**A Proof-of-Concept Framework of Municipal Solid Waste Location Routing Problem**

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Municipal Solid Waste Management (MSWM) includes the processes associated with collection, transportation, treatment, recycling and disposal of waste in a safe, hygienic and cost-effective manner. Among different managerial aspects of MSWM systems, locating the system’s facilities and routing between them are the most important and challenging issues as they affect the system’s whole cost considerably. This paper aims to nominate a new realistic framework for municipal solid waste location-routing problem. The proposed framework considers selecting the locations of the waste management system’s all facilities including transfer stations, treatment centres, recycling centres and disposal centres among the candidate locations, and identifying the routes to and from the facilities in order to minimize the total cost of the system which is measured by cost of transportation and the facilities establishment.

# 1. Introduction

Municipal Solid Waste Management (MSWM) is considered as one of the most challenging issues in many populous cities. Generally, MSWM includes the processes associated with collection, transportation, treatment, recycling and disposal of waste in a safe, hygienic and cost-effective manner. A successful MSWM requires the appropriate site selection of the waste management system’s facilities such as recycling and disposal facilities, and transportation of wastes among the facilities. The extensiveness and complexity of the factors affecting MSWM (e.g. limited resources such as land, investment costs and operational costs) make it difficult to be properly implemented.

There are different kinds of municipal solid waste (MSW) such as rubbish, food waste, commercial waste, industrial waste, construction waste and sanitation waste. Generally, MSW includes recyclables (such as paper, glass and plastics), toxic substances (paint, pesticides, used batteries, medicines), compostable organic matter (fruit and vegetable peels, food waste) and soiled waste (blood stained cotton, disposable syringes, etc.) ([Sharholy et al., 2008](#_ENREF_12)). However, in a broader classification perspective we can divide MSW into the three main categories: hazardous wastes, recyclable wastes and garbage.

In spite of great importance of transfer station in waste transportation networks, they are often neglected in relating studies. These facilities play a significant role in economizing the costs of the waste management system. A transfer station is a processing site used for the temporary deposition of wastes by collection vehicles. Prior to being loaded into larger vehicles, the wastes are sorted and balled into the different sorts ([EPA, 2002](#_ENREF_4)).

The MSWM network can be more complex when the types of hazardous wastes and their required treatment technologies are taken into consideration as a real world case. Different types of hazardous wastes require distinctly different treatment processes and technologies such as incineration and chemical treatment. That is, a compatible treatment technology must be selected based on the waste characteristics ([Nema and Gupta, 1999](#_ENREF_9)).

In addition, an integrated MSWM system (as the one proposed here) requires consideration of different disposing processes and therefore different disposal centres. In practice, disposal centres for hazardous wastes are different from other disposal centres because more strict regulations and controls such as leachate are applying to them ([EPA, 1996](#_ENREF_3)).

The existing mathematical models for the Location-Routing Problem (LRP) in waste management have been focused on hazardous wastes only d([Nema and Gupta, 1999](#_ENREF_9), [List and Mirchandani, 1991](#_ENREF_8), [Jacobs and Warmerdam, 1994](#_ENREF_6), [Giannikos, 1998](#_ENREF_5), [Alumur and Kara, 2007](#_ENREF_1), [Zhao and Zhao, 2010](#_ENREF_13), [Samanlioglu, 2013](#_ENREF_11)). To the best of our knowledge, no research on a comprehensive integrated model has been found for the optimization of the locations of the system’s all components and routes among them consisting of transfer station, recycling centre, treatment centre, hazardous and non-hazardous disposal centre. In literature, mostly the locations of recycling centres are neglected and transfer stations are not included, however, these facilities are inseparable parts of a waste management system because optimization cannot be achieved without considering their interrelations with the other system’s components. Mathematical models can be utilized to design the system by describing objectives, component interactions and possible management strategies. A comprehensive mathematical model can provide a systemic means with which the decision-makers can make an optimal management plan ([Nema and Gupta, 1999](#_ENREF_9)). This paper aims to propose a systemic model framework for MSWM to provide a sketch for optimizing the locations of its components and routing plan for different types of waste transportation flows in order to minimize the total cost of transportation and facility establishment.

# 2. Model framework

The Location-Routing Problem (LRP) considers the simultaneous optimization of facility location and design of an underling transportation network. It is observed that the separated design of depot location and vehicle routing often yields a suboptimal solution and generates extra cost. In LRP, the joint decisions consist of opening a single or a set of depots and designing a number of routes for each opened depot, with the objectives of minimizing the overall cost comprising the fixed costs of opening the depots and the costs of the routes ([Lin et al., 2014](#_ENREF_7)).

