Prosjektet Smart Sirkulær By i regi av Byen som Regional Motor (BRM)

Delprosjekt 2: Digitale modeller for analyse, simulering og optimalisering av Smart Sirkulær By

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Summary:

The project is a collaboration between Ålesund kommune, Årim, Tafjord Kraftvarme and NTNU, and it is financed by 'Byen som regional motor'.

The project arose because of Ålesund municipalitiy needs to have an overview of the solid waste volumes it has today and what it can expect in the coming years. The municipality wanted to be well prepared for sustainability challenges. To be able to implement appropriate solutions from an economic, environmental and technological perspective where important social considerations are considered with increasing population and a larger municipal structure following the amalgamations. The goal has therefore been to help develop new and future solutions based on smart circular models.

The project consists of three sub-projects; 1) Waste Target 2030 – Ålesund Region; 2) Digital models for analysis, simulation and optimization of smart circular city; 3) Competence building - Smart Circular City and a Roadmap for implementation.

Key words:

Distribution/access: Open

Forord

Prosjektet **Smart Sirkulær By** er et samarbeidsprosjekt mellom Ålesund kommune, ÅRIM, Tafjord Kraftvarme, Bingsa Gjenvinning AS, og NTNU. Det er delfinansiert gjennom programmet **Byen som Regional Motor (BRM)** i regi av Møre og Romsdal fylkeskommune, og gjennom egenfiansiering blant samarbeidspartnere.

Prosjektet er gjennomført i et hovedprosjekt med tre delprosjekter:

1. Målbilde avfall 2030 – Ålesundregionen
2. Digitale modeller for analyse, simulering og optimalisering av Smart Sirkulær By
3. Kompetansebygging - Smart Sirkulær By / guidelines for implementering

Prosjektet er forankret i Ålesund kommune, og med NTNU som faglig koordinator.

Dette delprosjektet er ledet av Ibrahim Hameed (Department of ICT and Natural Science)

Prosjektperioden har vært 1.01.2019 til 31.12.2019.

Ibrahim Hameed

Ålesund 24.01.2020

Innhold

1. Mål, gjennomførte aktiviteter og resultat

Prosjektansvarlig for dette delprosjektet er Ibrahim A Hameed, Institutt for IKT og Realfag, NTNU i Ålesund. Delprosjektet er summert opp i en artikkel «Smart and Sustainable Solid Waste Management System for Smart Norwegian Municipality» som er inkludert i vedlegg 1.

Bakgrunn og målsetting

Bakgrunn: Benytte simuleringskompetanse til å utvikle modeller for smartere logsitikk og material/avfallshåndtering.

Dette delprosjektet vil videre inngå i et større pilotprosjekt Smartbyen Nye Ålesund som opprettes som et forskningsprogram med et sett av forskningsprosjekter.

Innenfor dette temaet har IIR spesiell kompetanse til å:

1. Utvikle Virtuelle nye Ålesund, en digital tvilling som plattform for tverrfaglig forskning og samfunnsplanlegging.
2. Innføre visuelle stedbunden informasjon for framstilling av trafikk og endringsprosesser
3. Utvikle metoder for å løse optimaliseringsproblem

Overordna målsetting: Å kunne optimalisere framtidige scenarier for avfallhåndtering og avfallslogistikk i Nye Ålesund kommune

Dette ligger til rette for at forskningen ved IKT gjøres i to forskningsgrupper, som ledes av forskningsleder:

1. Visualiseringsgruppe: Virtuelle Ålesund, geodata, VR, digitale spor, big data.
2. AI-gruppe: Metoder for å løse optimaliseringsproblem. Parallell datakraft.

Kommentar: IKT har i dag kompetente folk til begge gruppene. Videre kan Msc studenter i Sim&Vis benyttes i arbeidet. Forskningsleder er den som har kontakt ved AI-Lab i Trondheim.

Gjennomførte aktiviteter

Hovedaktivitetar og milepæler:

	2018	Q1-2019	Q2-2019	Q3-2019	Q4-2019
Etablere 2D/3D terrengmodell					
Lage 2D/3D representasjon av avfall					
Utvikle kostnadsfunksjoner for avfall og logistikk					
Utvikle AI-baserte metoder for optimalisering					
Data collection, testing, and validation					
Paper and report writing					

