

# A CONCEPTUAL MODEL OF AN IOT-BASED SMART AND SUSTAINABLE SOLID WASTE MANAGEMENT SYSTEM: A CASE STUDY OF A NORWEGIAN MUNICIPALITY

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## KEYWORDS

Conceptual Model, Internet Of Things, Smart And Sustainable, Infrared Sensors, Ultrasonic Sensors, RFID Sensors, Iots Based Smart Bins, Smart Bin App, Data Transfer Technologies, LoRaWAN

## ABSTRACT

The core processes of waste management have been changed during the last few decades. Through advanced technologies, sensors, cameras, actuators, IoT controls, data driven and data transfer technologies, the old and insufficient processes for waste management can be replaced. In this paper, we propose a conceptual model for an IoT-based smart and sustainable waste management system for a Norwegian municipality. The model illustrates all the aspects needed to develop a smart IoT-based waste management system. A Norwegian municipality constituted our case study. Our conceptual model proposed here, provides a design solution with data analysis in such a way that it can easily be adopted by the current infrastructure and practices of the municipality. Finally, features of a prototype system are suggested.

## I. INTRODUCTION

With the advent of recent advancements of smart devices, the abstraction of connecting everyday objects via the existing networks has become highly favorable. The Internet of things (IoTs) is an arrangement of web related items that can accumulate and exchange data. A result of the evolution of conventional networks that link billions of connected devices together defines a world where almost anything can connect and interact in a smarter fashion than before (Silva, et al. 2018). Technological advancements in ubiquitous computing (UC), wireless sensor networks (WSN), and machine-to-machine (M2M) communication have further strengthened the notion of IoT (Vaisali, et al. 2017). Moreover, linked devices share their information and access authorized information of other devices to support contextual decision making. As a result of these developments, new business areas and opportunities have originated, summarized into various smart city and smart factory concepts. Due to the dramatic urbanization all over the world, the continuous developments into smart cities

have become the main concern in the past few decades. Information and communication technology (ICT) have made cities efficient in several aspects. However, incorporating only ICT does not fully interpret the smart city concept. In general terms, a smart city is an urban environment that utilizes ICT and other related technologies to improve performance efficiency of regular city operations and quality of service provided to urban citizens (Kamm, et al., 2020). IoTs link various areas/operations of a smart city into holistic entities. In Figure 1, the concept of an IoT enabled smart and sustainable city is illustrated. In a smart and sustainable city, all the aspects of a society are connected through shared IoT clouds. This enables the use of the new opportunities offered by IoT platform, thereby empowering us to set a sustainable footprint to the world. Smart waste management is one fundamental concern in smart and sustainable city development (ITU 2019). According to Periathamby et al. (2014) the global population will increase into 9 billion in 2050. In addition to that, the increased level of urbanization will lead to a massive pressure on the current infrastructures and practices of municipalities. This led us towards investigating good practice of solid waste handling. Current practices for a waste management system includes waste collection, waste sorting, waste recycling and its transportation as in Figure 4. They can often be improved by reengineering. A vital concept in this circumstance is Key performance indicators (KPIs) for solid waste, categorized by the EU report agenda (ITU 2019). This is a conceptual framework that achieved the KPIs described in Figure 2.

Our paper is structured as follows: The related literature for smart and sustainable solid waste management systems based on IoTs technologies are discussed in section II. The conceptual models are described in detail in section III. Current practices and relative techniques to develop a smart and sustainable solid waste management system are proposed. In the discussion section, we also provide future recommendations.

## II. LITERATURE REVIEW

A solid waste material hierarchy, Figure 3, can be described as follows: The material should be prevented as much as possible and if it can't then it goes for reuse.

