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Research Note

Development of a Simplified Procedure for Routeing Solid Waste Collection

A.R. Awad*, M.T. Aboul-Ela[1] and R. Abu-Hassan[2]

Solid waste management is concerned with the control of generation, storage, collection, transportation, processing and disposal of waste according to the principles of public health, economics and other environmental considerations. The routeing problem is one of the main components of solid waste management. The objective of this paper is to suggest a suitable routeing system for the city of Irbid. Two basic approaches are normally applied to vehicle routeing:

1. The Chinese postman problem (arc routeing) which finds the minimum distance of a continuous tour through a network that travels all arcs and cannot be applied to the case of solid waste collection in Irbid.
2. The traveling salesman problem (node routeing) which requires that a visit must be made to a number of specific points (pick-up points) and the routeing problem is solved as a node covering one. The traveling salesman system was found to be the most suitable approach that can be applied to the solid waste collection problem in Irbid.

Several techniques mainly based on computers and mathematical programming (such as Monte Carlo simulation, heuristic algorithm and modified heuristic algorithm) were implemented for solving the traveling salesman problem in the eastern region of Irbid. The results of this paper indicate that the use of modified heuristic algorithm is best suited for this problem due to its simplicity and practical application.

INTRODUCTION

The increasing trend towards urbanization and population growth, combined with a growing environmental concern have created a critical situation for the management of house hold solid waste. The problem of solid waste and its management is complex in small towns and critical in large metropolitan areas [1]. The management of solid waste has become an important issue worldwide.

Solid waste management can be divided into two major activities: a) Collection including storage and transport and b) Disposal. In management, the goal is to achieve some desired level of service at minimum cost. Cost analyses by Ludwig and Black [2] reveal that 85% of the solid waste system cost is due to collection and only 15% to disposal.

Several modeling approaches have been examined for the determination of waste disposal sites. These include linear programming technique [3] and heuristic techniques [4]. Future developments would likely provide an increasing challenge for container sitting and collection logistics [5]. Up to mid-1995, at least 66 papers were published in journals and conference proceedings related to transportation, in the fields of traffic flow and control (25), planning (13), demand analysis (11), routeing and scheduling (11) and pavement management (6) [6]. In many of such papers, however, little effort was made to handle the problem of routeing solid waste collection.

The objective of this research is to suggest a suitable traffic routeing system for solid waste collection vehicles in the city of Irbid, Jordan. The collection operation in Irbid begins when workmen with handcarts collect plastic bags containing residential

*. *Corresponding Author, Department of Environmental Engineering, Tishreen University, Lattakia, Syria.*

1. *Department of Civil Engineering, Minya University, Minya, Egypt.*
2. *Department of Civil Engineering, Jordan University of Science and Technology, Irbid, Jordan.*

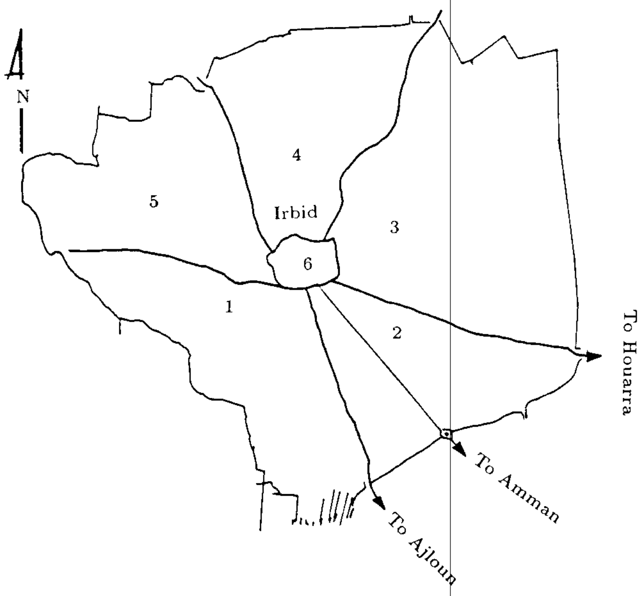

Figure 1. The divided regions of Irbid.

solid waste. These bags are carried to the nearest pick-up point where there are steel containers of 1100 liter capacity. The containers are unloaded into special compact vehicles.