Resultater

I dette prosjektet utvikles en smart avfallshåndteringsplattform for selektiv avfallsinnsamling. Den utviklede plattformen er i stand til å overvåke og visualisere fyllenivåer av avfallsdunker i sanntid. Fyllnivået detekteres ved hjelp av ultralydsensorer som er montert inne i hver dunk. Mengden/volumet av avfall i hver dunk anslås via to tilnærminger. Den første tilnærmingen er basert på en ultrasonisk senor som måler avstanden fra toppen til bunnen av avfallsdunkene. Den andre tilnærmingen relaterer seg til nedgravde dunker hvor estimering skjer gjennom telling av antall dunkåpninger av avfallsdør. Historiske oppfyllingsnivåer brukes til å estimere oppfyllingsnivåene. Flere regresjons- og maskinlæringsmodeller er anvendt for å forutsi påfyllingsnivåene med nøyaktighet. GPS-koordinatene til hver avfallsdunk brukes til å identifisere plasseringen av dunkene som grunnlag for innsamlingsprosessen. Når fyllingsnivået oppnår en forutbestemt grense, vil dunken planlegges for tømming. GPS-koordinatene til settet av dunker for tømming anvendes til å generere en optimalisert avfallsinnsamlingsrute. En optimalisert rute er en rute som bruker mindre tid, mindre kjøring, og dermed mindre kostnader for å samle samme settet med dunker. En utvidet kostnadsfunksjon som består av innsamlingstid, kjøreavstand, antall stopp etc. brukes.

Vurderinger i forhold til målet med delprosjektet

I dette prosjektet har vi lagt merke til at avfallsinnsamlingsbedrifter bruker forskjellige plattformer for å overvåke empiriske prosesser, slik at kundene kan rapportere når avfallsdunkene er fulle. Imidlertid ble innsamlingsprosessen utført manuelt der hver sjåfør har ansvar for alle registreringer og tilhørende kostnader. Basert på dette har vi besluttet å automatisere denne prosessen ved bruk av sanntidsmålinger og bruk av presisjonsmodeller for å estimere neste fylling. Når avfallsdunkene er fulle, vil en optimalisert rute bli generert og gitt til føreren i innsamlingsprosessen. Den optimerte ruten, når den følges, vil redusere flere kriterier som kjøretid, kjøreavstand osv. Den optimaliserte ruten har oppnådd reduksjon i kostnader i området fra 30 % til 60 % sammenlignet med tradisjonell avfallsinnsamling.

Resultatmål

- Utvikle digitale løsninger og verktøy som bygger opp under en sirkulær økonomi.
- Øke kompetansen hos samarbeidspartene og i regionen for øvrig.

Gjennom prosjektet har en skaffet seg innstikt i problemstillingen, samt en fordståelse av de sosiale og miljømessige muligheter for forbedring. Prosjektet har også bidratt til større aktsomhet og forståelse av optimale avfallsinnhentimhg systemer.

Måleindikatorer

Følgende måleindikatorer er satt for å måle progresjonen i prosjektet

- Utviklet sirkulære modeller for avfallshåndtering.
- Det er utviklet en platform som kan hjelpe kundene, kommunen og andre interessenter til en bedre samordning av gode løsninger.

2. Forslag til oppfølgingstiltak

Hvert av delprosjektene har gitt nyttige resultater i seg selv, og det er flere områder som kan følges opp:

Forslag til oppfølgingstiltak delprosjekt 2

Avfallshåndteringssystem dekker alle aspekter relatert til denne oppgaven, for eksempel innsamling av avfall, sortering, resirkulering og transport. Dette forskningsarbeidet fokuserte på å finne den korteste veien med minimale kostnader og tid. En av de fremtidige anbefalingene for dette arbeidet er smart sortering og gjenvinning for å gjøre lønnsomme bedrifter. For eksempel kan sensorene i SWMS modifiseres for smart sortering på en slik måte at de kan føle og varsle avfallstypen.

Vi kan legge til kostnader for CO2 og utslipp av CO2 avhengig av årstider (hvordan det påvirker miljøet og vårt bidrag til å redusere det). For å gjøre plattformen generisk, implementere optimaliseringsløsning ikke bare for ett enkelt deponeringssted, men også for alle kategorier av styringssystem for fast avfall, kan vi bruke optimalisering av ant colony i stedet for TSP for flere deponeringssteder.

En annen måte å utvide denne forskningen på, er gitt løsning til kommunen for fremtidig installasjon av avfallsbeholderne ved å studere innbyggerne, og hvordan deres vaner og levekår påvirker avfallsproduksjonen og -håndteringen.

3. Avsluttende kommentarer

Resultater fra delprosjektene 1 og 2 vil bidra til en felles handlingsplan og tilpassede veikart for implementering av nye løsninger for håndtering av materialstrømmer etter sirkulære prinsipper. Dette vil danne grunnlag for implementering av Universitetskommune 3.0 som en direkte oppfølging av Delprosjekt 3.

