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# Assessing dynamic models for high priority waste collection in smart cities

Theodoros Anagnostopoulos [a,b,*], Kostas Kolomvatsos [c], Christos Anagnostopoulos [d], Arkady Zaslavsky [b,e], Stathes Hadjiefthymiades [c]

[a] *Community Imaging Group, University of Oulu, 90570, Finland*
[b] *Department of Infocommunication Technologies, ITMO University, 197101, Russia*
[c] *Department of Informatics and Telecommunications, University of Athens, 15784, Greece*
[d] *School of Computing Science, University of Glasgow, G12 8QQ, UK*
[e] *CSIRO Computational Informatics, CSIRO, Box 312, Vic. 3169, Australia*

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ABSTRACT

*Waste Management* (WM) represents an important part of *Smart Cities* (SCs) with significant impact on modern societies. WM involves a set of processes ranging from waste collection to the recycling of the collected materials. The proliferation of sensors and actuators enable the new era of *Internet of Things* (IoT) that can be adopted in SCs and help in WM. Novel approaches that involve dynamic routing models combined with the IoT capabilities could provide solutions that outperform existing models. In this paper, we focus on a SC where a number of collection bins are located in different areas with sensors attached to them. We study a dynamic waste collection architecture, which is based on data retrieved by sensors. We pay special attention to the possibility of immediate WM service in high priority areas, e.g., schools or hospitals where, possibly, the presence of dangerous waste or the negative effects on human quality of living impose the need for immediate collection. This is very crucial when we focus on sensitive groups of citizens like pupils, elderly or people living close to areas where dangerous waste is rejected. We propose novel algorithms aiming at providing efficient and scalable solutions to the dynamic waste collection problem through the management of the trade-off between the immediate collection and its cost. We describe how the proposed system effectively responds to the demand as realized by sensor observations and alerts originated in high priority areas. Our aim is to minimize the time required for serving high priority areas while keeping the average expected performance at high level. Comprehensive simulations on top of the data retrieved by a SC validate the proposed algorithms on both quantitative and qualitative criteria which are adopted to analyze their strengths and weaknesses. We claim that, local authorities could choose the model that best matches their needs and resources of each city.



## 1. Introduction

In modern societies, the increased population accompanied by the industrial development leads to a boost of economies. Booming economies, rapid urbanization and the rise in community living standards have greatly accelerated the waste generation rate in developing countries (Minghua et al., 2009). Through this perspective, *Waste Management* (WM) is a critical issue for every modern society/city. The reason is that waste should be efficiently managed in order to minimize its negative effects in the environment and, thus, to increase the quality of life for citizens. Local authorities or private companies can undertake the responsibility to provide a high quality mechanism for WM. In the past, important improvements have been observed in WM. Related research has identified the relevant stakeholders and organizations that may have an interest in adequate WM. For instance, some of the reported stakeholders are: national or local governments, municipal authorities, city corporations, non-governmental organizations, households, private contractors, Ministries of Health, Environment, Economy and Finance, recycling and waste processing companies.

The WM process involves a number of issues ranging from the collection of waste to the recycling. *Waste Management Systems* (WMSs)

* Corresponding author at: Community Imaging Group, University of Oulu, 90570, Finland. Tel.: +358 (0) 44 917 4649.

*E-mail addresses:* tanagnos@ee.oulu.fi (T. Anagnostopoulos), kostasks@di.uoa.gr (K. Kolomvatsos), christos.anagnostopoulos@glasgow.ac.uk (C. Anagnostopoulos), arkady.zaslavsky@csiro.au (A. Zaslavsky), shadj@di.uoa.gr (S. Hadjiefthymiades).

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are devoted to provide functionalities that effectively handle the lifecycle of various types of waste. *Information and Communication Technologies* (ICT) can offer many advantages when incorporated in WMSs. Sensors and actuators enable the new era of *Internet of Things* (IoT) that can be adopted in *Smart Cities* (SCs) and help in WM. The provision of intelligent applications that control the entire line of WM based on sensor observations facilitates the necessary processes and maximizes the performance. A SC could deploy a number of sensors attached to waste bins in order to gather/collect data related to waste (e.g., weight, odor). A central system could have a view on the waste information realized 'in-the-field' and, thus, it could be able to take the appropriate decisions related to the demand for waste generation/collection. In addition, such system could be responsive when alerts are triggered in real time. For instance, the system could rearrange the routes of collection trucks, when necessary, leading to a dynamic WM scheme.