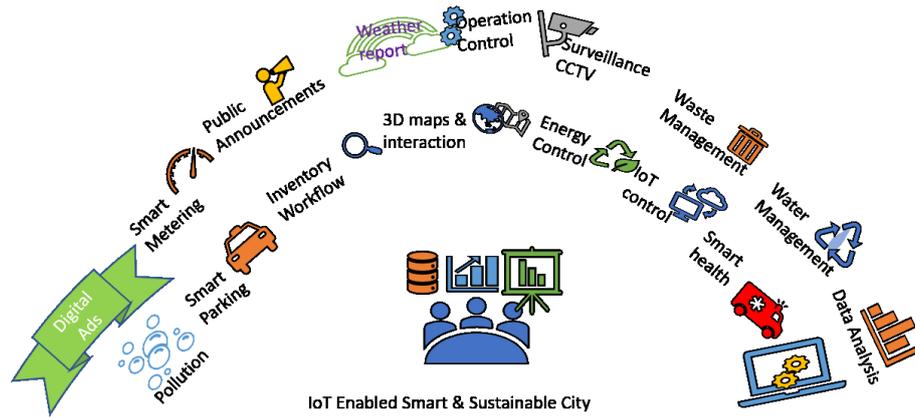


Figure 1: A Conceptual Model of an IoT Enabled Smart And Sustainable City

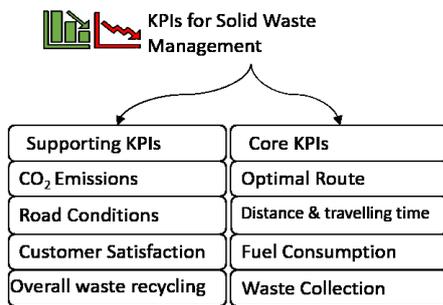


Figure 2: Smart And Sustainable Solid Waste Management KPIs

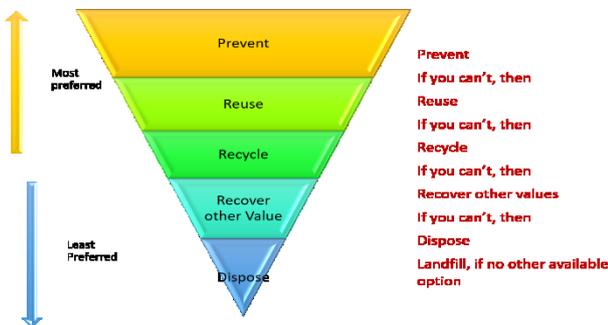


Figure 3: Solid Waste Material Hierarchy

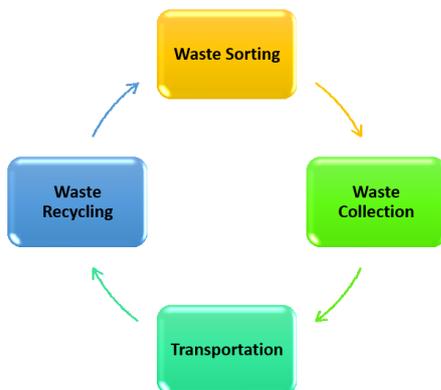


Figure 4: Smart And Sustainable Solid Waste Management System

If reuse isn't possible, then it goes for recycling. When recycling is not an option, a possibility might be to recover other values. If that isn't possible disposing is the last option.

The disposal and reuse procedure associated with each waste material is different. Additionally, there are several solid waste management projects executed worldwide in rural and urban areas. The solutions proposed in these projects are based on different techniques and data transfer technologies (Kamm, et al. 2020).

One important issue in waste management is transportation. The transportation of waste includes collection from waste bins and the transportation to various disposal sites as illustrated in Figure 4. For waste collection and transportation several methods have been proposed in literature. For example, in an article by Mingaleva et al. (2019) waste management in green and smart cities are discussed. Further on, current practices and further actions towards sustainable cities are described. In Patel et al. (2019) dry and wet dustbins are segregated, and different sensors and Wifi module for waste collection are used for their proposed model. Dugdhe et al. (2016) propose a method for waste collection scheduling for truck drivers, using mathematics to calculate the shortest route between filled-up bins and bins producing harmful gases.