Prosjektet Smart Circular City har startet de første trinnene med å analysere det lokale potensialet, ressursene, tapte ressurser og evner som kan være medvirkende til å oppnå visjonen. Arbeidet bør fortsette med ytterligere analyse av regional og nasjonal statistikk; benchmarking mot internasjonale standarder; og konsultasjon med interessenter (intervjuer, fokusgrupper, undersøkelser, workshops). Samarbeid mellom forskere og kommune er essensielt, og arbeidet kan strekke seg utover kommunens avfallssektor.

Kompetansen innen sirkulære modeller, systemanalyser, miljøeffektvurderinger, miljøledelse, kommunikasjon ved hjelp av indikatorer, visualisering gjennom digitale løsningen mm, bør utnyttes i nært samarbeid mellom forksere ved NTNU og Ålesund kommune. Teknologi som data mining som gir informasjon i sanntid og visualisering og kunne være et godt case for Sustainability Analytics, noe som kan bringes inn som er viktig utviklingstema under paraplyene Universitetskommune 3.0.

4. Vedlegg

Smart and Sustainable Solid Waste Management System for Smart Norwegian Municipality

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***Abstract*— Smart, sustainable solid waste management system is a global concern. Researchers from around the world have been working to develop improved solutions for sustainable and smart waste management system (SSWMS) . Waste collection and its transportation are the major expenditure of waste management. In this paper, we investigate the waste management system in the Norwegian municipality—as a case study. Various scenarios for route planning have been considered to improve cost and time. The study provides an auxiliary smart management tool for optimal waste management which improves the sustainability of the system. The SSWMS-GIS platform has been developed using Python Libraries. A predication model has provided by which all the challenges such as road conditions, traffic, Co_2 emissions and fuel consumption have taken into consideration. The developed prediction model considered the hazards for scheduling the waste collection trips - like food waste needs to be emptied more frequently than the other waste type such as plastic and paper. Both models signify consistency and correctness.**

Keywords— Smart Waste Bins, Solid Waste Management, Sustainable Solutions, Cost and Time Effective, Route Length

I. Introduction

The smart city paradigm encompasses all the factors that can affect the society in terms of — smart economy, smart traffic, smart health, smart energy, smart municipality and so on. These factors are inter-linked under the smart city umbrella. The smart sustainable city can be defined as [17]:

" A smart sustainable city is an innovative city that uses information and communication technologies and other definition 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 the respect to economic, social, environmental, as well as cultural aspects."

With the increasing urbanization and climate change, municipal waste management is the focus area of the city [1].There are many initiatives taken by governments and public authorities around the world to manage waste collection and its disposal. With the growth of infrastructure facilities in economically developing countries, the implementation of smart and sustainable waste management system has become a key objective. To regulate waste management at central and local level in several cities in Norway, the government requires municipal and local industries to set the infrastructure for development of waste collection and treatment solutions [1].

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

This leads us to find the optimal way for waste collection in waste bins and analyzing each bins' capacity. This process links with complex tasks such as routes and planning for transportation networks and may require various options. The paper focuses on the optimal transportation issue where the solution for domestic waste collection finds the minimal route length, reduces fuel consumption by reduction in cost and time[15].

This smart planning would also reduce the Co_2 emissions in the environment.

The paper is structured as follows. Section II presents the literature review in the area of smart and sustainable waste management systems for smart cities. Section III describes main features and scenario of usage. Section IV describes the methods to implement the developed smart, cost and time effective and sustainable waste management system. Section V concludes the paper and section VI discusses the future recommendation.

II. Literature Review

Solid waste management system includes collecting, sorting, recycling and transporting the waste. The area of route planning and optimizing logistic purposes are well- researched and hundreds of intelligent transportation systems already exist. There are many projects going on all around the world to provide the effective and efficient system for waste collection and management. A dynamic decision model (DSS) which was integrated in a geographical information system based (GIS- based) decision support system, proposed in [9]. The objective of this research was recycling management and dynamic optimization of material collection. It optimized the daily waste materials recycling in order to reduce storage and transportation costs and increase benefits from selling the material. In [10], five routes in different areas of Ipoh city, Malaysia were modified for pilot study and initialized routes have been optimized to reduce the length of the routes collectively in terms of time required to complete the tasks. Another technique used is combinatorial optimization and integer programming. GIS tools have been used to minimize collection time, operational and transportation costs while enhancing the current solid waste collection practices [11].

