Waste Management as an IoT-Enabled Service in Smart Cities

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Waste management as an IoT enabled service in Smart Cities

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Abstract. Intelligent Transportation Systems (ITS) enable new services within Smart Cities. Efficient Waste Collection (WC) is considered a fundamental service for Smart Cities. Internet of Things (IoT) can be applied both in ITS and Smart cities forming an advanced platform for novel applications. Surveillance systems can be used as an assistive technology for high Quality of Service (QoS) in waste collection. Specifically, IoT components: (i) RFIDs, (ii) sensors, (iii) cameras, and (iv) actuators are incorporated into ITS and surveillance systems for efficient waste collection. In this paper we propose an advanced Decision Support System (DSS) for efficient waste collection in Smart Cities. The system incorporates a model for data sharing between truck drivers on real time in order to perform waste collection and dynamic route optimization. The system handles the case of ineffective waste collection in inaccessible areas within the Smart City. Surveillance cameras are incorporated for capturing the problematic areas and provide evidence to the authorities. The waste collection system aims to provide high quality of service to the citizens of a Smart City.

Keywords: Waste Collection, Smart City, Internet of Things (IoT), Intelligent Transportation Systems, Surveillance systems

1 Introduction

Recent advances in production of mobile computers and smartphones, smart sensors and sensor networks in connection with next generation mobile networks opened vast opportunities for researchers and developers of various systems and application in the field of Smart Cities and Intelligent Transportation Systems (ITS). Thought some areas like application for

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monitoring public transport are already well researched, other areas are still working with outdated technologies and models. One of such areas is the management of solid waste collection process. In a Smart City collection of waste is a crucial point for environment and its quality should be considered seriously. In order to understand the concept of Smart Cities in depth, a suitable definition is provided. In this research we use the most suitable definition for the IoT-enabled waste collection in Smart Cities, which is [1]: "A Smart City is a city well performing in a forward-looking way in the following fundamental components (i.e., Smart Economy, Smart Mobility, Smart Environment, Smart People, Smart Living, and Smart Governance), built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens". In this definition we can see important component - Smart Environment - which is tightly connected to environmental pollution. The main countermeasure to environmental pollution in terms of a Smart City is the IoT-enabled waste collection. The following definition of IoT is used in this paper [2]: "The Internet of Things allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service". IoT technologies enable new services and reshape the existing ones in Smart Cities [3]. For instance static waste collection is redesigned to Waste Collection as a Service. As the result this enables online dynamic scheduling and routing of the trucks [4]. Issues connected to dynamic waste collection could be divided into 2 main problems: (i) when to collect waste form bins (i.e., scheduling), and (ii) what route the trucks will follow (i.e., routing).

In this paper we propose waste collection system enhanced with IoT services which enable dynamic scheduling and routing in a Smart City. We also present the design of a cloud system for organization of waste collection process and applications for waste truck drivers and managers. The proposed system also features an on-board surveillance system which raises the process of problem reporting and evidence collection to a higher level.

The rest of the paper is structured as follows. Section II presents related work in the area of IoT-enabled waste collection in Smart Cities. Section III describes the main features of the system and some scenarios of usage. Section IV presents the system model architecture and two applications. One is a mobile application for the waste truck driver and another is a web application for waste management company. Section V contains the evaluation on one possible scenario and section VI concludes the paper and discusses future work.

2 Related work

The area of route planning and optimizing for logistic purposes is well-researched and hundreds of Intelligent Transportation Systems already exist. There are also a number of projects aiming to provide an effective system specializing on waste collection needs. A Geographical Information System (GIS) transportation model for solid waste collection that elaborates plans for waste storage, collection and disposal has been proposed in [5] for the city of Asansol in India. In [6] an enhanced routing and scheduling waste collection model is proposed for the Eastern Finland, featuring the usage of a guided variable neighbourhood thresholding metaheuristic. In the city of Porto Alegre in Brazil authors propose [7] a truck-scheduling model for solid waste collection. The aim of the research was to develop an optimal schedule for trucks on defined collection routes. Examples of other systems are described in [8],[9],[10] and [11].