Irbid is divided into six regions which are considered as separate solid waste generation areas (Figure 1). Each of these regions has its own department which regulates the solid waste services in the region. Every morning the vehicles are driven from the garage to the regions, where they begin to collect residential solid waste from the pick-up points. There is no specific routeing basis for the vehicles being left to the driver's choice. Occasionally, one pick-up point may be missed. In regions which have two collection vehicles, they may meet at the same pick-up point several times. Once the solid waste is loaded into the vehicles, it is carried out of Irbid to the disposal site located 30 km to the north-east of the city.

BACKGROUND

The urban environmental models and growth including infrastructure services such as urban solid waste routeing technique, based on engineering knowledge, heuristic model or system analysis for the screening of development options are reported in the literature [7,8].

The basic problem of deciding how vehicles should be routed through street networks depends on system policies such as transportation and urban problems in terms of growth and development, place and frequency of collection, weather and equipment type and capacity [9]. Once such policies are set, the basic issue of how vehicles are routed can be divided into two alternative approaches: arc routeing and node routeing [10].

The routeing problem in Irbid is a node routeing or traveling salesman problem. A set of nodes are given to be serviced by some vehicles. The problem is to construct a tour through n points with a minimum distance.

Many publications from the beginning of this century proposed solutions for the traveling salesman problem and, until now, all techniques have been limited to a definite number of nodes. Extensive research has been conducted recently on the traffic routeing and network equilibrium, which mainly depend on the concepts of dynamic route choice models [11], integrated models [12], planning models [13], operational research and analysis of algorithms [8,14-17].

In general, the problem has attracted a great deal of attention because it is simple to state but difficult to solve [14]. The exhaustive procedure of solving the traveling salesman or node routeing problem starts by numbering the n nodes with integers from 1 to n. Then, the problem is solved by generating all permutations of the first $(n-1)$ positive integers. For each permutation, the corresponding tours are constructed and its cost, or distance or time computed. Proceeding through the list of all permutations, the tour that has the least cost, so far, is saved.

The algorithm for the exhaustive procedure enumerates the permutations of the first $(n-1)$ positive integers. There are $(n-1)$ of these permutations. In the case where the vehicle does not have to return to the starting point, there will be $(n-2)$ permutations. If three nodes are involved, there are two possible routes. For four nodes, there are six possible routes. However, for eleven nodes there are approximately 3,700,000 possible routes. It has been reported by Coney [15] that a 21-location tour would require 77,100 years of computer time on a one million instructions per second computer. Mathematical programming approaches have had rather limited success with this problem. For a 20-node problem, integer linear programming requires 8000 variables and 440 constraints while dynamic programming is limited to 13-node problems [16].

Heuristic algorithms are usually very fast [4,17]. The heuristic traveling salesman algorithm is based on the hill-climbing idea. The problem is reduced to the set of subgoals of finding out, at each step, the cheapest node to visit. The worst feature about the algorithm is that its ability to pick up very cheap nodes at the early and middle executions can force it to choose very expensive nodes in the last few executions. One way to avoid this, is to repeat the algorithm for the same initial node and then, perhaps, go back to using the cheapest edges. One would then choose the smallest of the tours.

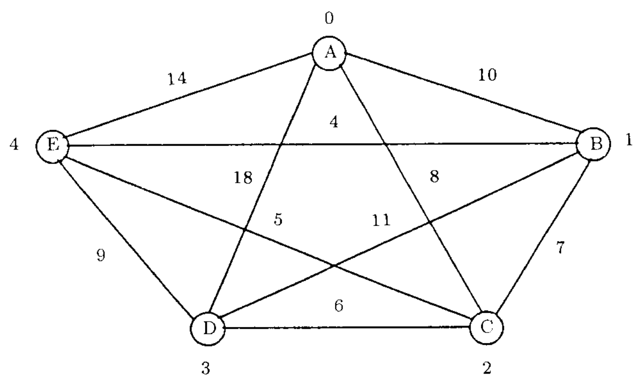

Figure 2. A five-node traveling salesman problem.

