RESEARCH ARTICLE

•Arch Hyg Sci 2013;2(4):150-7
•Journal Homepage: http://jhygiene.muq.ac.ir

Optimization of Solid Waste Collection and Transportation System by Use of the TransCAD: A Case Study

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A-R-T-I-C-L-E I-N-F-O

Article Notes:
Received: Oct 15, 2013
Received in revised form: Nov 28, 2013
Accepted: Dec 18, 2013
Available Online: Dec 27, 2013

Keywords:
Route optimization
TransCAD
solid waste collection
waste disposal facilities
Iran

A-B-S-T-R-A-C-T

Background & Aims of the Study: Collection and transportation of municipal solid waste (MSW) for various reasons, especially economic and social are considered as one of the most important elements of the solid waste management system. More than sixty percent of the costs in solid waste management systems in different countries are due to the collection and transportation process including laboring cost, the high price of fuel and machinery and equipments maintenance. This paper aims optimization of solid waste collection routes of Marvdasht, located in Fars province of Iran.

Materials & Methods: This approach consists of several steps. First step includes filed visits, surveys, and interviews with relevant authorities and individuals in the form of questionnaires through which available information about the current route of solid waste are collected. TransCAD, a professional and specialized software for solid waste routing, is then employed for solid waste collection optimization taking into account factors such as shortest path length and time, minimum U-turn and capacity of machinery, etc…

Results: The proposed routes were compared to the existing routes for collection of waste considering costs and collection time. According to the results obtained from TransCAD software for the considered case, compared to the current service the total distance and travel time can be decreased up to 16% and 30%, respectively.

Conclusions: TransCAD software can perform appropriate routing for solid waste collection, which has the optimized total distance travelled and travel time as did for Marvdasht city.

Please cite this article as: Talebbeydokhti N, Amiri H, Shahraki M. H, Azadi S, Ghanbari ghahfarokhi S. Optimization of Solid Waste Collection and Transportation System by Use of The TransCAD: A Case Study. Arch Hyg Sci 2013;2(4):150-7.

Background

Waste (solid) has been in existence since the creation of Adam. During the early periods of civilization, solid waste was conveniently disposed of without any problem, since the population was low and there was a large open space(1).

With the advent of urbanization and industrialization, waste generation increased and hence an increase in solid waste disposal.

This increase in solid waste began to pose health challenges and so urban planners were tasked to find how to dispose of waste from our communities. The collection, transportation and disposal of solid waste involve a large expenditure. Three of the aspects of waste management are the design of efficient route, efficient and economic collection of waste and the location of dumpsites (2).

The vehicle routing is to define one or more routes to be traveled by vehicles of a fleet, passing places to be visited (3). These sites may be specific points; it was characterized as a network of roads or segments. The segments of roads are called arcs or links.

The vehicle routing can be classified into three types of problems: coverage problem for nods (when the collection is performed at specific points), covering problem of arcs (when the collection is held in segments of roads) and general problem of routing (when the collection is performed on nodes and arcs). The routing of vehicles to collect household solid waste is a routing problem (Arc Routing Problem - ARP) (4).

The operation of solid waste collection is characterized by the involvement of citizens, who should properly package them and present them in days, times and places pre-established. This service is to transport the solid waste from sites where they were put to the final destination. For the service of garbage collection occurs satisfactorily, it is necessary to implement an efficient system that operates throughout the urban area and, also, that is regular, i.e, the vehicle must pass regular collectors in the same places days and times.

According to waste management plan in Fars province, cleaning services absorb between 7 and 15% of the resources of a municipal budget, of which about 50% is allocated to the collection and transport of waste. For this reason, the operations of collection and transportation services are important to the city administration.

The routes of the vehicles cannot be defined using mathematical techniques (3). The mathematical techniques are called non-empirical method. The techniques use mathematical algorithms and routing can be performed by manual method or computer. In the computational method, the algorithm is integrated with software called scripted. Software like scripted defines the best route according to the variable you want to optimize distance or travel time.