In [12], described the optimization of vehicle routes and the planning for municipal solid waste collection in Eastern Finland. The solutions have been generated by a recently developed guided variable neighborhood thresholding metaheuristic that is adapted to solve real-life waste collection problems. The [13] has proposed a dynamic routing algorithm which would robust and cope when a truck is overloaded or damaged and needs a replacement. It also incorporated a system model which assumed two types of trucks for waste collection, the Low capacity truck and High capacity trucks. By incorporating high capacity trucks, they have achieved reduction of the waste collection operational costs because of the route planning, that reduced the trips to dumps. As our objective is to provide services for smart and sustainable city to manage solid waste, [14] proposed an advanced DSS for efficient waste collection in smart cities. The proposed system integrates a model for real-time data sharing between truck drivers for waste collection and adaptive route optimization. The system could handle the inadequate waste collection in the problematic areas and provide evidence to the authorities. The proposed system aimed to provide high quality service to the citizens of a smart city.

Such mentioned models inspired and directed this research in developing an auxiliary waste management system platform. The developed visualization tool provides the optimal route length and plans for waste collection trips.

III. Main feautres and scenarios of usage

System architecture have two main targets. First target is providing software as a service (SaaS) for customers. The main customer is the company responsible for waste collection, owing waste trucks, organize drivers for trucks, give contracts to other companies for performing different tasks and pass waste for recycling or to the disposal sites. Second target is developing a system focusing on cooperative communication among all the stakeholders involved in the chain of development of smart sustainable city. In this case, a list of possible stakeholders of the system and their brief description is presented below:

- City administration must understand the broad picture of waste management such as making reports, overprice control etc.
- District authorities are interested in controlling the waste collection process, in checking quality of service, in resolving disputes and problems efficiently and effectively. Municipalities can deploy and maintain the smart city infrastructure such as bins capacity sensors and wireless data transfer networks.
- Waste trucks companies need platform for organizing and optimizing their business process without major investments in developing, deploying and supporting their own systems.
- Waste truck drivers need navigation system to fulfill their tasks. Some major issues are route length, road traffic, and reporting problems to the operators in the office, instead of wasting time in thinking how to solve the problem.
- Managers of disposal sites and recycling plants can publish their needs or possibilities for obtaining certain amount of waste for recycling.
- Traffic Police can get reports of any unpleasant incident that may cause hazards for waste collection.
- Citizens want to have better services at lower cost and accessible, odorless waste collection system

All these stakeholders will be interdependent in smart and sustainable municipality. It is possible to develop plenty of system usage scenarios to fulfill each stakeholder's need. In this paper, we have developed a time and cost-effective optimization model for solid waste management system. This developed platform utilized the current practices and infrastructure for route length reduction, for reduction in fuel consumption and Co_2 emissions. The prediction model has been developed for planning the trips to waste bins and predicting the level of waste volume in bins.

A. Challenges and Risks

Waste management alongside waste collection itself is a big challenge for any city or municipality. In our case, we studied the challenges and risks for the Norwegian municipality to deploy a smart and sustainable waste management system. There are the following few risks and challenges, we need to take into consideration before developing a solution model.

1) *Narrow and steep roads*- In the city center, there are several narrow and steep roads that make it impossible to pass through large waste trucks for waste collection.
2) *Busy roads*- In the current practices, there is no optimized template for truck drivers to pursue while scheduling trips to waste bins. Such methods/practices might have been cost and time inefficient.
3) *Non-environment friendly*- The absence of any optimization template might cause delay in waste collection from bins. These circumstances could create an uncomfortable and unsanitary environment in the neighborhood.
4) *Location of Waste bins*- There are many locations in current infrastructure where bins are located far from the road. It is quite challenging and time-consuming for truck drivers to collect waste from such locations as shown in fig1-a.
5) *Open Bins*- Although this problem is becoming rare with the growth of urbanization. It is still present in some part of the city and caused unpleasant odor and sight for inhabitants shown in fig1-b.

At the initial stage of our research, we want to solve the problems of the city center where there are narrow and steep roads with low capacity waste bins. After spending time and studying the situation in detail, we concluded that there was a need to build a generic optimized solution regardless of the waste bin type. In the current infrastructure, there are three types of waste trucks in municipality to collect different types of waste from different waste bins scattered around the city as shown in fig 2.

Due to extreme weather or road conditions, it is quite difficult to drive all types of trucks in the city and it is time consuming and cost inefficient to take back and forth trips for waste collection. One way to solve this problem is to use specific type of truck for each route.

