An Optimized IoT-Based Waste Collection And Transportation Solution: A Case Study Of A Norwegian Municipality

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Abstract. Smart and sustainable solid waste management systems (SWMS) are of major interest in the development of smart sustainable cities (SSC). Selective waste collection and transportation are known to be major expenditures of city waste management systems. In this paper, we investigate a waste management system for domestic waste in a Norwegian municipality as a case study. Different scenarios for route planning are considered to improve cost and time usage. The study provides an auxiliary management system for multi-objective TSP using Google Maps and operation research (OR) tools for optimal domestic waste collection. Additionally, a prediction model for scheduling future waste collection trips is provided, whereby challenges such as road conditions, road traffic, CO_2 and other gases emissions, and fuel consumption are considered. The proposed prediction model considers the hazards associated with food waste bins that need to be emptied more frequently than bins containing other waste types such as plastic and paper. Both proposed models signify consistency and correctness.

Keywords: Cost and Time Effective · Domestic Waste · IoT Technologies · Multi-objective Optimization · Route Length · Smart and Sustainable Solutions · Smart Waste Bins · Solid Waste Management · Smart Sustainable City · Traveling Salesman Problem

1 Introduction

The smart city paradigm encompasses important factors that can affect the society in terms of smart economy, smart traffic, smart health, smart energy, a smart municipality and so on. These factors are interlinked with ICT technologies and the use of Internet of things' (IoTs) applications for the development of a smart city. A smart sustainable city (SSC) can be defined as [11]:

> *"An innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets*

the needs of present and future generations with respect to the economic, social, environmental, as well as cultural aspects."

Pertaining to urbanization and climate change, waste management is an important focus of many cities and municipalities [1]. There are ongoing initiatives taken by governments and public authorities around the world to manage waste collection and its disposal. With the growth of ICT technologies and infrastructure facilities in economically developing countries, the implementation of smart and sustainable solid waste management system (SWMS) has become a key objective. Internet of Things (IoT) technologies enable new services and reshapes existing technologies in SSC. IoT represents an internet evolution known as the next generation of the internet (i.e., the Fourth Industrial Revolution) [2]. Equipping waste bins with IoT-based sensors provides a smarter future for waste management.

Generally, solid waste refers to the solid material in a flow pattern that is discarded as useless or unwanted by society. It includes organic and inorganic waste materials which have lost their value to the first user in categories of domestic waste, industrial waste, commercial and institutional waste. In turn, solid waste management (SWM) involves waste sorting, collection, recycling, and transportation.

There are different key indicators proposed for SSC and the SWM key performance indicators (KPIs) organized in the environmental category by the United for Smart Sustainable Cities (U4SSC) EU report [11]. In our research, a set of cores and supporting SWM KPIs was used to find the optimal way for waste collection from the waste bins. The intelligent way of waste collection links with complex tasks such as route planning and planning for transportation networks. In this paper we focus on the optimal transportation problem where the solution for domestic waste collection relates to achieving minimal route length along with reduced fuel consumption, and minimal associated costs and work time [12]. Correspondingly, smart waste management also reduces the emissions of CO_2 and other gases in the environment due to the reduction in unnecessary trips to waste bins.

The paper is structured as follows: Section 2 presents a literature review in the area of smart sustainable solid waste management systems for smart cities. The current practices and main features of the case study are described in section 3. The multi-objective TSP and prediction model used to implement the developed smart, cost, and time effective, sustainable waste management system are described in section 4. Section 5 concludes the paper and section 6 provides future recommendations.