The routing method used in this work is the computer. The software used is TransCAD, which is considered a Geographic Information System for Transportation (GIS-T). This software allows you to develop routes using the routing algorithm called Arc, which performs the procedure in arc routing.

Literature review

The model that most closely resembles the setting of curbside collection is the Capacitated Arc Routing Problem (CARP). In this problem, a certain demand is specified for each arc. Moreover, there is a capacity constraint on the total demand a vehicle can serve. CARP belongs to the class of NP-hard problems too. CARPs arise naturally in several applications related to garbage collection, road gritting, mail delivery, network maintenance, snow clearing, etc.(5). Nuortio et al.(6) distinguish the arc routing and node routing problem in more detail. Population density, for example, can play a role in deciding which type to choose. Another important factor is the amount of detail required. If the problem data (capacities demand) are specified in terms of streets, the arc routing modeling approach is more appropriate. If, on the other hand, the problem data (capacities, demand) is specified in terms of bins, the node routing approach is more likely to be adopted.

Mourao and Almeida (7) solved a capacitated arc routing problem (CARP) with side constraints for a refuse collection Vehicle Routing Problem (VRP) using two lower-

bounding methods to incorporate the side constraints and a three-phase heuristic to generate a near optimal solution from the solution obtained with the first lower-bounding method. Then, the feasible solution from the heuristic represents an upper bound to the problem. The heuristic they developed is a route-first, cluster-second method.

Li, Borenstein and Mirchandani (8) designed a truck schedule operation plan for Porrto Alegre city, Brazil to optimize solid waste collection costs. They used recycling facilities instead of disposal sites. Furthermore, the results showed that the number of vehicles and distance travel of solid waste collection has been reduced 25.24% and 27.21%, respectively.

Ogwueleka (9) used a heuristic method for solving solid waste collection problem in Onitsha, Nigeria. Computational results indicated that by using this method the travelling length and time has been reduced 16.31% and 23.51%, respectively.

Fernandez and Pereira (10) by transforming of arc routing to node routing problem using an ant colonies heuristic solved solid waste collection routes in Sant Boi de Llobregat, Barcelona. Computational results showed that this method could save about 35% in total distance collection routes.

Aims of the study: The aim of this study was optimization distance and time of solid waste collection of Marvdasht which is located in Fars province of Iran.

Materials & Methods

Collection of solid waste from specific points in our streets is an arc routing problem. In this paper, we shall use TransCAD software that use Arc Routing algorithm to model and optimize the solid waste routes on the streets using minimum path and shortest time. The area under study is Marvdasht city that located at Fars province of Iran.

TransCAD is the first and the only Geographic Information System (GIS) based program designed specifically transportation profession which can store, display, manage, and analyze transportation data.

TransCAD includes a comprehensive library of logistics procedures that apply to all modes of transportation and can be used to solve a variety of logistics problems that called Vehicle Routing and Logistics and include Arc Routing. Arc routing problems are a class of problems that involve finding efficient ways to travel over a set of links in a transportation network.

The routing method used in this work is based on a computational method which is fulfilled through TransCAD program that allows the user to develop routes using the routing algorithm called Arc, which performs the procedure in arc routing.

Analysis using a Geographic Information System for vehicle routing in the solid waste collection in order to minimize the total distance travel is done by comparing the routes defined by empirical and a computational method. In this case, the computational method simulates routes to the service studied throughout his routes. The simulation of vehicle routing is performed based on data collected in the real system. The data were tabulated so as to be inserted in the input files of the software TransCAD. There are four main steps to solve the vehicle routing problem using TransCAD (10).