Concurrent optimization of site selection and routing in a waste management system has been studied by some researchers. ([Zografros and Samara, 1989](#_ENREF_14)) utilized a goal-programming approach to modelling of a hazardous waste management system. Their main objective is to minimize the total travelling time and risks. However, they considered only a single type hazardous waste and allocation of only one treatment centre to each generation node.([List and Mirchandani, 1991](#_ENREF_8)) proposed a model for a hazardous waste location-routing problem while considering only treatment and disposal centres. ([ReVelle et al., 1991](#_ENREF_10)) developed a mathematical model specifically for nuclear waste to locate storage facilities and select shipment routes while only one type of waste was taken into account. ([Jacobs and Warmerdam, 1994](#_ENREF_6)) proposed a mathematical model for a hazardous waste LRP to minimize a linear combination of costs and risks in time while site selection of the storage and disposal facilities were included in their addressed problem.

More realistic location routing problems for hazardous waste were developed by ([Alumur and Kara, 2007](#_ENREF_1)), ([Samanlioglu, 2013](#_ENREF_11)) and ([Boyer et al., 2013](#_ENREF_2)). However, recycling centres and routing of wastes to and from these centres were not considered by ([Alumur and Kara, 2007](#_ENREF_1)). Moreover, ([Samanlioglu, 2013](#_ENREF_11)) and ([Alumur and Kara, 2007](#_ENREF_1)) did not study the ability of direct routing between generation nodes and disposal centres in their proposed models. Beyond these differences, different types of waste and waste-technology treatment compatibility are also neglected in the presented approach by ([Boyer et al., 2013](#_ENREF_2)).

In addition, intermediate transfer stations and distinct disposal facilities for hazardous and non-hazardous waste residues have not been taken into consideration so far in the literature. Overall, lack of a new location-routing problem for an integrated MSWM system with the ability of responding to the mentioned shortcomings is inferable in the literature. Considering real-world aspects, our presented framework can be utilized for modeling a real-world municipal solid waste location routing problem to minimize the total cost of the system including the transportation costs and the opening costs of the system’s facilities.

A schematic display of our defined framework is presented in Figure 1. The diagram in Figure 1 starts with transportation of wastes from generation nodes to transfer stations ($x\_{i,j}$) where the wastes are sorted and balled into the recyclable, hazardous and garbage balls. After the sorting process, the balled wastes are sent to their distinct destinations by larger vehicles. Recyclable wastes are transferred to recycling centres ($l\_{i,j}$); hazardous wastes are sent to treatment centres with compatible technologies ($y\_{w,i,j}$) and garbage which are neither hazardous nor recyclable is transported to non-hazardous disposal centres ($p\_{i,j}$). After the treatment process, a waste mass is reduced ($r\_{w,q}$) and the parts which are recyclable are sent to recycling centres ($k\_{i,j}$) and non-recyclable waste residues are transported to final hazardous disposal centres ($z\_{i,j}$). At the recycling centres, after the recycling process, recyclable wastes are sent to the markets or other factories ($β\_{i}$) and the generated waste residues are sent to the final non-hazardous disposal centres ($v\_{i,j}$).



Figure 1. Schematic view of the defined problem

The proposed problem framework consists of concurrent site selection of the locations of the system’s facilities (e.g. transfer stations, treatment-, recycling- and disposal centres) from the candidate locations and the determination of routes and amounts of shipments among the selected locations to minimize the total cost of transportation and facility establishment.

# 3. Concluding remarks

The main contribution of this paper is a new framework of a location routing problem of MSWM where different waste types are simultaneously factored in, and then transfer stations and distinct disposal facilities for hazardous and non-hazardous residues are taken into account. The proposed framework can be utilized for mathematically modeling the addressed problem for optimizing the locations of the system’s components and routes among them. Taking the above-mentioned aspects into consideration together with the other real-world features such as waste-treatment compatibility, locations of recycling centres, possibility of locating different facilities in the same node, and considering minimum requirement amount constraints, led us to develop a comprehensive and yet more practical framework in waste management context. The main utilization of the presented study is to provide a framework for mathematically modeling the problem in order to find the optimal locations of the MSWM system’s facilities consisting of transfer stations, treatment, recycling and disposal centres, and to determine the optimum routing strategy to and from these facilities in order to minimize the total cost of establishment and transportation.

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