2 Literature Review

A solid waste management system (SWMS) includes waste collection, sorting, recycling, and transportation. The area of route planning and optimizing logistics purposes has contributed to the development of hundreds of intelligent transportation systems. Even so, there are still many projects going on, all around the world, to provide effective and efficient systems for waste collection and management. The waste collection and transportation problems are also considered as combinatorial optimization problem [8, 12, 13]. Different techniques in literature are used to solve this problem. For instance, a dynamic decision model (DSS) which is integrated in a GIS- based decision support system is proposed by Anghinolfi et al.[6]. In [7] five routes in different areas of Ipoh city of Malaysia are optimized to reduce the length of the routes collectively in terms of time required to complete the tasks. GIS tools and a combinatorial optimization technique are used to minimize collection time, operational and transportation costs whilst enhancing the current solid waste collection practices [8].

In [9] the optimization of vehicle routes and the planning for municipal solid waste collection in Eastern Finland is described. The solutions are generated by a developed guided variable neighborhood thresholding meta-heuristic that is adapted to solve real-life waste collection problems. In [10] a dynamic routing algorithm is proposed for a situation whereby a truck is overloaded or damaged and needs a replacement. The solution also incorporates a system model which assumes two types of trucks for waste collection, a low capacity truck and a high capacity truck. By incorporating high capacity trucks, the researchers in [10] achieved a reduction in waste collection operational costs because of a reduced need for trips to waste bins.

In [5] an advanced DSS for efficient waste collection in smart cities is proposed. The proposed system integrates a model for real-time data sharing among truck drivers for waste collection and adaptive route optimization. Furthermore, the proposed system can handle inadequate waste collection in problematic areas and provide evidence to the authorities.

[12] proposes an optimal transportation solution of classified garbage that improves the sustainability of the present practices and considers a city of China as a case study. In [13] an optimization model for municipal solid waste (MSW) collection and transportation through heuristic solutions is proposed. The proposed heuristic solutions minimize the route length which efficiently reduces waste collection and transportation cost.

The mentioned publications have inspired and directed our research development of a visualization tool providing insight into optimal route lengths and plans for waste collection trips. An optimization model is embedded into the tool to achieve the shortest possible route for collecting waste in minimum time and cost.

3 Current Practices and Main Features- A Case Study

Generally, system architecture for waste management has two main targets [12]. The first target is to provide software as a service (SaaS) for service provider companies. These companies own their own waste trucks, hire the truck drivers, give contracts to other companies for performing different tasks and pass waste for recycling or recovering other profitable values from waste [12]. The second target is to develop a system focusing on cooperative communication among all the stakeholders involved in the chain of development of a smart sustainable city.

The current solid waste management practices and infrastructure for domestic waste have three different types of waste bins for selective waste collection as shown in Figure. 2. The sensor-based waste collection bins notify the volume of waste in bins, if it is filled or empty to schedule the trip for waste collection truck drivers as shown in Figure. 6. However, the lack of optimal transportation is a major concern in current practices. This technical gap makes the current solutions time and cost inefficient which effects the listed stakeholders of the investigated municipality. A list of possible stakeholders and their roles in SWM is presented below:

1. *City administration* must understand the broad picture of waste management such as generating reports and ensuring overprice control etc.
2. *District administrations* are interested in controlling the waste collection process and checking the quality of services (QoS) to resolve disputes and problems effectively.
3. *Waste management companies* need a system for organizing and optimizing their business processes without the need for large investments in developing, deploying, and supporting such a system.
4. *Waste truck drivers* need optimal solutions for smart navigation to fulfill their tasks. Some major needs are automatic insight into route lengths, road traffic, and the ability to report problems to operators in the office, instead of wasting time in thinking how to solve the problem themselves.
5. *Managers of disposal sites and recycling plants* can publish their needs or possibilities for obtaining certain amounts of waste for recycling.
6. *Traffic police* can get reports on unpleasant incidents that have caused hazards in waste collection processes.
7. *Citizens* are interested in and can experience better services at lower costs through an improved waste collection system.

All these stakeholders are generally interdependent in smart and sustainable municipality using IoT technologies and it is possible to develop plenty of system usage scenarios to fulfill each stakeholder's need. In what follows, we present our insight into the development of a time and cost effective optimal SWM system addressing current practices and infrastructure for reduction in route length, fuel consumption, CO_2 and other gases emissions. A prediction model is embedded into the system to enable the planning of trips for waste trucks drivers based on prediction of the level of waste volume in bins. With this prediction model in place, future trips for selective waste collection can be planned in an improved manner compared to current practices.