With all the proposed IoT techniques described in literature, we are now able to solve many obstacles associated with waste management systems. Still there are many issues that need to be solved pertaining to reliability, scaling, bandwidth, security and power consumption.

### III. CONCEPTUAL MODEL

A conceptual model can be defined as a simplified representation of a system used to describe its main physical features and principal processes (Helmig 1997; Tatomir et al. 2018). In what follows, we propose a conceptual model of an IoT-based smart and sustainable solid waste management system. The model provides a

Norwegian municipality with a blueprint of a potential system design that can easily be adopted into the municipality's current infrastructure and practices. We assume that the model might also be relevant for others as an initial template for building smarter waste management systems.

### ***Current practices***

The current practices and infrastructure of the Norwegian municipality's solid waste management system relates to different types of bins (for example, standard volume waste bins, underground waste bins and sensor based underground waste bins) for all types of waste (household waste, paper, plastic, glass, metal and food waste), mounted and scattered around the municipality. In Nasar et al. (2020) current practices for the Norwegian municipality under study are described.

Both 2G and 3G communication techniques are used for data transfer and data analysis (Nasar et al. 2020). Experience indicates that battery life of sensors devices is a major problem that should be resolved. Additionally, the product portfolio of service providers in the municipality differ from each other. Pertaining to the ultrasonic sensors used to sense the fill-up volume of waste in the bins, most of them communicate through GSM technology.

As regards data transmission via GSM, this also faces some challenges in relation to high power consumption and dependency of the network provider. In our proposed conceptual model, all these facts such as data transfer technologies, sensors, planning to future development etc are considered to enable the construction of a smart and sustainable solid waste management system based on IoT technologies.

### ***Towards an IoT-based smart and sustainable solid waste management system***

Our conceptual model is presented in Figure 5. Several stakeholders or actors, for example management companies, truck drivers and citizens, are in this improved system, connected to a database so that they can make choices and corresponding actions as regards the functioning of the waste management system. Additionally, truck drivers are equipped with a display screen with GPS and GIS information for waste collection from the bins scattered in the city.

As regards the citizens, they are connected to and can interact with the smart waste bin application via their mobile phones. The waste management companies get

direct access to the database in the same manner. That the stakeholders communicate through the same platform makes communication smarter by being easier and more efficient.

A challenge in current practice is that the waste truck drivers follow a traditional way for waste collection whereby optimization has not been an issue. After deploying the proposed conceptual model focusing on IoT use, this problem can be solved by making active use of the possibilities provided by sensors combined with the use of KPIs and optimization algorithms to achieve reduced cost, distance and time. An evident outcome of an implementation of the conceptual model will be reduced CO<sub>2</sub> emission in the atmosphere as shown in Figure 2.

### ***Sensor-based bins***

In Figure 6, our proposal for how an IoT-based smart waste bin system can be designed, is illustrated.

In current practices, sensors-based bins are subject to many problems, due to different service providers using different platforms for data transfer and data handling etc. Another experienced problem is low battery life. The proposed IoT-based smart waste bin solution attach ultrasonic sensors, RFID sensors, Infrared sensors, and solar batteries with the cloud for data capturing and data transmission process. In the IoT-cloud, machine learning techniques are used to predict the fill-up volume of the waste bin. Optimization algorithms are used to find the truck drivers' optimal routes by taking total waste cost management into consideration.

The waste management cost for  $N$  number of bins can be described as:

$$W_{total} = \sum_{i=1}^N W_i^c + \sum_{i=1}^N W_i^t + \sum_{i=1}^N W_i^p + \sum_{i=1}^N W_i^d \quad (1)$$

where  $W_i^c$  is the collection cost,  $W_i^t$  is the transportation cost,  $W_i^p$  is the processing cost,  $W_i^d$  is the disposal cost for  $k$  number of unused or produced waste material after processing and  $W_i$  is the constant cost that depends on other parameters such as accident, maintenance of collection center, transfer station and trucks.