As an example, consider the network shown in Figure 2 with distances between the nodes. The exhaustive algorithm gives the route 0-1-4-3-2-0 and 0-2-3-4-1-0, as the shortest tours with a distance of 37. This has been achieved by evaluating (5-1)! = 24 possible tours. For the heuristic algorithm that begins with node 0, the following are obtained:

(0.2) with distance 8,

(2.4) with distance 5,

(4.1) with distance 4,

(1.3) with distance 11,

(3.0) with distance 18.

The minimum tour will be 0-2-4-1-3-0, with a distance of 46. However, starting with a different node 2 results in:

(2.4) with distance 5,

(4.1) with distance 4,

(1.0) with distance 10,

(0.3) with distance 18,

(3.2) with distance 6.

The minimum tour will be 2-4-1-0-3-2, with a distance of 43.

The modification is not suitable for application in routeing solid waste collection vehicles in the city of Irbid, since collection vehicles start at the node which is close to their garages or the previous region. It can be noticed that the heuristic algorithm provided a tour which is 46/37 = 1.24 times longer than the optimum tour (obtained by the exhaustive algorithm).

METHODOLOGY

The heuristic traveling salesman procedure does not appear to be a practical technique for solving the solid waste collection problem in the city of Irbid.

Modifications in the original exhaustive algorithm were made to make it more suitable and to satisfy the problem of routeing the solid waste collection vehicle in Irbid, so that it would not be necessary to return to the starting point again. It is possible to define the initial and end nodes for the algorithm. This will ensure the collection of solid wastes from the nearest node (pick-up point), when the vehicle comes from the municipality garage, ending at the nearest point to the main street before departure to the disposal site. Another important modification is that the vehicle may not be able to visit a particular node only once (which is a requirement of the traveling salesman problem), it may pass by a node twice.

The suggested procedure for solving the vehicle routeing problem in the selected region of Irbid begins with a particular node closest to the garage or the previous region and ends with the node closest to the disposal site. This reduces the number of permutations considerably. Furthermore, for comparison, Monte Carlo simulation is used to randomly select the shortest route.

The following detailed procedures were taken step by step while implementing the modified heuristic technique.

The first step was to locate the pick-up points on the map. There are thirty-one pick-up points (nodes) in Region 2 (Figure 1) with about fifty containers distributed on it.

The second step was to define the streets as one-way and two-way and, also, to find the channelized streets which prohibit certain movement. Many visits were made to the site.

The third step was to make a survey of the study area which revealed the following. Two major streets pass through the area of Region 2. They divide the total area into three small areas, each having its own nodes. This simplifies the problem, so that each area can be studied alone, i.e., the collecting vehicle collects the containers from one area and then moves to the next. Furthermore, this reduces vehicle conflict when intersecting major streets, probability of accidents, ability to visit crowded streets and accelerates the operation. The average speed of vehicles was about 40 km/hr and the average time needed for unloading the container in the vehicle, i.e. loading time, about 5 minutes.

The fourth step was to construct imaginary lines between each pair of nodes and put down the estimated distances on it and then to estimate the distance between each and all the other nodes. All distances are estimated to the nearest 5 meters. Left and right turns, intersections and rotaries were all taken into consideration during the estimation process.

As shown in Figure 3, three networks were constructed, with each network having its distance matrix. Network I has 9 nodes (pick-up points), network II, 7 and finally network III, 15 nodes.