3.1 Challenges and Risks

Waste collection and transportation are well-known challenges in many cities or municipalities. In the case we studied, the challenges and risks for the municipality to deploy a smart and sustainable SWMS were subject for investigation. The following challenges were collected and taken into consideration when developing the prediction model:

1. *Narrow and steep roads* in the city center make the task of collecting waste sometimes impossible for waste collection trucks.
2. *Busy roads* are one of the major concerns in the current infrastructure. At present, there is no optimal template for truck drivers to pursue whilst planning trips for waste collection. Present practices are cost and time inefficient.
3. *Non-environment friendly* and non-optimal ways of waste collection cause delays which can create an uncomfortable and unsanitary environment in the neighborhood.
4. *Location of Waste bins* in the municipality is also an issue. Many bins are allocated relatively far away from the road. It is quite challenging and time-consuming for truck drivers to collect waste from such locations as shown in Figure. 1-a.
5. *Open Bins* is a problem becoming rare with the growth of urbanization, but still present in some areas thereby causing unpleasant odor and sight for inhabitants as shown in Figure. 1-b.

At the initial stage of our research, the proposed solution for addressing challenges in current practices and infrastructure focused on the city center where there are narrow and steep roads with normal size waste bins. Various types of waste bins for selective waste collection are scattered around the city as shown in Figure. 2. Due to extreme weather and road conditions in present practices are time-consuming and cost inefficient for trucks with waste collection done in a non-optimal manner. The service providers need to spend a lot of money on feasible trucks able to function in such challenging locations. The smart and sustainable SWMS we propose, considers current practices and infrastructure of the municipality where waste truck drivers among others report on their inability to collect waste in rush hours. Evidently traffic and conjugation on roads increase fuel consumption and CO_2 emissions in the environment and is both cost and time consuming.

4 Waste Collection Models

In a case like this, smart decisions depend on details of the surroundings and require geographical information to help distinguish one place from another and to make appropriate decisions for that location [14]. Recent developments in ICT have opened-up vast potentials in communication and in, spatial and temporal data analysis. It is possible to store and process data representing the real world for later presentation in simplified form for suitable needs. In the waste generation model, geographical information of the city is viewed through Google Maps. The Google Maps app has its own Geo-analytical tools and can perform network analysis. It enables traffic and driving queries [15]. Google Maps provides rich, multi-layered maps that are proved easy to combine with our data and third-party data. It also provides various features such as maps, street view,

Fig. 1: Challenges and risks in the city (a) Waste bins located aside from the roads, (b) Open Waste bins

Fig. 2: Types of waste bins (top- Standard underground waste bins, left bottom- Sensor-based underground bins, right bottom- normal bins)

routes, directions, distance matrix, roads, time zone, places details and so on [15], making it a relevant tool in systems development.

4.1 Optimization Model

Fig. 3: Optimized shortest route length with estimated cost, distance, and time via multi-objective TSP

For the development of the waste generation model, data collected from standard underground and sensor-based underground waste bins was analyzed. In general, an optimized waste collection and transportation scheme effectively reduces the cost for waste collection and transportation and tends to minimize the

Table 1: Traveling time and distance covered by vehicle

Traveling Time	2.58 hours
Traveling Distance	136.4 km
Route for Vehicle	$0->3->1->9->5->2->4->7->6->8->0$

route length of each trip for transportation. Studies related to these problems are generally divided into three categories with respect to the number of disposal sites [14].