B. Scenario

Solid waste management companies and waste truck drivers report on their inability to drive in rush hours. It causes unnecessary traffic and conjugation on roads that is cost and time consuming, maximizes fuel consumption and Co_2 emissions in the environment. The SWMS platform has considered the current practices and infrastructure of norwegian municiplaity. In this scenario, there are few risks and challenges in the city such as steep roads as described in section above and extreme weather which affects the driving conditions.

Fig 1. Challenge in the city (a)Waste bins located aside from roads,(b)Open Waste bins

IV. model

In this section, the developed smart and sustainable waste management system has been described. The input requirements for the system are listed below.

A. Input Requirements:

Inputs for the developed solution system are arranged into a dataset. This dataset is based on the current infrastructure and practices. The dataset has following information.

1) *Bins:* This columns in the dataset contain information about the waste bins ID, their longitude and latitude (x and y coordinates). In which area of the city, the certain bin is located. There are approximately sixty-eight underground and sensor based waste bins installed in this municipality.
2) *Waste and truck type*: In our case, various types of sorted waste bins at every residential area. The dataset also has information about how many days it takes to reach the fill up threshold. In this Norwegian municipality, there are three types of waste bins- normal bins, underground bins and sensor-based underground bins. There is a specific truck for each bin type as shown in fig 2 and 3.
3) *Starting and Stopping points:* The starting and ending points along with the number of stopping point data is known to the drivers.

4) *Distance matrix:* The distance matrix is created by calculating the shortest path between all the pairs of stop points. It describes the driving distance and driving time for paths connecting the stop points.

B. Geogrphical Information

In such cases, our decisions depend on the details of the surrounding and requires information about specific places on the surface of earth. The recent development in information technologies have opened vast potential in communication, spatial and temporal data analysis. It is possible to store and process data representing in the real world so they can later be presented in simplified form for suitable needs.

Fig 2. Types of waste bins (top-Underground waste bins, left bottom-Sensor bins, right bottom- normal bins)

This is called Geographical information that helps us to distinguish one place from another and to make appropriate decisions for that location. [17]

In waste generation model, the geographical information of the city has been viewed through google maps platform. Google maps app is one of the best mapping platforms. It has its own geo-analytical tools and can perform network analysis. It enables traffic and driving queries [18].

For a business whose service based on driving and transportation, Google maps does possess all the spatial queries and visualization capability requires for such business. No further investment is needed. Google maps platform provides the rich, multi-layered maps that can easily be combined with our data and third-party data. Google maps platform provides various features such as, maps, street view, routes, directions, distance matrix, roads, time zone, places details and so on [18].

C. Waste Generation Model

For waste generation model, the data collected from underground and sensor-based waste bins have been utilized. In general, an optimize waste collection and transportation scheme effectively reduces the cost for waste collection and transportation and tends to minimize the route length of each trip for transportation. Studies related to this topic is mainly divided into three categories in respect of the number of disposal sites [17].

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

This problem of minimize route length is often referred as TSP which is classical combination optimization problem. TSP is a NP-hard problem and there is no polynomial time algorithm for obtaining its exact solution [17].

Let number of waste bins $b_1, b_2, \ldots., b_N$ are installed at the different location of the city. To visualize different waste types, the toggle is present in the map to select the bin type, for instance, residual waste, paper, plastic, food waste, glass and metal etc. The ROG (red, orange, green) colors on the map indicates the current status of waste volume in that bin. To make system adaptive, these colors will help to calculate the route and planning for the trips. The colors of the bins are represented as:

1) Green - empty bin. $b_{rog} > \gamma$

2) Orange- fill up level is within the threshold range but second priority if the truck has capacity.

$$b_{rog} \leq \gamma$$

3) Red- fill up level exceeds the threshold, primary priority bins. $b_{rog} < \gamma$

The threshold γ is set according to the current practices, i.e., if the waste volume reaches or exceeds the set threshold. The truck driver would schedule a trip for waste collection accordingly. The ROG b_{rog} level sets for minimum route length collection.

D. Optimization Model

Norwegian Municipality has been taken as the case study to demonstrate the visualization model. In this municipality, two disposal stations are used to dispose waste collected from all types of waste bins in the community. 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 starting point for each truck is same but there are two end points depending on the type of waste collected by the truck. This is multiple travel salesmen problem with multiple routes and multiple disposal sites.