A survey presented in [12] reviews the researches done on waste collection in developing countries from 2005 to 2011 and considers challenges for developing countries in waste collection sphere. The research focuses on determination the stakeholders' actions/behaviour and evaluation of influential factors defining their role in waste collection process. The models in the survey were tested on real data. In [13] a survey considering system approaches for solid waste collection in developing countries is presented. The research compares the history and the current practices, presented from 1960s to 2013. Information about the challenges and complexities is also given there. The output of the survey is drawing a conclusion that developing and implementing solid waste collection approaches in developing countries are of a great importance. The main issue is that waste collection does not include innovation that IoT can provide. Models do not use real time information of the waste collection, although some approaches use advanced scheduling and routing via exploiting modern ICT algorithms. Information about bins status was not considered as part of waste collection. All the reviewed surveys do not propose a model that will use IoT technology for Smart Cities, though they consider different approaches for waste collection.

Moreover, enabling combined participation of stakeholders like road police and city administrations in one system is not covered. Finally, the concept of implementing an on-board surveillance system for fast problem reporting and evidence collecting is not implemented in mentioned projects, but is described in [14] and [15] separately from waste management topic. All this allows stating the need for development a system facilitating the usage of IoT data, dynamic routing models and participation of diverse types of stakeholders.

3 Main features and scenarios of usage

System architecture aims to suit two main targets. First target is providing software-as-a-service (SaaS) products for customers. Mainly, these customers are private companies that are involved in waste collection, owning waste trucks, organize work of drivers, get contracts from municipalities and pass wastes to recycling organizations or city dumps. Second main target is developing a system, which makes possible mutually beneficial communication between all the stakeholders involved in the chain of supplying goods and utilizing solid waste in smart city.

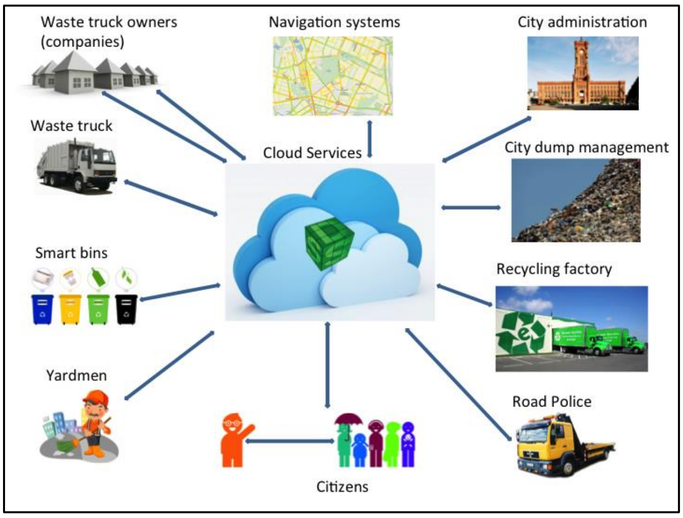

Fig. 1. The big picture of a waste collection management system

A list of possible stakeholders of the system and brief description of their needs, business rules, possibilities and connections with others is presented below:

- City administration needs understanding of the big picture, generating reports, control over pricing etc.
- District administrations are interested in controlling the process of waste collection, checking quality of service (all waste collected, all in time, waste collected cleanly, waste transported to special places), quick and legal ways for solving disputes and problems. Municipalities can also deploy and maintain smart city infrastructure like capacity sensors in waste bins and wireless networks for data transferring.
- Waste trucks owning companies need platform for organizing and optimization of their business process in general without serious investments in developing, deploying and supporting their own system. Such system must include effective dynamic routing based on IoT data for the truck fleet. Besides, controlling drivers and tracking the fleet is also an important issue.
- Waste truck drivers need navigation system for fulfilling their tasks. Another issue is reporting problems and passing them to the operators in the office instead of thinking how to solve the problem, this can sufficiently save time of a driver and vehicle. Drivers also need evidence that their work was done correctly and cleanly.
- Managers of dumps and recycling factories can publish their possibilities or needs in acquiring certain amount of waste for storing or recycling
- Staff that is responsible for trash bins in the current yards needs communications with waste management companies and truck drivers.
- Road police can get reports about inaccurate car parking that leads to impossibility of waste collection.

- Citizens want to have better service, lower cost and having easy accessible reports on what has been done and how much it cost.