- Single disposal site, single route
- Single disposal site, multiple routes
- Multiple disposal sites, multiple routes

The following are important aspects of waste collection associated with our case:

- Number of trucks: There is one vehicle available at a time for selective waste collection and its optimized route is shown in Table. 1.
- *Starting and Stopping points*: The starting and ending points along with the number of stopping points are known to the drivers. A starting point indicates the truck's starting location and the ending point is normally the recycling site or the landfills site.
- *Selective Waste type*: In the investigated case, different types of sorted selective waste collection bins are placed at each residential area. For each selective waste collection, there are dedicated trucks in this Norwegian municipality shown in Figure. 2. Usually two disposal sites are used to dispose waste collected from selective waste bins. One disposal site for recycling of waste such as paper, cardboard, plastic, glass and metal and another disposal site for residual and food waste.

The waste collection and transportation problem can be solved by the traveling salesman problem (TSP) [14]. Generally, TSP is known as a NP-hard problem and there is no polynomial time algorithm for obtaining its exact solution [14]. TSP can be defined as:

> *A list of cities N and the distances between each pair of cities is given. The traveling salesman must find the shortest possible route to visit each city and return to the origin city.*

TSP can be classified as single-objective optimization problem (SOP) such as calculating optimal routes with minimal length, and as multi-objective optimization problem (MOO) such as calculating optimal routes with minimum cost, time, distance and so on [16]. The problem can be represented graphically as [16]:

$$G = (V, E) \tag{1}$$

Where $V = v_1, v_2...., v_N$ is a set of N nodes and E is a set of edges. While the distance d_{ij} and time t_{ij} are associated with each edge $(v_i, v_j) \in E$ respectively as in Figure. 5. In the investigated case, we are classifying TSP as MOO which can be represented as [18]:

$$TSP_{MOO} = \begin{cases} min\ F(x) = (f_1(x), f_2(x), ..., f_m(x)) \quad \text{s.t.} \quad x \in S \end{cases} \tag{2}$$

where $F(x)$ is the objective vector; $m \geq 2$ is the number of objective functions; $x = (x_1, x_2, ..., x_n)$ is the decision variable vector where n is the of cities/waste bins; x is a permutation of $1, 2, ..., n$ that minimizes $F(x)$. S is feasible solution space. The set $O = F(S)$ corresponds to the feasible solution in the objective space, and $y = (y_1, y_2, y_3, .., y_m)$, where $y_i = f_i(x)$ is a solution. For the TSP under consideration, m = 2 where $f_1(x) = traveling\ distance$ and $f_2(x) = traveling\ time$ [16].

An OR-tool solves the optimization problems by computing the cost of transportation by distance matrix between two nodes $(x_i, y_i),\ (x_j, y_j)$ is calculated using Manhattan distance which sum up the absolute distance of $x\ and\ y$ coordinates respectively in Table. 1 & Figure. 3. This can be mathematically obtained as [20]:

$$C = |x_i - x_j| + |y_i - y_j| \quad where \quad i \neq j \tag{3}$$

The mathematical representation of the stated problem is as follows:

$$min \begin{cases} f_1 = \sum_{i,j=1,i\neq j}^{N} d_{ij} c_{ij} \\ f_2 = \sum_{i,j=1,i\neq j}^{N} t_{ij} c_{ij} \end{cases} \tag{4}$$

where

$$\begin{cases} c_{i,j,i\neq j} = 1, & \text{if } bi, j \geq \gamma \\ c_{i,j,i\neq j} = 0, & \text{elsewhere} \end{cases} \tag{5}$$

In here, d_{ij} is the distance between nodes $i\ and\ j$, c_{ij} is the collection decision. If $c_{ij} = 0$, then the nodes do not belong to the optimal route, the truck does not visit the between the i_{th} bin and j_{th} bin. The optimization model shows the optimal shortest route for waste collection with minimum driving time, driving distance, driving cost in Figure. 3 & 4. The locations of waste bins are pinned in a map to visualize the route for selective waste collection. The route is established according to a threshold of waste volume. The threshold γ is set according to current practices, i.e., if the waste volume reaches or exceeds the set threshold. The γ is calculated by the waste volume in the bin over the total number of opening of lid. The truck driver schedules a trip for waste collection accordingly. The optimization model achieves the following aimed solid waste key performance indicators (KPIs) [11]:

1. Reduction in fuel combustion.
2. Reduction of the CO_2 emissions in environment.
3. Reduction in unnecessary road traffic.
4. Improved cost and time effectiveness.
5. Minimization of route length.
6. Reduction in the trips for drivers due to optimal planning solutions.