Let there is only one disposal station for recycling waste in the network for all recyclable waste is transported to the same recycling station. The optimal problem is case 1: Single Disposal station, Single Route. In order to find the optimal transportation route, the domestic waste transfer problem is transformed to a routing TSP. $b_1, b_2, \ldots . b_N$ bins are nodes distributed in the city at various locations and $d_1, d_2, \ldots . d_N$ is the distance between node i and j. The distance matrix has been measured to find the length of all possible paths connecting this waste bins location. The distance matrix is an array whose i, j entry is the distance from location i to location j in kilometers. The data assumptions are:

- The number of vehicles is one.
- The starting location for the route is given.
- The stopping time at each node is known.

The mathematical representations of model are as follow:

$$min \sum_{i,j=1}^{N} d_{ij} x_{ij}$$

$$min \sum_{i,j=1}^{N} t_{ij} x_{ij}$$

In here, x_{ij} is the node and d_{ij} is the distance matrix. If $x_{ij} = 0$, then the nodes do not belong to optimal route, the truck does not visit the between the i^{th} bin and j^{th} bin. It will consider shortest distance and shortest time to cover that distance. The optimization model shows the driving time, driving distance, driving cost and volume of collected waste as shown in fig 5.

The following Key performance indicators (KPIs) have been achieved from developed smart and sustainable solid waste management system.

- Reduction in fuel combustion
- Reduce the CO_2 emissions in environment
- Cost and time effective
- Reduction in unnecessary road traffic
- Minimized route length
- Reduction in the trips for drivers due to optimal solution.

E. Predicition Model

According to the current SWM platform, total volume of waste collected in 2019-- from household sensor-based bins is 930400 liters (930,400 m3) as shown in fig 10. The sensors tracked the fill-up level of each bin to update the developers.

One of the major problems in current practices is, the trips scheduled for waste collection from these smart bins have often been overlooked or delayed. This might have caused unsanitary environment. The developed optimal SWM

