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Routing An Urban Solid Waste Collection System Using Geographic Information System: Case Study in the City of Tiros, MG, Brazil

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Abstract: The objective of this work is the optimization of an urban solid waste collection system of a small city from the application of a geographic information system. The optimization in this case is done by the choice of the best possible route. Studies carried out in other municipalities have proved the efficiency of using the TransCAD software for this purpose. Therefore, aiming at a reduction of operational costs, this work presents a case study of the routing of a collection system and destination of all solid urban waste generated in the city of Tiros (MG). Field surveys have confirmed that the route of the collection system is performed empirically, making a total daily route of 40.8 km, within 8.1 hours. The TransCAD (SIG) computational program vehicle routing with time windows tool was used. From the routing, minimizing the distances, the total route was 34.9 km, which represents a saving of 13.3% in mileage. With routing minimizing the time of travel, if you can reduce it in 23 minutes it will represent a saving of 4.8%. Therefore, routing is a great tool to save expenses with waste collection and disposal fleets, and consequently, public spending and routing optimizing distance is the most effective.

Key words: geographic information system, optimization, urban solid waste

1. Introduction

The public administration nowadays has a low economic clout because of the big amount of expenses and a low income, moreover, some cities and Brazilian states have been passing through a state of public calamity due to debits accumulation. For small-sized cities, the budget is already very low and some essential services consume a big part of it. Therefore, it's necessary to find ways to reduce the public expenses and make it more efficient, what is crucial to improve the cities' financial condition.

According to the Technological Research Institute (IPT) and the Business Commitment to Recycling [1], between 7 and 15% of the municipal economic clout are spent with the cities' cleaning services and from this amount, 50% is spent in the collection and destination of solid waste produced in the urban area of the city. Thus, cutting costs in the application of solid waste collecting and destination sources must bring big savings for the government.

The costs of solid waste collecting and destination in a city can be reduced in several ways, like population awareness, collecting process streamlining, usage of low fuel consumption vehicles and routing the vehicles' fleet Routing the fleet entails bigger savings, since there's a reduced route, there's also a reduced fuel cost, reduced labor expense and reduced costs with vehicles' maintenance as well.

Authors have already proved that an optimization in the route of solid waste collecting and destination trucks can reduce significantly the costs of the process, since this route is usually done in an empiric way, based in the driver's experience or habit. Brasileiro

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and Lacerda (2008) [2] were able to reduce the distance driven by the collecting vehicles system in the city of Ilha Solteira (SP) in 41% while Lima, Lima e Silva (2012) [3] could make an average reduction of 20% of the driven mileage in the city of Itajubá (MG).

Throughout these experiences, the efficiency of the routing optimization was proved and the application of this routing became a very important tool for a cost-cutting program. Therefore, this project is justified by the necessity of public costs reduction, making the total cost of the solid waste collection and destination the lowest as possible.

The study object of this project is the city of Tiros, in the state of Minas Gerais.

2. Objectives

The general objective of this project is to optimize the waste collection vehicles route in a small-sized city using Geographic Information System. In this case, the optimization means choosing the route with the smallest distance or with the shortest time, in other words, the route with lowest costs.

The specific objectives were:

- Deploying the computer program (SIG) TransCAD to itinerate a waste management fleet in a small town.
- Itinerate the waste collection fleet in the city of Tiros, MG, optimizing the distance driven.
- Optimize the vehicles' route used to collect and give destination to the solid waste of a small town, covering the whole area in the shortest time.

3. Routing Using Geographic Information System

A SIG is a kind of information system that develops, in an interactive and systematic way, database, personal technology, being able to perform spatial analyses, store, manipulate, visualize and handle geo-referenced data to obtain new information, accordingly, Câmara (1994) [4] defines a SIG environment. A SIG environment has uncountable applications nowadays, however, because of its spatial analyses capacity, and very specific and positive application, it's included in the Space Decision Support System (SADE), as reported by Lima, Lima, e Silva (2012) [3].