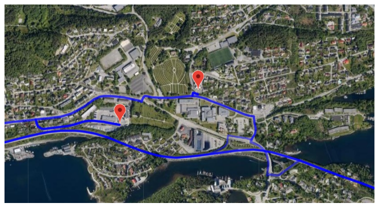


Fig. 4: Satellite view with optimal routes by TSP

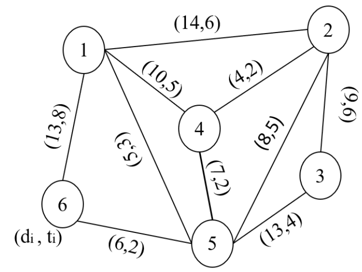


Fig. 5: MOO-TSP representation with edges- traveling distance and time, and nodes b_N

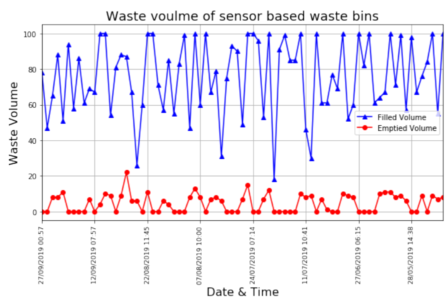
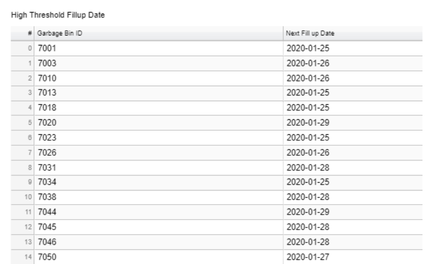


Fig. 6: Waste Volume gather through sensors



High Threshold Fillup Date

#	Garbage Bin ID	Next Fill up Date
0	7001	2020-01-25
1	7003	2020-01-26
2	7010	2020-01-26
3	7013	2020-01-25
4	7018	2020-01-25
5	7020	2020-01-29
6	7023	2020-01-25
7	7026	2020-01-26
8	7031	2020-01-28
9	7034	2020-01-25
10	7038	2020-01-28
11	7044	2020-01-29
12	7045	2020-01-28
13	7046	2020-01-28
14	7050	2020-01-27

Fig. 7: Prediction model for trips scheduling

4.2 Prediction Model

According to the current practices of the investigated municipality, the total volume of waste collected in 2019 from domestic sensor-based bins is 930.40 m^3. The sensors tracked waste volume of each bin to update the database. One of the major problems in current practices is that trips scheduled for waste collection are often overlooked or delayed. This causes an unsanitary environment. The proposed optimal SWMS solves the delaying problem by using a prediction model. In our case, the prediction model is scheduling trips for waste collection truck drivers as illustrated in Figure. 4. The prediction coefficient (γ) predicts waste volume for each bin. In the prediction model dummy variables are used to predict time *(t)* for the next trip and driving cost of each trip as shown in Figure. 7 & 6.

$$\gamma = waste\ volume_{threshold}$$

$$\nabla\ volume = \gamma * t$$

Table 2: Time and cost comparison between current practices and the developed data-driven solution