As it is shown on fig. 1, the main component of the system is the cloud based decision support system (DSS). It is a platform that provides possibilities for intercommunication of all the stakeholders. Waste trucks generate sensor data about their capacity, location, fuel available and consumed. Besides, truck drivers load video fragments or pictures of problems they meet while performing their tasks. Sensors located in smart bins generate data about capacity, pollution etc. Waste management companies after registering in the system create rules and business logic for waste collection. Creating the business logic and rules means registering the companies' fleet and drivers, registration of smart and non-smart bins from which waste must be collected, defining time windows for waste collection that corresponds to local laws and terms of contract with the municipality. Important issue is gathering, processing and storing data from heterogeneous sensors, including capacity sensors in bins and trucks, cameras, Internet connected objects (ICOs), etc. On-line navigation systems provide data about traffic situation, which is crucial for effective routing. It is much more convenient and cost effective to use this data from special services using sensing-as-a-service [16] model, rather than implementing such function inside the DSS system.

Having all this information in DSS it becomes possible to provide customers with best possible routing for each truck. Moreover, reports from drivers when they encounter a problem on the road are processed semi-automatically that results in a much faster problem solving. It is possible to count plenty of system usage scenarios but due to the lack of space we present and evaluate only one, which is presented in the "Scenarios" section of this chapter.

3.1 Scenario – inaccessible waste bin

Waste truck drivers report about his inability to drive inside the yard or approach the waste bin with the truck and get wastes. Usual reason for it is inaccurate car parking, which is shown in fig. 2.

Fig. 2. – Inaccessible waste bin scenario

This report includes video or picture of a problem made with drivers' smartphone or tablet on which the client android app is running. This data is annotated by a voice message, GPS coordinates and other available data. Then this report is processed in the DSS and if it is correct it is sent to organizers of waste collection in this particular place and to the road police. The truck driver doesn't waste time for waiting, he/she goes to the next point and the route is dynamically recounted. When the problem is solved the system recounts the route for one of the available trucks and the waste from unlocked bin is collected. It is combined with dynamic routing algorithms [17] to maximize the efficiency of waste collection. As it is stated in [17] static models do not fit the idea and IoT-enabled potentiality of a smart city. It is often faster and cheaper to make a longer route saving time from traffic congestions or waiting for a road problem to be solved; thereafter the need for IoT-enabled dynamic routing engine for the fleet becomes one of the main features of the designed DSS. Schematically old static and new dynamic approaches are shown on fig. 3.

Fig. 3. – Static and dynamic routing approaches

4 System Model Architecture and Applications

As most Intelligent Transportation Systems, the designed system also implements the engine for storing, rendering, updating and displaying maps as one of the main components. Some of the criteria for choosing the engine were licence independence, possibility for making changes in existing maps and possibility to build a separate instance in a private own cloud. As a result OpenStreetMap [18] has been chosen as the main technology for acquiring maps data and for displaying maps and routes both for the drivers' android application and web application for managers and other clients. Nominatim [19] is a part of OpenStreetMap project; it is used for geocoding – finding latitude and longitude by in OSM data by name and address.

As it was already mentioned above, a typical client of the described system is a waste management company that owns a heterogeneous fleet of vehicles and needs to service a number of points in a city. This is a well-known problem in logistics and transportation - the vehicle routing problem (VRP) [20] and its objective is to minimise the total route cost. There are several variations and specializations of the VRP but their description is omitted in this paper due to space limitations. A number of open source and commercial projects exist enabling fast solution of VRP. Examples of such projects are JSPRIT [21], Open-VRP, OptaPlanner, SYMPHONY, VRP Spreadsheet Solver etc. JSPRIT [21]–java based, open source toolkit for solving rich traveling salesman (TSP)[26] and vehicle routing problems (VRP) has been chosen the main library used for solving VRP and building initial routes due its lightness, flexibility and ease of use. Another advantage of JSPRIT library is its easy extensibility that will be significantly useful while adding special features and algorithms specific for waste collection. GraphHopper [27] is a fast and memory efficient Java road routing engine. It is used for calculating optimized routes for waste trucks based on OpenStreetMap data.

A web-based application for waste management companies is presented in fig. 4. It provides managers and operators with facilities like registering the infrastructure and vehicles, tracking the fleet, mark waste bins as blocked and unblocked etc. A mobile Android-based application for a waste truck driver is shown in fig. 7. As the main feature it delivers smart navigation options to the driver. Secondly, the application provides an option of reporting a problem. In fig 7. (right) a process of making a report about a blocked by car waste bin is shown. Noticeably, we implement a feature of annotating a report with voice that allows not distracting the driver from his work.