- **The input data Preparation**

Files should be prepared that contain the geographic location of the deposits and the charts, along with information on demand. Basically, two input files are required: the file stops (stop layer) and the storage of vehicles (vehicle table). Deposits and stops must be in the same geographic file, which is referred to as the file stops (stop layer). The file still must have the following fields: ID (a number that specifically identifies the parade) Name (a name or number that is used to identify the reports of the parade route); Workload (demand at the stop); length of each route and truck's speed in each route. To solve the vehicle

routing problem with time windows, you should also prepare a file of vehicles (vehicle table). This file contains information specific to each type of vehicle (Figure 1). The file of vehicles must have the following fields: Depot ID (identification of the node of deposit for each vehicle type), Type (type code vehicle), Capacity (the ability of each type of vehicle); Num_vehs (the number vehicles of each type) and Cost (the cost of acquisition / operation / rental of each type of vehicle). Figure 2 shows the input data to TransCAD.

Dataview1 - sadra

Length	Dir	Distric	EntLineWt	lenght1	Inght	velocity_m	[Street name]	[AB speed]	[BA Speed]	[Time (min)]	[AE
555.04	0	1	40	266.33	266.33	166.67	12	166	166	3.34	
275.29	0	1	40	100.89	100.89	83.33	54	83	83	3.32	
324.85	1	1	40	126.67	126.67	166.67	61	166	166	1.96	
324.89	0	1	40	128.29	128.29	166.67	63	166	166	1.96	
298.05	0	1	40	105.30	105.30	83.33	163	83	83	3.59	
203.87	0	1	40	69.61	69.61	83.33	168	83	83	2.46	
70.60	0	1	40	23.07	23.07	83.33	171	83	83	0.85	
592.98	1	2	40	168.30	168.30	166.67	284	166	166	3.57	
187.35	1	2	40	53.16	53.16	83.33	291	83	83	2.26	
564.34	0	1	40	165.91	165.91	83.33	299	83	83	6.80	
636.61	-1	1	40	180.69	180.69	166.67	313	166	166	3.83	
248.70	0	1	40	128.90	128.90	166.67	4	166	166	1.50	
265.39	0	1	40	75.09	75.09	83.33	24	83	83	3.20	
166.53	0	1	40	64.86	64.86	83.33	86	83	83	2.01	
200.59	0	1	40	70.39	70.39	83.33	129	83	83	2.42	
65.03	0	1	40	18.80	18.80	83.33	136	83	83	0.78	
212.43	0	1	40	76.73	76.73	83.33	137	83	83	2.56	
209.14	0	1	40	59.18	59.18	83.33	148	83	83	2.52	
170.44	0	1	40	48.38	48.38	83.33	150	83	83	2.05	
183.34	0	1	40	61.97	61.97	83.33	154	83	83	2.21	
69.55	0	1	40	22.66	22.66	83.33	157	83	83	0.84	
100.86	0	1	40	28.66	28.66	83.33	158	83	83	1.22	
384.65	0	1	40	128.64	128.64	166.67	181	166	166	2.32	
250.10	0	1	40	71.92	71.92	83.33	182	83	83	3.01	
313.37	0	1	40	96.41	96.41	83.33	338	83	83	3.78	
245.01	0	1	40	72.05	72.05	83.33	348	83	83	2.95	
519.66	0	1	40	149.12	149.12	166.67	356	166	166	3.13	
471.75	0	1	40	137.05	137.05	83.33	380	83	83	5.68	
290.14	0	1	40	85.27	85.27	83.33	392	83	83	3.50	
135.87	0	1	40	39.39	39.39	83.33	394	83	83	1.64	

Figure1) Input data to TransCAD

ha1 - Notepad

File Edit Format View Help

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                         Itinerary Report

ROUTE ID 1            : depot/district 1
Workload              : 11160.00
Total Time            : 1249.27
Deadhead Cost         : 0.00
# Deadhead Links      : 0 (out of 540 links)
# Left Turns          : 121
# Right Turns         : 114
# U-Turns             : 72
# straight Turns      : 232
Turn Penalty Cost:      0.00