The profit gain by the  $N$  number of sources is:

$$W_{management\_cost}(profit) = \sum_{i=1}^p R_i - W_i \quad (2)$$

Where  $R_i$  is achieved by the recyclable materials, sales of compost products and electricity sales.

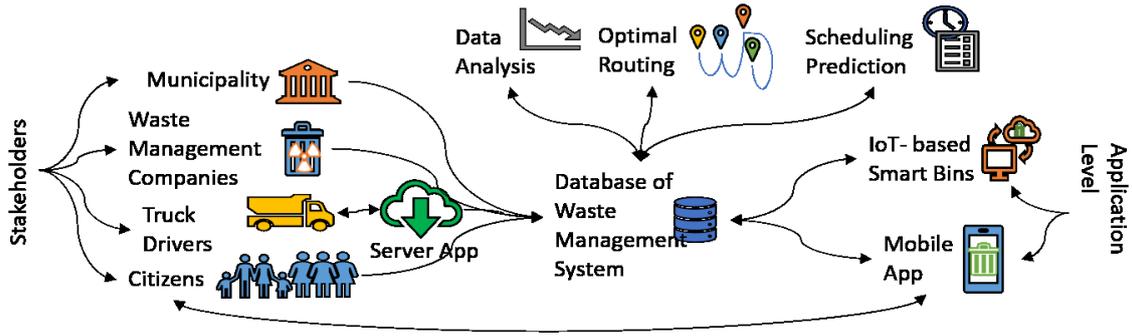


Figure 5: A Conceptual Model of a Smart and Sustainable Solid Waste Management System

In general, the objective of a waste management system is to develop mechanisms that will increase the overall profit  $W_{management\_cost}(profit)$  associated with the system by reducing the  $\sum_{i=1}^N W_i^c$ ,  $\sum_{i=1}^N W_i^t$  and increase  $W_{management\_cost}(profit)$ .

A transportation problem for a waste management system in such cases is referred as a combinatorial optimization problem. The main objective for such problems is to reduce cost, distance, travelling time and fuel consumption. Besides that, to build a prediction model for smart waste collection, we must consider both road and weather conditions as these will impact on fuel consumption.

In our proposed conceptual model, ultrasonic sensors are embedded to sense the present waste volume in the waste bins. Infrared sensors are implemented to sense the type of waste material. These will be helpful to achieve correct waste sorting and correspondingly to increase the waste management company's revenue. Implementation of RFID sensors will be used to identify where bins are placed. As the performance and lifetime of sensors depends on batteries, we suggest the use of solar batteries. Whilst using solar batteries have the potential of solving the experienced problems associated with present battery life. Developments within these types of batteries provide enough energy for all system actions in a very sustainable manner. Further on, it is very important to produce low power consuming hardware and to schedule the sleep mode for the proposed waste management system. The sleep mode, as in several electronics' devices, are embedded to enable energy savings when a sensor-based bin is not measuring, processing or sending data.

In order to provide independent telecommunication for enabling smart and sustainable city initiatives, an IoT network will be installed. The term IoT-WAN (also known as Low Power Wide Area Network-LPWAN) contains a variety of technologies such as LoRa, Sigfox or NB-IoT (Kamm, et al. 2020).