Inside all this SIG environment there are several kinds of computer programs, among them a specific computer program to route vehicles, called TransCAD. This program is a specially projected SIG for transportation professionals, in order to store, visualize and analyze transportation data [5]. TransCAD convers logistic processes that can be applied to all the transportation methods and solve several logistic problems like creating routes, arc routing and network flow analysis and distribution, according to Caliper (2015) [5].

TransCAD has become a very important tool in the waste vehicles routing system, fact proved by authors like Brasileiro e Lacerda (2008) e Lima, Lima e Silva (2012). Vehicle routing is the definition of one or more routes driven by a fleet of vehicles, passing through places which must be visited, as said by Brasileiro (2004) [6]. Cunha (1994) [7] emphasizes that the routing passes through a term, and this term is associated to the computer networks. Therefore, this routing seems to be the best choice to solve certain problems, passing by all the intermediate spots, using computer tools.

In this work, a SIG environment, more specifically, the computer program TransCAD is used to solve a routing problem in the waste management vehicles' fleet of a small town. The solution for this problem is choosing the smallest route for the truck, since it would reduce this activity expenses, bringing lower costs for the government.

4. Methodologies

The city reported in this study is Tiros, MG, located the Alto Paranaiba region and has 6,019 inhabitants, according to the Brazilian Geographic and Statistic

Institute [8]. The city produces in a daily average, twelve tons of solid waste. The collection and destination of this waste is done by an outsourced company in the city. The collection is done in the whole city on Mondays, Wednesdays and Fridays. It's done by a compressor truck with approximately six tons capacity. Usually they do two daily commutes with the solid waste and cover around 40.8 km a day. The route is chosen by the truck driver according to his customs and it talks about 8.1 hours.

Knowing the data of the solid waste collection and destination system, the next step was to route the vehicles' fleet in order to optimize the system. The tool used in the routing was *vehicle routing with time windows*, in the TransCAD computer program, in its 4.5 version. This tool optimizes the route of one or more vehicles according to the shortest time needed to cover the area or the smallest distance to cover the area.

The first step in TransCAD was the insertion of the geo-referenced map of the city (Tiros, MG), using the UTM (Universal Transversa de Mercator) system and the spindle 23. After that, layers were created to identify the waste collection spots (spots layers), as well as the starting point (spot layer). Routes were also created (line layer), where the vehicle can go through. All the corners and the middle of the blocks were considered as collecting spot, so the collecting truck had to pass by all the corners and go at least to the middle of each block. This way, there are few places without visiting, but these places are a maximum 25 meters of the closest collecting spot, so there's no obstacle for the resident to put their garbage in the appropriate place.

After that, the collection system routing was done. The current system has only one truck, however, as two daily commutes are done and the program doesn't recognize that the same truck can make a second commute after the first one, in the data entrance two trucks were inserted.

The other considered data for the routing were:

- Garage: opening at 7:00 AM and closing at 5:00 PM
- Collecting spots: opening at 7:00 AM and closing at 5:00 PM
- Truck capacity: 6 tons
- Amount of daily solid waste: 12 tons (average)

The total mileage was considered by the sum of the distance from the city's exit to the urban solid waste destination place, involving a total of 4 times (because there are two trucks, and it's a round-trip route) and the sum of the distance driven by the two trucks.

After making the routing, considering the smallest distance driven, a time-based routing was also done. This routing aimed at visiting all the collection spots in the shortest time possible, considering the speed limit of each street. The considered speed was 40km/h in the main passage that crosses the city and 30km/h in the other passages. Besides that, in the school areas, the speed considered was 20 km/h maximum, to avoid any kind of accident. Fig. 1 shows the speed limit in each street for this study.