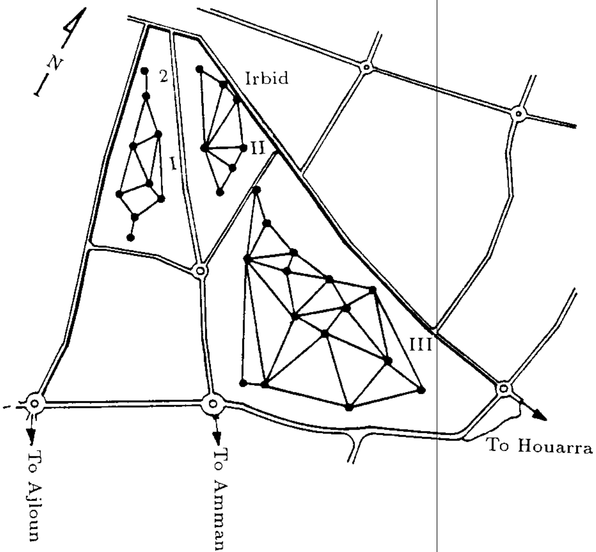

Figure 3. The constructed networks in Region 2.

Every morning, the vehicle starts from the garage and enters the network from the nearest node to it, then passes by each node in network I and so on to networks II and III, passing only once by each node. Finally, from the third network at one of the nodes close to the main street, it leaves for the disposal site.

It was shown that the computer running time for a complete tour, i.e., a good tour for collecting the solid waste in Region 2 of Irbid, had an average of about 5 minutes for a 15-node network, proving it is a fast technique.

IMPLEMENTATION

The south-eastern region of Irbid city (Region 2) was used as a case study (Figure 3). It contained 15 nodes with 1 or 2 containers at each node, consisting of three networks (I, II, III). The collecting vehicles are equipped with compactors and have to collect the contents of about fifty full containers. Network III and distances between nodes are shown in Figure 4.

The solution began from node 1. Several runs were made using Monte Carlo simulation (one million random trials) and the shortest route beginning with node 1 and ending at node 15 and passing through all nodes was found to be: 1-2-3-4-5-7-9-8-9-10-11-12-6-11-13-14-15, with a total distance of 6715 m.

The heuristic algorithm gave the route: 1-2-4-5-7-10-11-6-12-13-15-14-9-8-3, which is not acceptable since it ends at node 3, very close to the starting node.

The modified heuristic algorithm which starts at node 1 and ends at node 15 gave the following route: 1-2-4-5-7-10-11-6-12-13-14-9-8-3-15, with a distance of 7945 m. The difference between the modified heuristic and Monte Carlo solutions is about 1.2 km.

A comparison was made with the existing route situation followed by a driver on a particular day.

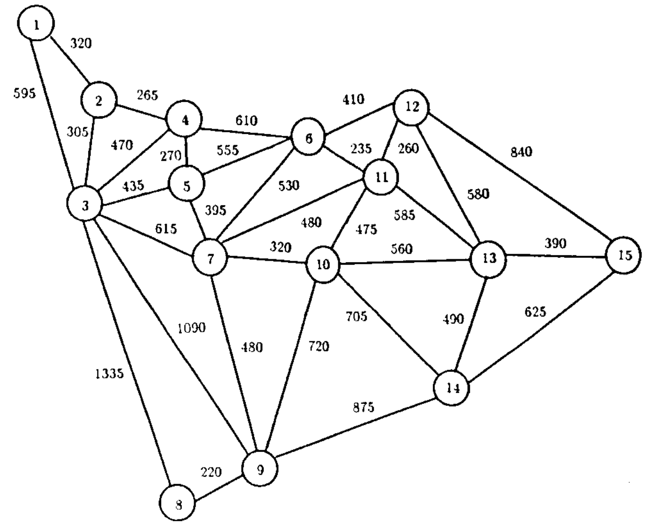

Figure 4. Network III of Region 2.

It was found that applying the modified heuristic traveling salesman algorithm saves about 5 km/day, which leads to 1800 km/year. These savings can reduce maintenance and fuel costs and will enable the municipality to offer more funding to other services related to health and welfare. It can also help the municipality to give more consideration to the disposal of solid waste in a proper and healthy way.

CONCLUSION

The objective of this research was to develop a suitable routeing system for solid waste collection vehicles in the city of Irbid. Several procedures were discussed and it was decided to use a modified heuristic procedure capable of producing a good solution that is easy to apply. Furthermore, Monte Carlo simulation was utilized to select the shortest route, as determined by the other techniques. The procedure was implemented within an eastern region of the city of Irbid.

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