Route	Waste type	Waste bins b_N	Current practices		Developed practices		Cost Saving %
			Time (hours)	Cost(NOK)	Time(hours)	Cost(NOK)	
1	Paper	b_1, b_2	1.50	1207.0	0.57	459.0	62.0
2	Residual	b_1, b_2, b_3	2.06	1661.0	1.09	877.0	47.0
3	Paper	b_1, b_2, b_3, b_4	2.50	2013.0	1.55	1248.0	38.0
4	Paper	b_1, b_2, b_3, b_4, b_5	3.00	2348.0	2.42	1984.0	17.0
5	Residual	b_1, b_2, b_3, b_4, b_5	3.00	2348.0	2.42	1984.0	17.0
6	Plastic	b_1, b_3, b_5, b_6	3.20	2576.0	2.00	1610.0	37.5
Total			15.27	12153.0	10.05	8090.0	33.4

5 Discussion and Conclusion

Smart and sustainable solid waste management systems are main concerns for smart sustainable municipality development initiatives. This paper present findings from the investigation of current infrastructure and practices of waste collection from waste bins and its transportation in a municipality, and provides a solution to achieve smarter ways for waste collection. The objective of achieving solid waste KPIs is fulfilled to some extent and optimized multi-objective TSP algorithm used to find the shortest route length in minimal time for each trip. The route planning is based on the prediction model. In the developed data driven solution, the historic data is used for implementing an optimization model and a prediction model. The solution can easily integrate real-time data to predict and plan trips for truck drivers with minimal cost, distance and time. The time (in hours) and cost (in Norwegian kroner) comparison between current and a data-driven practice is shown in Table. 2 and in Figure. 8. The bar graphs based on Table. 2 clearly show that the smart and sustainable SWMS is cost and time effective. In the table, six different routes are used to calculate the driving time, driving cost and driving distance between current practices and the developed data-driven system. The 33.4 % saving cost shows that the data-driven system is more profitable than the existing one. In these routes, the truck drivers are subject to selective waste collection from different bins $b_1, b_2, ..., b_N$ and the routes are calculated by MOO-TSP. The developed system is data-driven as it is based on analysis of the data retrieved from current practices and infrastructure which is practical and helpful for future developments.

6 Future Recommendations

In this research, the focus is to contribute insights into building an optimal solution for the sensors and for the standard underground waste bins scattered around a Norwegian municipality. A next step towards smart and sustainable SWMS development process can be to integrate the developed optimized solution into a generic waste management system. This can then easily integrate future developments such as multiple disposal sites and multiple routes such as MOO-mTSP.

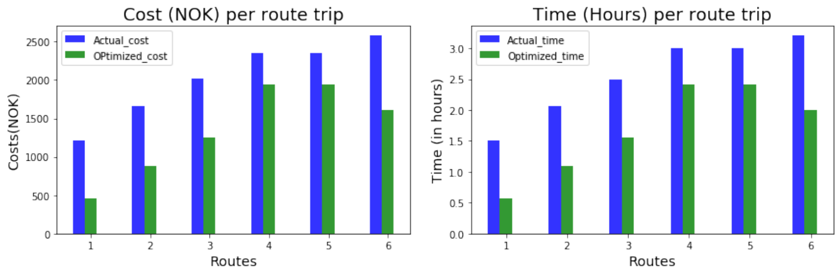


Fig. 8: Comparison between Proposed system and current system

The tasks regarding developing a waste management system usually include waste collection, sorting, recycling and transportation. This paper focuses on MOO waste collection and transportation by finding the shortest path with minimal cost and time usage. It can be extended for smart sorting and recycling with the help of IoT technologies such as cameras, actuators and wireless networks. For instance, the sensors can be modified for smart sorting to sense and classify the waste material. The waste management system can also be modified by studying and taking into account the behavior of inhabitants as regards how their age and general living conditions for example influence the waste production, sorting and management.

The multi-objective can also be used in many other applications where the developers need to solve such a problem with achieving multi-objectives such as printing scheduling, mission planning and so on.

A Current Technologies

Senor-based waste bins transmit data in real-time through wireless networks to the BioEnable waste management system. 2G and 3G telecommunication modules available through WCDMZ and GSM networks for data transfer. One of the main problems in current SWM practices is lack of optimal solutions which affects the SSC goals for SWMS.

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