 No.     ID       Dir Movement          Street_Name                      Service    Time
------------------------------------------------------------------------------------------
   1      314     AB   Start East on    314                              Right      0.71
   2      314     BA   U-turn on        314                              Right      0.71
   3      359     BA   Continue on      359                              Right      4.28
   4      358     BA   Continue on      358                              Right      4.56
   5      357     BA   Continue on      357                              Right      2.36
   6      356     BA   Continue on      356                              Right      3.13
   7      355     BA   Continue on      355                              Right      5.10
   8      354     BA   Continue on      354                              Right      4.47
   9      353     BA   Right on         353                              Right      3.41
  10      344     BA   Right on         344                              Right      2.96
  11      361     AB   Left on          361                              Right      3.90
  12      362     AB   Right on         362                              Right      2.36
  13      363     AB   Continue on      363                              Right      3.40
  14      364     AB   Right on         364                              Right      2.15
  15      386     BA   Left on          386                              Right      3.97
  16      373     AB   Left on          373                              Right      1.52
  17      373     BA   U-turn on        373                              Right      1.52
  18      385     AB   Left on          385                              Right      3.60
  19      385     BA   U-turn on        385                              Right      3.60
  20      372     BA   Left on          372                              Right      3.49
  21      371     AB   Left on          371                              Right      0.92
  22      338     BA   Continue on      338                              Right      3.78
  23      374     AB   Continue on      374                              Right      3.53
  24      376     AB   Left on          376                              Right      3.38
  25      148     BA   Continue on      148                              Right      2.52
  26      147     BA   Continue on      147                              Right      1.58
  27      130     BA   Left on          130                              Right      2.13
  28      140     BA   Right on         140                              Right      2.34
  29      141     AB   Right on         141                              Right      1.54
  30      143     AB   Continue on      143                              Right      4.32
  31      144     BA   Right on         144                              Right      2.49
  32      144     AB   U-turn on        144                              Right      2.49
  33      146     BA   Continue on      146                              Right      2.31
  34      145     AB   Right on         145                              Right      1.39
```

Figure2) the text files containing the route of each vehicle

➢ Create the routing matrix (matrix source / destination)

