nodes representing the first or second level. Majority of networks studied in social network analysis are natural and dynamic. It originates by itself and undergoes changes over time. But in the current situation, we propose to build an artificial (man-made) network named waste management network. This network is very comprehensive and must contain all individuals in a geographical area under study. Next we proceed to discuss more about a network that can be developed artificially. As we have mentioned earlier waste collection centers are the second level nodes in the network. Waste recycling centers and engineered landfills are nodes at the third level and the state and central government have representation in the network at the apex level. The proposed network is a multi layered system. At the bottom level we include the Households, offices and small business centers. The collection and processing centers belong to the middle level and the final processing centers and recycling points become the top level in the hierarchy.

Next, we discuss a network model, which represents the waste management system in the capital city of Kerala, Thiruvananthapuram. In 2011 there was only one waste dumping area (called Vilappinsala) in the city limit. It was forced to shut down due to the protest from the public over the mismanagement of waste at the site. As a solution to the problem of waste, the Thiruvananthapuram Municipal Corporation (TMC) adopted a decentralized system for the management of waste.

Total area of Thiruvananthapuram city, which is divided into 100 wards has land area 214.86 square kilometers. The population of the city is approximately 0.9 million. According to government statistics the city produced 250 tones of municipal solid waste. Following the protest in 2011 the TMC adopted a policy called segregated collection of waste. Segregation of waste at the origin and resource recovery at the root level is the main feature of the policy. Additionally participation of the individuals and institutions is ensured uniformly all over the city. It is based on the principle of proximity, which ensures that the waste collection agents or collection centers are in the easy reach of every individual of the society. The responsibility of waste management of bulk generators and commercial establishments rests basically on them. But the facilities of processing will be provided by the local self government. The TMC has established a system of collecting the segregated waste from the houses by imposing a monthly charge of Rs 800. Residential flats and gated communities are encouraged to set up organic waste management facility offering 50 per cent subsidy. TMC also established collection centers at about 25 places in the city, where people can drop the separated and waste materials [15, 16].

According to the records of TMC about 50% percent of the total households in the city and 350 bulk generators compost their wet waste. Approximately 100 bulk generators and 4000 households have setup biogas plants for the treatment of waste. Pipes, kitchen-bin, pot or bio composting, aerobic bins etc are various technologies used for composting. Using these methods approximately 67% of the waste has been diverted from the landfills [15]. In Table I, we sum up various infrastructure facilities that are effectively being used in the waste management and the percentage of waste that each facility can handle [15]. The quantity of waste is given in tone in the third column and the percentage utilized in the fourth column.

In the Figure 1, a graph theoretic representation of the waste management system in TMC is given. There are thousands of households, business enterprises, hotels, etc which generate solid waste. They are together represented by the red ellipse in the figure. It is a huge network of thousands of nodes which are connected to 15 yellow coloured nodes that represent the collection points of waste materials. Unfortunately, there are no major recycling centres or disposal centres in the city. So, level 3 is empty in the first figure.
Table 1. Infrastructure and percentage of waste it can handle at Thiruvananthapuram

| Infrastructure                        | Units | Capacity: tons per day | Utilization: % tons per day |
|---------------------------------------|-------|------------------------|----------------------------|
| Kitchen Bins                          | 19000 | 19.00                  | 80%                        |
| Bio Bins                              | 109   | 2.72                   | 60%                        |
| Biogas Plants                         | 3982  | 3.98                   | 60%                        |
| Pipe compost Units                    | 87000 | 87.00                  | 87%                        |
| Organic Waste Converters              | 2     | 0.5                    | 100%                       |
| Aerobic bins                          | 383   | 11.49                  | 100%                       |
| Mobile composting units               | 154   | 4.62                   | 100%                       |
| Community biogas plants               | 23    | 23.00                  | 80%                        |
| Dry waste collection bins             | 2     | 0.2                    | 100%                       |
| Dry leave collection bins             | 3     | 0.3                    | 100%                       |
| Material recovery facilities          | 44    | 44.00                  | 100%                       |
| Resource recovery facilities          | 2     | 10.00                  | 100%                       |
| Facilities in the private sector      | 19    | 150.00                 | 60%                        |
| **Total**                             | **356.8** |                       | **67.89%**                 |

This shows very clear laxity from the side of the corporation in setting up modern waste processing and recycling centres. The corporation must have started waste processing centres to manage effectively the waste materials collected at the collection points. Instead, the segregated materials are either buried or sent to other states for further processing. It is a clear evidence of the lack of interest from the side of the municipality.

Fig. 1. Current SWM of Thiruvananthapuram

The Figure 2 is a modified representation of the network by including some waste processing centres. Waste to energy generation centre, material recycling centre and permanent disposal centre are the three centres proposed. In the new imaginary network, the three new processing centres are given green colour. The first collection centre is connected to all three processing centres. Similarly, all the remaining collection centres are connected to the processing centres. It is represented by the blue-coloured dots in the figure. It is clear that the current system which exists in Thiruvananthapuram city is not efficient.
We can call a waste management system sufficient if it can handle the entire quantity of all type of waste materials without making problems to the society and environment during a particular time period. So a system which can process only a portion of waste is not sufficient. A system is consistent if it can manage the waste generated constantly for a long time. A WMS, which is efficient, must be sufficient also. But a sufficient system may not be efficient always. Consistency checks whether a system shows steady performance for a long time. This measure evaluates the performance of the system based on time. From the data presented in the Table 1, it is clear that the WMS of TMC is not sufficient to meet the requirement because only 67.89% of the waste generated is processed currently. In addition to this no data is available regarding the income generated from waste processing and recycling, job opportunities created by the current system etc. So the system is highly inefficient.

In order to improve the waste management system in India, we need to develop an efficient waste management network artificially. Waste collection and post collection procedures must be modified using modern technology. Every individual taking part in the waste management procedure must be properly trained and must be equipped to meet the challenges of waste management in the future. The best and most appropriate methods for waste collection and disposal must be implemented. A professional approach to the problem is a pressing need. There is also a lack of accountability in current SWM systems throughout India. The responsibility to implement the WMS in the country must be shifted from local authorities. It must be reassigned to the State government and the Central government. The central government must take a pivotal position in the whole process.

4. Conclusion

This paper is a step forward to improve the waste management system in India. It can be attained by redefining the role of all members in the society in the big task of waste management. Three important measures of a WMS is defined and discussed. The situation is analyzed for the waste management system of Thiruvananthapuram Municipal City. The network representing the current WMS of the city is given along with the suggestions to improve the performance of the system.

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