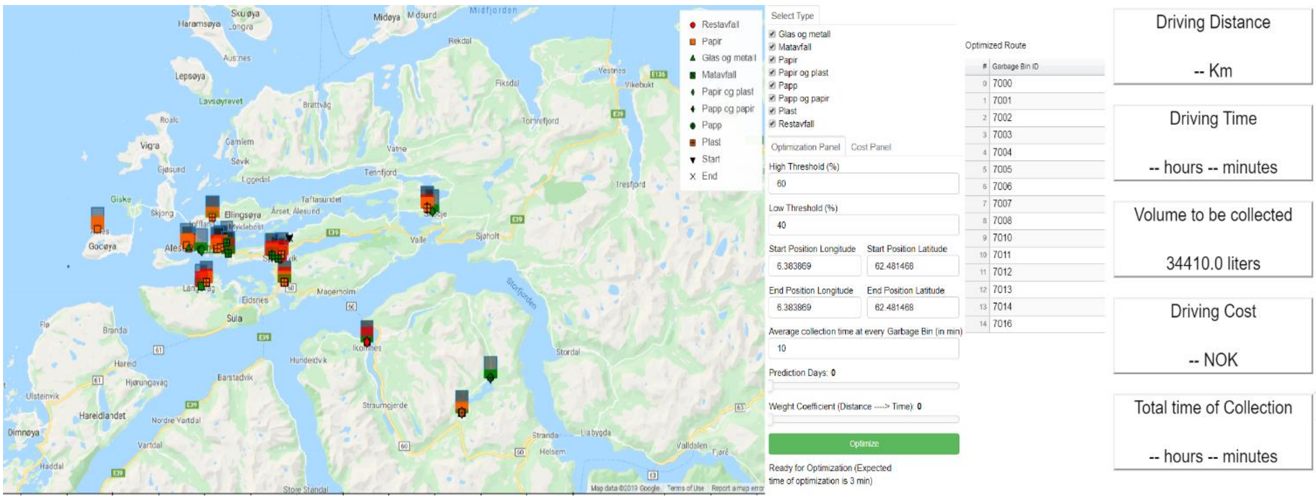

Fig 3. Smart and sustainable Waste Management system platform

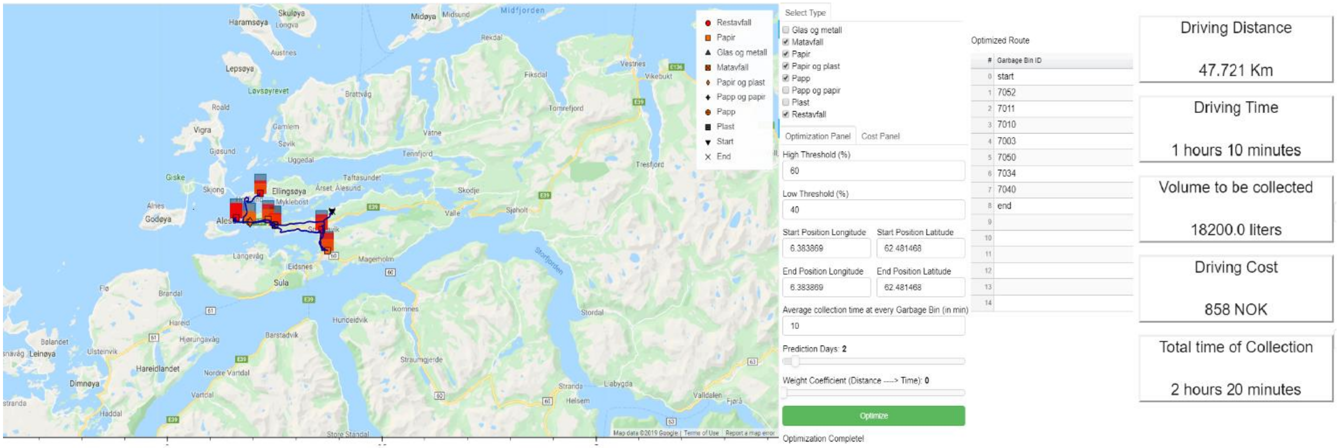

Fig 4. Optimized route with estimated cost, distance and time

Route Number	Waste type	Waste bins areas (b_n)	Current practices		Developed Platform		Cost Savings in %
			Time (hours)	Cost (NOK)	Time (hours)	Cost (NOK)	
1	Cardboard and paper	b_1, b_2	1.5	1207.0	0.57	459.0	62.0
2	Residual waste	b_1, b_2, b_3	2.06	1661.0	1.09	877.0	47.0
3	Cardboard and paper	b_4, b_3, b_1, b_2	2.5	2013.0	1.55	1248.0	38.0
4	Residual Waste	b_3, b_1, b_2, b_4, b_5	3.0	2348.0	2.42	1948.0	17.0
5	Cardboard and paper	b_3, b_1, b_2, b_4, b_5	3.0	2348.0	2.42	1948.0	17.0
6	Plastic	b_5, b_6, b_3, b_1	3.2	2576.0	2.0	1610.0	37.5
Total			15 hrs 16 min	12.153	10 hrs 3 mins	8090.0	33.4% cost saving

Table 1. Time and Cost comparison of current practices and developed platform

system has solved this problem through prediction model. In this case, the prediction model is predicting the fill-up level of the waste bins to schedule future trips for truck drivers. The prediction coefficient predicts fill volume date for each bin. The prediction coefficient (γ) will help to schedule trip as shown in fig 7. The variables used in prediction model are dummy variables to predict time *(t)* for next trip and driving cost of each trip.

$$\gamma = waste\ volume\ in\ \%$$

$$\Delta fill\ up = \gamma * t$$

V. Discussions and conclusion

Solid waste management system for smart municipality is a vast project. This paper studied the current infrastructure and practices of waste collection from waste bins and its transportation to provide the optimal solution. The aim has been fulfilled to some extent. The optimized TSP algorithms used to solve the waste management problem. This optimization model has given the optimal solution with shortest route length in minimal time and for each trip. The develop platform is the best data-driven platform for the municipality to adopt in order to make their system time efficient and cost effective.

In this data driven solution system, dummy variables and historic data have been used to generate optimization and prediction model. This platform can easily integrate real-time data set to predict and plan the trips for drivers with minimal cost and time. The time and cost comparison between current and developed practices has been shown in table below. The graphical representation of cost and time comparison clearly shows that the developed smart and sustainable SWMS is cost and time effective as shown in fig 8 and 9.

VI. future recommendation

The developed optimized SWM system can be integrated for developing a generic platform regardless of waste and waste bins type. In this work, the focus was to develop an optimal solution for sensor and underground waste bins scattered around the municipality. Internet of Things (IoT) technologies enables new services and reshapes the existing technologies in smart sustainable cities. The IoT represents an internet evolution known as the next generation of the internet (i.e., the Fourth Industrial Revolution) [2]. IoT sensors waste bins are the smart future of smart and sustainable waste management system. This data driven SWMS could easily integrate IoT sensor-based platform. The developed system can consider as the initial step towards the path that would come in the quest to make the smart and sustainable municipality.

Waste management system covers all aspects related to this task such as waste collection, sorting, recycling and its transportation. This research work focused on finding the shortest path with minimal cost and time. Another recommendation to extend this work is smart sorting and recycling for making profitable businesses. For instance, the sensors in SWMS can be modified for smart sorting in such a way that it can sense and notifies the waste type. Another way to extend this research is given solution to the municipality for future installation of the waste bins by studying the inhabitants, and how their habits and living conditions affects the waste production and management.