### Features of a Smart Waste Bin Application

#### User End

In the proposed conceptual model, the application level is divided into two parts. One part constitutes IoT-based

smart waste bins, and the other one contains a smart waste bin mobile application. In current practice, the waste management company offers a mobile app for customers with limited possibilities. Features of an improved application, Figure 8, can be:

- *Waste volume status* – The app will notify about the volume of waste in the customer's bin which will help the customer to decide whether to go out for throwing the trash or not.
- *Scheduled route* – The app will notify about the scheduled trips of waste trucks, so the citizens can put their waste bins outside.
- *Parking area status* – In current infrastructure, a vast area is dedicated specifically for waste trucks to collect waste. Instead of this practice, in the prototype app customers are notified about the waste trucks' schedule, thereby orienting the customer of when certain areas can be used for regular parking.
- *Customer credit* – In the present infrastructure there are different waste bins provided to the customers for different types of waste. These different types of waste are to be treated differently. For example, food waste needs to be emptied more frequently than other waste types. Similarly, the household waste is not considered as being recycling material and therefore are usually to be sent to disposal sites. Paper, plastic and other waste types are commonly sent for recycling in various recycling plants. To motivate customers to act properly pertaining to sorting waste, our prototype embeds the idea of giving away customer credits in the form of bonus points or some appreciating messages.

#### Smart App Server

Based on the data transfer technologies, a smart waste management application can be built (Kamm, et al. 2020). Various Python libraries can be used to build the platform shown in Figure 9. The implementation can be divided into three parts:

1. A smart bin App based on sensors which will detect waste material and sense the fill up volume of bins. Through the obtained data, the data analysis can be done as shown in Figure 7.

In this Figure, the fill-up volume before and after emptying the waste bins is shown. Sensor data from two types of waste, i.e., paper and household waste, are subject for data analysis.

- The second part is data connectivity between the sensor based smart app, a decoder and an application manager handler through an IoT-WAN infrastructure which is suggested to build the app.
- The last part is a smart waste application server.

#### IV. DISCUSSIONS & FUTURE RECOMMENDATIONS

In this paper a conceptual model is proposed as a blueprint for a smart and sustainable waste management system based on IoT technologies. We investigated a Norwegian municipality as a case study and based on our knowledge of current practice and the needs and wishes of the municipality we propose a design solution.

In the future it is our hope that this conceptual model can be implemented by the municipality using IoT technologies, sensors, cameras, actuators and Python for software development.

By implementing some of our suggestions we hope the municipality will end up with an IoT-based waste management system providing optimal routes and schedules for truck drivers via prediction models. For this different machine learning and artificial intelligence techniques can be used. To solve optimization problems, we can use techniques such as multiple travelling salesman problem (MTSP), constraint vehicle routing problem (CVRP) and multi objective optimization (MOO). These are all issues and possibilities to be investigated in future work.

In Nasar et al. (2020), the waste collection and transportation problem is addressed. The multi-objective traveling salesman problem (MOP-TSP) is used to find the optimal shortest possible route with multiple constraints such as minimum traveling time and distance as shown in Figure 10. The obtained results are compared with current practices and it is concluded that the proposed method is 34% cost and time saving. The solid waste KPIs i.e. stated in Figure 2 have been achieved with this proposed solution.