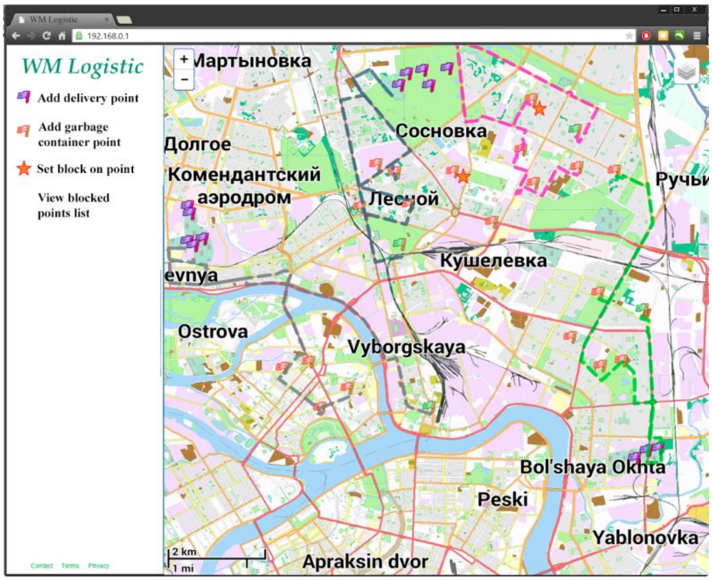

Fig. 4. – Web-based application for waste management companies

4.1 Surveillance System

As it was already mentioned in Introduction section, one of the main features of the proposed system is a waste truck based surveillance system that serves several purposes. These purposes are:

- Evidence collection system for easy accident analysis [14]
- Reporting road and other problems [15]
- Proof of correctly and cleanly done work

First two scenarios are based on CityWatcher application and are described in [14] and [15]. CityWatcher is an android based application for smartphones, which acts as an IoT car black box. It records video of the situation on the road and annotates it with time and coordinates. The difference with other black boxes is the ability of authorized personnel to make requests to local storage of all participating in the system devices to search for an evidence of road accidents.

The distinction from CityWatcher application is in the number of cameras used. CityWatcher was designed to use with the camera built into smartphone. This was a suitable solution for a civil purpose, but it may be not enough for professional service. In case of waste truck surveillance system several wired or wireless cameras can be used simultaneously.


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Fig. 5. – XML file with vehicle and task description

5 Experimental Evaluation

We use real and synthetic data to evaluate the proposed system. Real data is the road graph of St.-Petersburg and waste bins location. In the first experiment we use 6 trucks for collecting waste from 24 bins. The task for the JSPRIT library algorithms is described as an XML file, a part of which is presented on fig 5. The XML file contains the description of one vehicle and one pickup point, which represents a smart waste bin.

The result of the VRP solvation is graphically presented in fig 6. As a result after the first experiment we have routes for several trucks, distances, time and fuel consumed. This is the best-case scenario, as all the bins in this experiment are treated as accessible (not blocked).

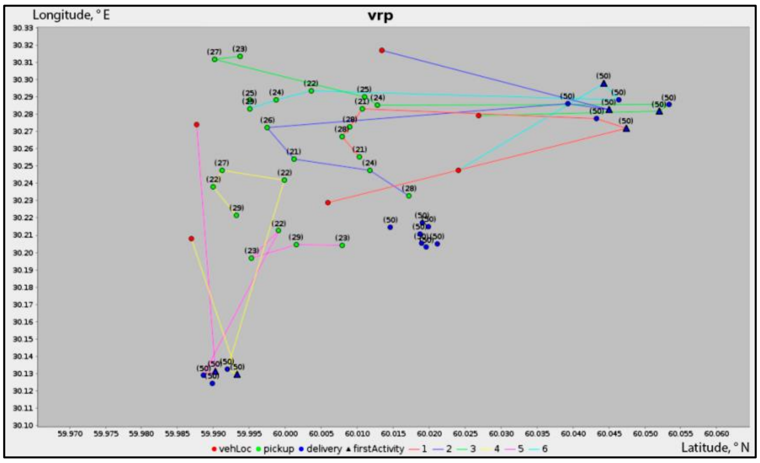

Fig. 6. - The result of the VRP solvation

Routes for this experiment are presented in fig. 4 (all trucks for manages) and fig 7 (one route for a truck driver).