The routine creates the Routing Matrix containing the distance and travel time between each stop and deposit and, between each pair of stops. To create a routing matrix, one should choose the following: stops, deposits and the method used to measure distance and time. There is two different ways to calculate distances and travel times: using a network or by using straight-line connections between points. The grid method is more accurate and allows creating a routing system with the resulting routing, but requires more data

preparation. The routes created by the routing matrix, using the straight-line connections between points, cannot be viewed as a system of routes on a map.

➢ The problem of vehicle routing

Routine Vehicle routing routes of vehicles develops and produces reports and itineraries. This routine identifies routes that serve a set of charts from a set of sinks. To use the Vehicle Routing routine, it's required to: choose the set of depots where vehicles begin and end their trips, choose the set of charts to be served, the ability to identify vehicles in the file of vehicles (vehicle table) and identify the demand for each stop on the file stops (stop layer). Routine Vehicle Routing produces two or three output files: (1) A text file containing the route of each vehicle, (2) A table containing the list of stops on each route (this report is produced only if the routing matrix is defined by the grid method), and (3) A summary report file (this file is produced if the option is turned on File Report Procedure in Procedure Settings dialog box (3). Figure 2 shows the text file containing the route of each vehicle.

➢ Case study

The case study was conducted in the city of Marvdasht, located in the Fars province of Iran, Marvdasht is located 30 kilometers north of Shiraz, the capital of Fars Province (Figure 3). At the present time the population of Marvdasht city is approximately 124,350 inhabitants. In field assessment of Marvdasht city locating container and storing of solid waste and collection route are mostly empirical and is based on personal sense and far from engineering evaluation. In addition, in absence of source separation program and separate containers, all the city solid waste is collected and stored as a mixed waste. Average production of solid waste per capita of Marvdasht city is 689gr/day. At the present time, the collection and transportation frequency of solid waste follows even and odd pattern, and collection program is done 6:30 am to 2:30 pm. Cost of collection transportation and cleaning of Marvdasht city is $68000 per month (11). Current Routes of collection and their times for each route are present in figure 4.

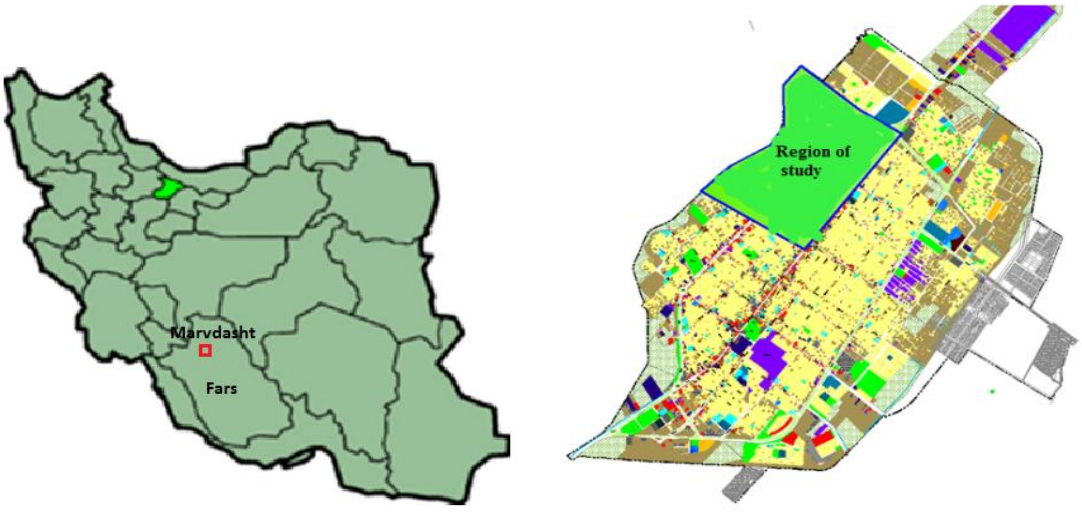

Figure3) Region of under study-Marvdasht city

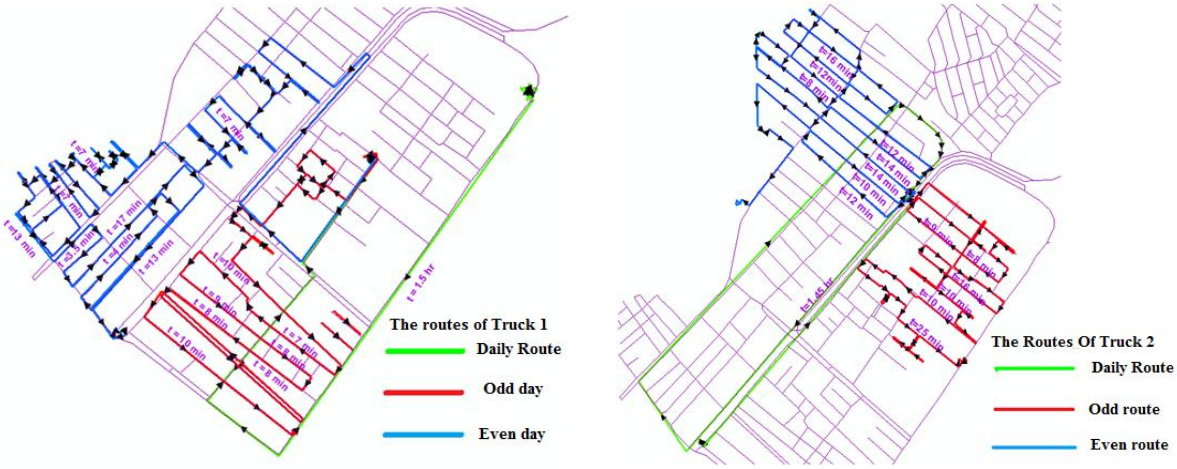

Figure4) Current Routes of collection and their times

The length and time of difference routes are present in table 1

Table1) Route characteristics at Marvdasht city

NO.	Truck Type	Length of collection(m)	Number Of U-Turn	Total Time (s)
1	Truck 1- Odd day	9031	5	**5129**
2	Truck 1- Even day	11945	15	**8434**
3	Truck 2- Odd day	9801	8	**6070**
4	Truck 2- Even day	11218	1	**5894**
Sum		41995	29	**25527**

Results