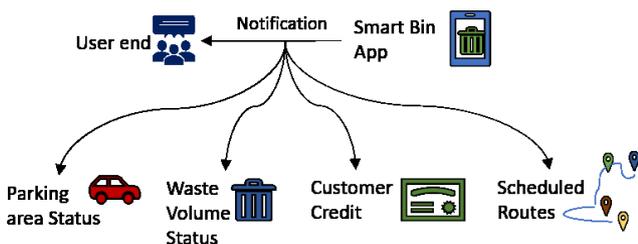


Figure 6: Smart Waste Bin Application at User end

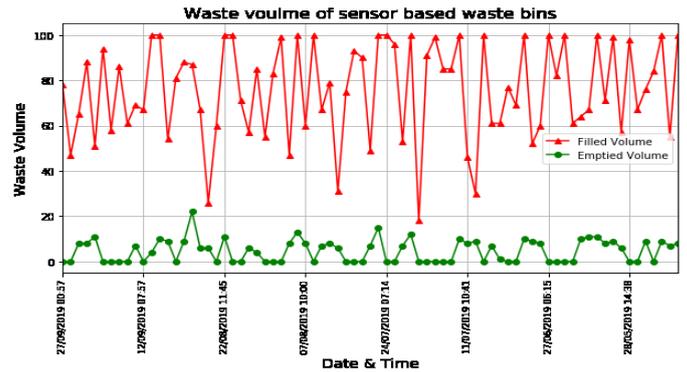


Figure 7: Sensor Measurement Of Waste Volume In Waste Bins

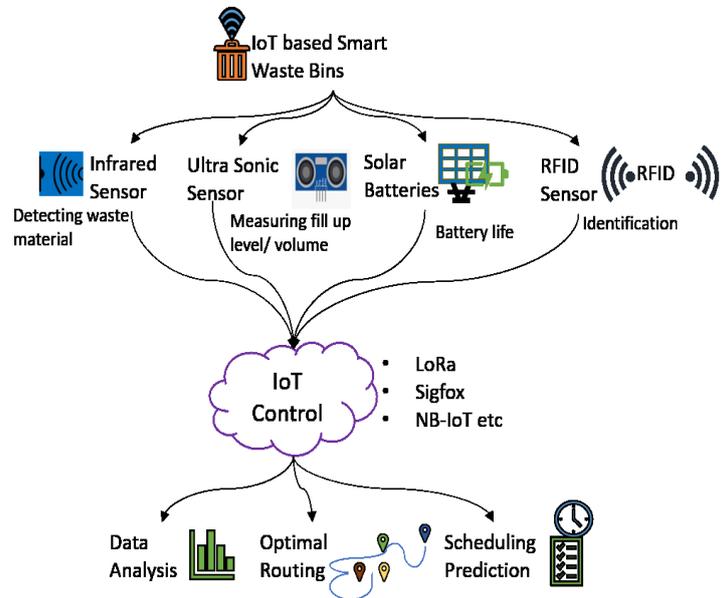


Figure 8: IoT-Based Smart Waste Bins

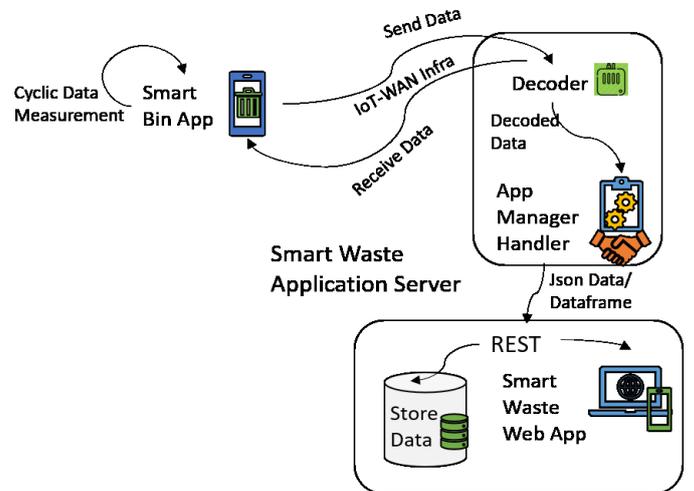


Figure 9: Smart Waste Bin Application Server

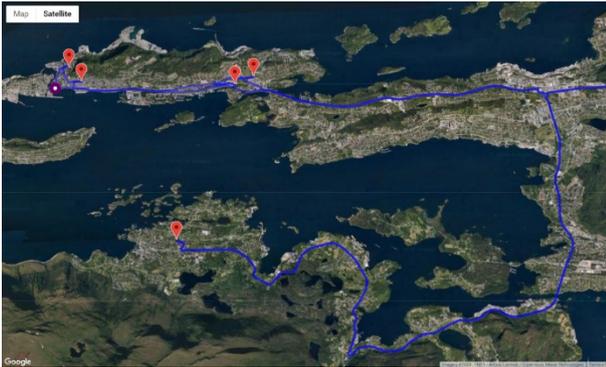


Figure 10: MOP-TSP optimal route finding with minimum distance and minimum time (Nasar et al. 2020)

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