Prior research focuses on the collection, transfer and transport practices and has proposed the appropriate strategies for collection schemes, route planning, collection schedule and the appropriate infrastructure or the number of the required resources for waste collection. However, some important issues are still open. For instance, there is the need of adopting effective methodologies for the management of: (a) *dynamic changes in the production of waste* and (b) *how cities affect WM*. Actually, these two issues are related to how and when waste is produced and what are the appropriate solutions for its efficient management in real time. Societies need an intelligent framework that dynamically responds to changes in the production of waste especially when waste is produced in critical (high priority) areas. As a critical (high priority) area in a city, we could define areas that are mostly affected by waste, especially, when the collection process is not frequently performed. There are specific types of waste that should be immediately collected and recycled due to the negative effects that they have in humans' lives. A representative example involves an area where specific amenities are located like schools, hospitals, university campuses, etc. In such areas, waste bins close to the discussed amenities should be immediately depleted. In addition, high priority areas could be also characterized areas where 'sensitive' groups of people are living (e.g., people living close to hospitals or fuel stations). Waste bins located in such areas could be characterized as ***high priority*** bins. High priority bins are related to: (i) *waste dangerous for human lives (*e.g.*, chemicals)* or (ii) *sensitive areas that are heavily affected by waste disposals (*e.g.*, schools, gas stations); such areas are characterized either by the type of the amenities located in them or by the type of people living at them*. In both cases, such bins should be depleted as soon as possible in order to minimize the effect of waste into the environment and the human lives. For instance, hospitals' waste should be immediately collected to minimize the risk of exposing humans to chemicals or other medical-related materials. Bins close to gas stations should also be immediately collected to minimize the risk of fire. The immediate collection of waste in high priority areas becomes imperative when no special process is applied for recycling dangerous materials.

In this paper, we present a WM framework to be adopted by a SC.

**Definition.** (Bakici et al., 2013). A SC is a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality.

Aiming to the increased quality of life, the proposed framework is responsible for deriving dynamic decisions for the efficient collection of waste especially for the management of high priority bins. The proposed system provides routing functionalities for a number of trucks and offers routes adaptation when waste collection needs are identified in high priority areas. The priority of each area is defined according to the type of the area, however, the system could be easily extended and rely on top of different constraints. An intelligent mechanism undertakes the responsibility of dynamically adapting the route for each collection truck when waste bins, in high priority areas, are full. Hence, the system gives priority to sensitive areas, thus, maximizing the quality of life for citizens together with the maximization of the performance for waste collection. We propose a set of collection strategies realized into four (4) models for facing the aforementioned scenario. Each strategy has specific characteristics concerning the method that the system adopts to manage high priority bins. The aim is to provide a set of solutions for the efficient collection of the high priority waste bins in a SC. We perform a large number of simulations in order to reveal the advantages of each model and present comprehensive evaluation results. Our aim is to provide a comparison between the proposed models and, accordingly, stakeholders can easily select one of them according to the special needs of each area. The following list reports on the contributions of our work:

- we adopt of the notion of high priority areas and high priority bins, respectively, in WM;
- we propose four (4) WM models for serving the immediate collection of high priority bins;
- we provide routing functionalities and routing adaptation for serving areas that are characterized as critical (high priority);
- the proposed models manage the trade-off between the immediate collection and the cost for waste depletion;
- the proposed framework dynamically responds to changes in the production of waste in high priority areas;
- we provide a comprehensive experimental evaluation of the proposed models that reveal their strengths and weaknesses over a large set of simulation scenarios.

We focus on areas that are mainly affected by waste disposal. Some examples of areas and amenities that could be characterized as high priority are: (i) hospitals (e.g., people can be exposed to medical-related materials), (ii) schools (e.g., pupils or students can be considered as 'sensitive' target group as far as the waste disposal consequences concerns), (iii) areas close to fuel stations (e.g., there is an increased risk of fire, especially in areas where high temperatures are observed), (iv) areas close to factories that utilize materials not supported by special plans for immediate treatment (e.g., in the case where no specific individual collection and recycling processes are present); (v) areas that, for specific reasons, the local authorities want to be managed as high priority (e.g., squares, places where people are gathered, playgrounds); In these cases, the seasonal aspects could be also applied (a location could be of high priority only for a specific time interval, e.g., various events, touristic areas).

The paper is organized as follows. Section 2 presents related research efforts while in Section 3, we discuss the proposed framework. We analytically describe the system and give its main characteristics. In Section 4, we describe the proposed models for managing high priority waste bins and in Section 5, we describe the application perspectives of our framework. In Section 6, we report on the performance of each model. We compare the proposed models for important performance metrics for waste management. Finally, in Section 7, we conclude our paper by giving future research directions.

## 2. Prior work

A number of dynamic models for waste collection have been proposed by the research community. There is a significant interest for dynamic models since static approaches cannot handle the dynamic nature of IoT potentiality. The dynamic scheduling and routing model discussed in Johansson (2006) adopts capacity sensors and wireless communication infrastructure, thus, it is able to be aware of each bin's state. The mechanism incorporates analytical modeling and discrete-event simulation in order to achieve real-time dynamic routing and scheduling. The authors in Wy et al. (2013)