The results of Arc routing are illustrated on Figure 5. According to this figure, collection of Marvdasht's domestic waste starts from truck parking and then continues according to the vector pass the route. The optimized route characteristics are summarized in Table 2, according to which two trucks with a capacity of 5000 kg are required. Each route takes time about 440.2 min. Suggested routes by TransCAD software are compared to the current Routes which demonstrate that the length and time of travel is reduced. The length of travel of Truck 1 and 2 in even and odd days in optimized route is 18585 and 16721 meters, respectively. The suggested routes of TransCAD software for Truck 1 and 2 reduced 2391 and 4298 meters, respectively. The total time of travel for Truck 1 and 2 are reduced about 77 and 57 minutes, respectively. The number of U-turn is a major case in optimization of time of travel. The filed data demonstrated that each U-turn costs about 3 minutes for collection system. TransCAD software could reduce the number of U-turn from 29 to 11.

Table 2) Optimized Route characteristics at Marvdasht city

NO.	Truck Type	Length of collection (m)	Number Of U-Turn	Total Time (s)
1	Truck 1- Odd day	8546	2	**4237**
2	Truck 1- Even day	10039	4	**4761**
3	Truck 2- Odd day	7312	3	**3882**
4	Truck 2- Even day	9409	2	**4672**
Sum		35306	11	**17552**

Figure 5) The optimized routes by TransCAD software

Discussion

The application of GIS TransCAD presented by the results obtained, percentage reductions of up to 15.7% in the total distance traveled, and 29.43% in total travel time, compared to the current service. In the table 3 Optimized Route characteristics are presented. The applicability of a GIS should be analyzed not only by economics but also the environmental aspects that are related to solid waste. An efficient system of collection and transportation of solid waste should minimize any type of pollution including soil, air or water pollution. Moreover, an efficient system of collection and transportation of solid waste should help to improve the aesthetic appearance of the city, to make life more pleasant for its residents to avoid visual pollution. A system that achieves these goals with least possible cost is desirable, but the financial and technical resources of the authorities responsible for urban sanitation are often limited. The advantages of TransCAD for vehicle routing of domestic solid waste collection are: production of a routing solution in less time, using actual values of distance and travel time across the road network, and the possibility of change analysis of the variables such as fleet and period of operation or analysis constraints, such as vehicle capacity and traffic rules. The TransCAD could not consider unloading site as constrain analysis.

Table 3) Reduction percent in length and time of Routes at Marvdasht city suggested by TransCAd sofware

NO.	Truck Type	Reduction percent in length of routes (m)	Reduction percent in Total Time (s)
1	Truck 1- Odd day	5.4	17.39
2	Truck 1- Even day	15.96	43.55
3	Truck 2- Odd day	25.4	36.05
4	Truck 2- Even day	16.1	20.73
Sum		15.7	29.43

On the other hand, TransCAD application has deficiencies such as that the Arc Routing routine does not consider the place of unloading in the collecting vehicle routing.

Footnotes

Acknowledgments:

We would like to say our thanks to the Dr. Ayoub Karimi Jashni, assistant professor of Shiraz University, and personnel of "Marvdasht Municipality" for their cooperation.

Conflict of Interest:

The authors declare no conflict of interest.

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