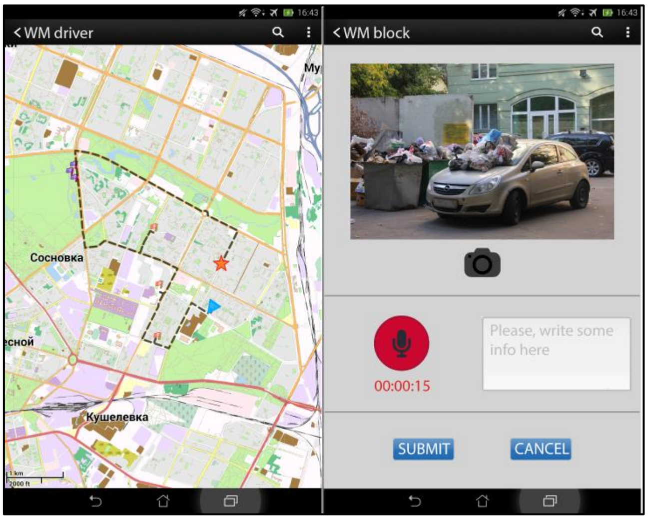

Fig. 7. – Navigation (left) and problem reporting (right)

In the second experiment several random bins are blocked. We use this approach several times on different percentage of blocked bins.

When the truck driver finds a blocked bin or other problem that makes it impossible to collect the waste he/she loses several minutes for reporting the problem via telephone and leaves the place. When all accessible points are collected the driver makes one more round for collecting waste from bins that are assumed to be unblocked now. This is the worst case

scenario, as the diver loses time for driving into the yard, recognizing the problem, reporting it and returning to the same place later.
In the third experiment we assume that when a bin is blocked the truck reports the problem with a mobile application and continues the trip. For example, the waste collection point in the yard contains four bins – for plastic, glass, paper and organics. While the truck that reports the problem (e.g. collecting plastic) does not get significant resource economy, other three trucks are informed about the problem and automatically exclude current point from their route. When the problem is marked as solved by police or municipality staff the route is dynamically rebuilt and one of the available trucks gets a task for collecting waste from that point. Line graph for this experiment are presented on fig 8. The lowest line represents the ideal scenario without blocked bins. It is easy to see, that total time (and accordingly cost) used by informed waste trucks (red line) in comparison with the scenario without informing drivers about blocked bins (green line) is significantly lower. This experimental evaluation showed that our approach for coping with blocked bins scenario is cost-effective.

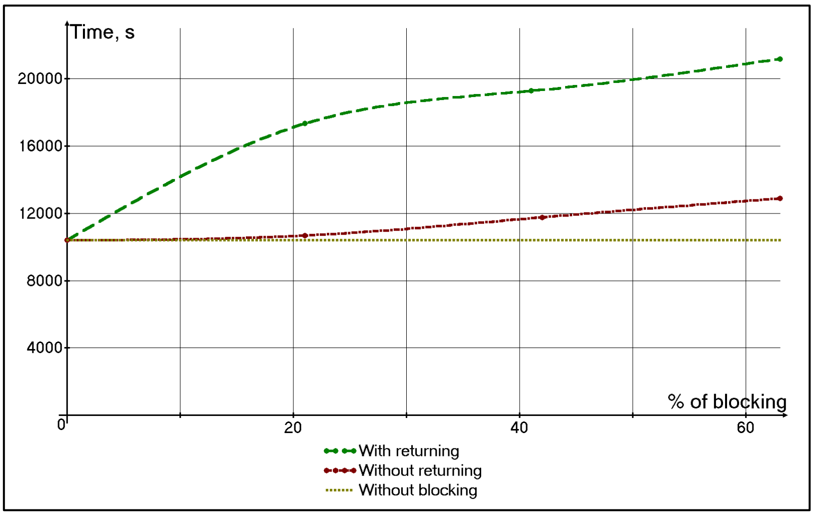

Fig. 8. Dependence of total time spent by fleet for the percentage of blocked waste bins

6 Conclusion and future work

In this paper we have presented a novel cloud-based system for waste collection in smart cities. The system aims to provide services for different kind of stakeholders involved in this area - from city administrations to citizens. Still, the design focuses mostly on providing SaaS services to commercial waste management companies. Development of applications for city administrations, municipal staff, recycling factories and other stakeholders is planned to be done in future. We have evaluated the proposed system and shown that implementing on-board surveillance cameras for problem reporting in conjunction with a cloud

DSS system and dynamic routing models can give a significant increase of cost-effectiveness, which is one of the most indicating criteria for the Smart City.

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