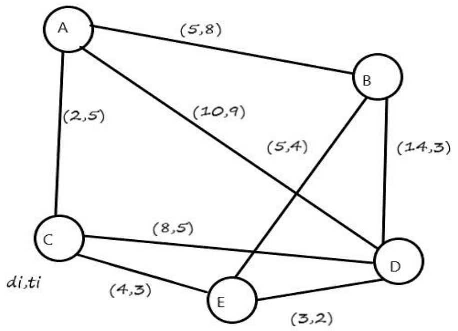

Fig 5. Travel salesman problem(TSP) representation (Edge represent cost: distance, time, route business)

High Threshold Fillup Date

#	Garbage Bin ID	High Threshold Fillup Date
6	7034	2019-12-17
9	7040	2019-12-18
3	7011	2019-12-18
2	7010	2019-12-18
0	7003	2019-12-18
13	7052	2019-12-19
12	7050	2019-12-19
14	7053	2019-12-20
11	7047	2019-12-20
10	7046	2019-12-20
8	7038	2019-12-20
7	7037	2019-12-20
4	7031	2019-12-20
1	7004	2019-12-20
5	7032	2019-12-21

Fig 6. Planning by prediction model

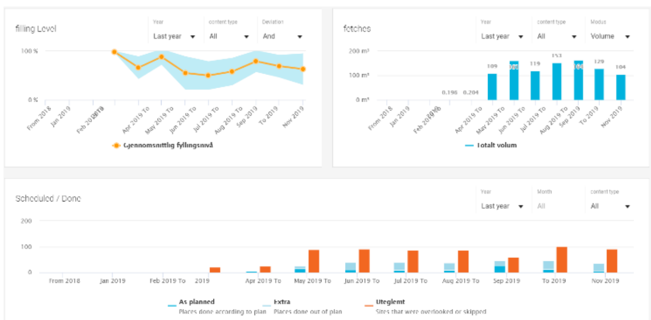

Fig 7. Current SWMS platform

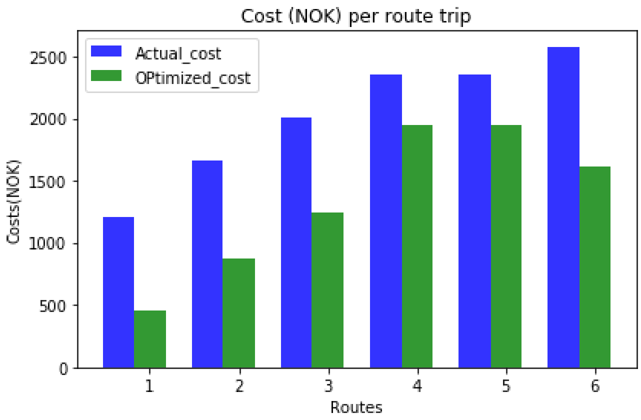

Fig 8. Cost Comparison(Blue bar- current practices, green- developed platform)

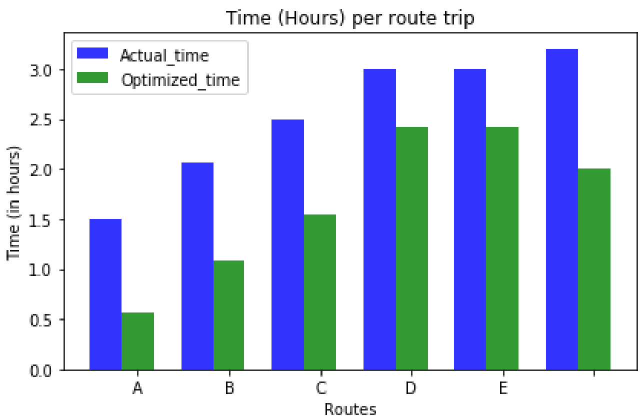

Fig 9. Time Comparison (Blue bar- current practices, green- developed platform)

Appendix A

A. Current practices and Infrastructre

The current SWMS infrastructure for household waste in this case, has three types of waste bins for waste collection. The sensor-based waste collection bins are used to notify the status of waste bins, if it is filled or empty. So, it can schedule the trip for waste collection from the filled bins. Smart waste bins transmit data in real-time through wireless networks to BioEnable smart waste management platform. 2G and 3G telecommunication modules available through WCDMZ and GSM networks. The current SWMS practices are not optimal or cost effective as shown in figure (current SWMS platform).

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