5. Results and Discussion

From TransCAD routing optimizing the distance, with the proper sum, the total distance approached driven by the truck was 34.9 km. The commuting is detailed in Fig. 2 and the visual representation of the routes is shown in Fig. 3. The green route in the Fig. 3

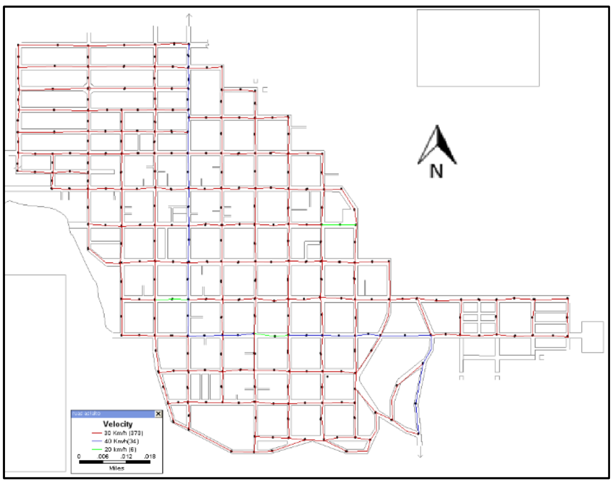

Fig. 1 Considered speed on each street in the city of Tiros, MG.

Itinerary Report

Route # : 1 Tot Time: 3:59 Capacity : 6000.0
Veh. Type: 1 Tot Dist: 9.8 Depart Load: 0.0

No.	Name	Arrival-Depart	Dist	Pickup
	1	7:00am		
1	302	7:00am- 7:02am	0.1	36.6
2	325	7:02am- 7:03am	0.0	36.6
3	294	7:03am- 7:04am	0.0	36.6
4	324	7:04am- 7:06am	0.0	36.6
5	246	7:06am- 7:08am	0.2	36.6
6	239	7:08am- 7:09am	0.0	36.6
7	247	7:09am- 7:10am	0.0	36.6
8	240	7:11am- 7:12am	0.0	36.6
9	236	7:12am- 7:13am	0.0	36.6
10	235	7:13am- 7:15am	0.0	36.6
11	233	7:15am- 7:16am	0.0	36.6
12	234	7:16am- 7:18am	0.0	36.6

Itinerary Report

Route # : 1 Tot Time: 3:59 Capacity : 6000.0
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11	233	7:15am- 7:16am	0.0	36.6
12	234	7:16am- 7:18am	0.0	36.6

Fig. 2 Trucks' commuting with the optimized route by the distance.

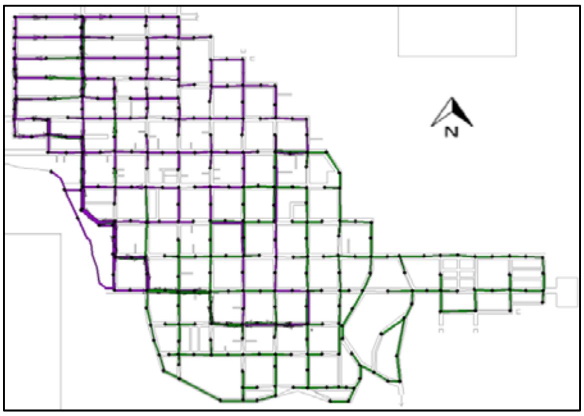

Fig. 3 Graphic representation of the trucks' route optimized by the distance.

represents the first truck's route and the purple route represents the second truck's route. In these tables, there are the Arrival-Depart representing the arriving and departure time, respectively. There are also Dist., which means the distance in a spot and pickup meaning the amount loaded to the truck in that spot.

Since the truck currently drives a total distance of 40.8 km and with the routing it would drive 34.9 kilometers, there's a saving of 14.5% with the optimization.

Using the program's routing to obtain the commuting shortest time, considering the speed limit on each street, the shortest time of 23 minutes was achieved. The commuting of the "two trucks" and the graphic representation of this route are detailed in Figs. 4 and 5.

Since the truck currently commutes in 8.1 hours, a 23-minute-reduction represents 4.8% of savings.

6. Conclusions

Throughout this work, the efficiency of the geographic information system application when routing of some vehicles became more evident, specially, in this case, the waste collection vehicle. With this optimization there's a lower consumption of public funds, what brings budget to invest in other areas.

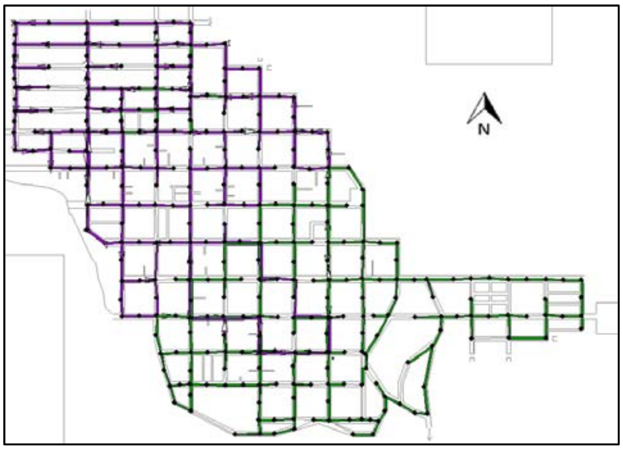

Fig. 4 Graphic representation of two trucks' route optimized by the shortest time.

Route # : 2 Tot Time: 3:48 Capacity : 6000.0
Veh. Type: 1 Tot Dist: 10.0 Depart Load: 0.0

No.	Name	Arrival-Depart	Dist	Pickup
	1	7:00am		
1	269	7:00am- 7:01am	0.0	36.6
2	65	7:01am- 7:03am	0.0	36.6
3	64	7:03am- 7:04am	0.0	36.6
4	81	7:04am- 7:06am	0.0	36.6
5	80	7:06am- 7:07am	0.0	36.6
6	79	7:07am- 7:08am	0.0	36.6
7	82	7:08am- 7:10am	0.0	36.6
8	83	7:10am- 7:11am	0.0	36.6
9	16	7:11am- 7:13am	0.0	36.6
10	17	7:13am- 7:14am	0.0	36.6
11	18	7:14am- 7:15am	0.0	36.6
12	15	7:15am- 7:17am	0.0	36.6
13	14	7:17am- 7:18am	0.0	36.6
14	13	7:18am- 7:20am	0.0	36.6

Route # : 2 Tot Time: 3:48 Capacity : 6000.0
Veh. Type: 1 Tot Dist: 10.0 Depart Load: 0.0

No.	Name	Arrival-Depart	Dist	Pickup
	1	7:00am		
1	269	7:00am- 7:01am	0.0	36.6
2	65	7:01am- 7:03am	0.0	36.6
3	64	7:03am- 7:04am	0.0	36.6
4	81	7:04am- 7:06am	0.0	36.6
5	80	7:06am- 7:07am	0.0	36.6
6	79	7:07am- 7:08am	0.0	36.6
7	82	7:08am- 7:10am	0.0	36.6
8	83	7:10am- 7:11am	0.0	36.6
9	16	7:11am- 7:13am	0.0	36.6
10	17	7:13am- 7:14am	0.0	36.6
11	18	7:14am- 7:15am	0.0	36.6
12	15	7:15am- 7:17am	0.0	36.6
13	14	7:17am- 7:18am	0.0	36.6
14	13	7:18am- 7:20am	0.0	36.6

Fig. 5 Trucks' commuting with the route optimized by the time.

Not only the routing using the smallest distance but also the one using the shortest time present efficient results to the optimization of the waste management vehicles in the city of Tiros, MG. The routing which reduced the distance driven was more efficient than the one that aimed to reduce the time spent since the saving in the distance was 14.5% while the saving in the time minimizing was 4.8%.

The optimization was shown as an important area to control public expenses, according to the savings it can afford.

Besides that, this work could show a SIG application for a small-sized city, which can be used in other places.

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