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Faculté de génie
Faculty of Engineering

Solid Waste Disposal (CVG 5133) Term paper

GIS based optimal collection routes of solid waste disposal

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Nov 2019

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Abstract:

Fast growth in the population caused generating municipal solid waste at accelerated rate. One of the most effortful operational tasks in solid waste management is collecting these wastes to meet the standards demanded by legislation, municipalities and urban population (Karadimas, Kolokathi, Defteraiou, & Loumos, 2007). Many research considered waste collection and its transportation as functional elements, which means that a huge amount solid waste management cost is invested on waste collection. This caused optimisation of collection routes has become a serious consideration in solid waste management. Although many efforts have been made, optimisation of collection routes in solid waste management has been a challenge for developing municipalities in terms of cost and environmental issues (Khan & Samadder, 2014). Geographical Information System (GIS) is a tool to overcome this challenge by designing and developing an efficient collection route. To define the most cost-efficient route various factors should be considered which lead to optimized routes. This paper reviews municipal solid waste route optimization from the fuel consumption aspect by the help of ArcGIS network analyst, which is an extension in ArcGIS software that can be applied as a decision-making tool to choose an optimal route. This can lessen the fuel consumption which leads to minimum collection cost of solid waste management and reduce the greenhouse gas emissions and their environmental impact during daily operation.

Keyword: Optimal collection routes, Solid waste disposal, ArcGIS, Network analyst, Geographical Information System, fuel consumption

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1. Introduction

Due to the urban population growth municipal solid waste management is considered as a challenging task for cities' authorities (Ghose, Dikshit, & Sharma, 2006). It has been defined that 70-80 percent of the solid waste management (SWM) system cost refers to collection part, so route optimization and transportation which include the use of great amount of fuel consuming trucks and machines is the principal component in the collection process (Deswal & Laura, 2014). The most commonly studied aspect of optimal transportation problems to design the optimized and cheapest distribution patterns for collecting solid waste disposal is route optimization (Hemidat, Oelgemöller, Nassour, & Nelles, 2017). To determine the efficiency of SWM, route optimization for collection of solid waste is proposed (Hemidat et al., 2017). To decrease the overall cost of solid waste management from transfer stations to disposal sites a GIS-based model for SWM can play a critical role in helping optimization the routes by improving the efficiency (Khan et al., 2014). A case study of Asansol district reported that by using GIS based route planning municipal solid waste collection and transportation costs can be lessen by 60% (Deswal et al., 2014). GIS techniques are used to optimize time and cost, disposition of waste collection and decreasing the haul distance to manage solid waste collection and transportation system efficiently (Hemidat et al., 2017). Users of GIS have access to classify, manage, use and study the geographical information organized by aim of graphic and alphanumeric data (Das & Bhattacharyya, 2015). GIS technology and municipal solid waste management are determined as the most promising approach to more efficient management of municipal solid waste systems and transport operation cost reduction (Deswal et al., 2014).

There are many elements that influence route optimization including population density, waste generation and composition, road networks, road length, collection vehicle speed, travel time, traffic direction, vehicle access, characteristics of waste containers and vehicles (Khan et al., 2014). The most significant related ones to the operational costs is personnel costs, fuel consumption and vehicle maintenance that may be achieved by using GIS technology (Zamorano et al., 2009).

Minimizing the fuel consumption is more influential rather than finding the shortest distances in optimization solid waste collection routes (Tavares, Zsigraiova, Semiao, & Carvalho, 2009). The reason is that fuel consumption is higher in some crowded and obstructed areas which the shortest distances are located there (Hemidat et al., 2017).

To analyze a vast load of spatial data in solid waste route optimization GIS is an appropriate aid to store, recover and explore data to lay out output visualization (Hemidat et al., 2017). Moreover, to simplify generating a 3D road network and determining segment-wise fuel consumption during the whole road, many three-dimensional (3D) modelling applications are used, one of which is ArcGIS 3D Analyst extension and ArcGIS Network Analyst extension which provide optimized Municipal solid waste collection in terms of minimum fuel consumption (Khan et al., 2014). Furthermore, to provide a practical network order which shows the rules and restrictions, limitations, fluctuating speed limits and other conditions ArcGIS Network Analyst has been used (Malakahmad, Bakri, Mokhtar, & Khalil, 2014). Thus, in calculating the optimal solid waste collection route from the aspect of decreasing overall fuel costs, ArcGIS Network Analyst plays a critical role.

2. Fuel consumption in waste collection

All human activities in the world today are a source for the generation of waste (Brunner & Rechberger, 2014). Back in the pre-historic age, waste management was not a problem because there was a large area of land relative to the small population that inhabited the planet (Amasuomo & Baird, 2016). Due to urbanization, industrialization and rapid increase in population, uncontrolled waste has instigated engineers and scientists into researching and developing better structured practices in waste management (Tavares et al., 2009).

The effective management of Municipal solid waste is tortuous as it involves proper sustainable solutions from the point of generation to its final disposal. Hence, an integrated solid waste management system is essential in the effective disposal of waste with the rapid increase in population in developing countries and the ineffective method in controlling those generated waste (Tavares, Zsigraiová, Semião, & Carvalho, 2008). In the integrated solid waste management system, collection and transportation of waste accounts for a huge amount of the total waste management budget as the cost of fuel is vital in the collection & transportation of waste and could account for over 60% of the waste management budget depending on the location (Dogan & Suleyman, 2003; Ghose et al., 2006).

With advancement in technology and urbanization, the movement of people from one place to another over short distances have been facilitated using automobile (Bale, Ugwu, Nwachukwu, 2016). This issue has affected standard of living by aiding rise of pollution from greenhouse gases (GHG) emission such as CO2 (Bale, Ugwu, Nwachukwu, 2016). Moreover, it increased travel costs from the aspect of congestion in transportation routes even on the routes that deemed to be the shortest (Bale, Ugwu, Nwachukwu, 2016).

Lexico defines a route as a way or path accessed in getting from one starting point to another destination. There are various paths is getting from one point to another, but the choice of a certain path is mainly dependent on time taken, costs and accessibility. Normally, in moving from one location to another with a time constraint, the use of the shortest route is always seen and selected as the most optimized route. Because, it saves time and cost but, this changes when such a route is subjected to certain factors and turns out to be the longest route that makes it the least optimal route at that point in time. Hence, the use of an optimized route factoring various factors is paramount when it involves collection and transportation of solid wastes (2019). Route optimization as defined by Verizon Connect (2019) is the process of ascertaining the most cost-efficient route. Various factors such as the number of stops and location are considered when determine the most efficient route as it is not limited to just the shortest path, but factors in the most cost-effective route. Optimizing route based on its cost-efficiency is of paramount importance as the primary objective of solid waste management is improving the quality of human lives by limiting the adverse impact of wastes to promote a sustainable environment in the most effective and cost-efficient way (LeBlanc, 2019).

Various optimisation models have been used over the years in municipal solid waste management. Technological innovations such as the use of routing software such as point-to-point routing has enabled solid waste collection operators in effectively optimizing routes to determine the most cost-efficient route in waste collection and transport (Rogoff & Ross, 2017). Authors like Baetz (1990) suggested a simulation model for suggesting optimal waste management practice. Cordeau (2002) made use of research program to invent tools for optimizing vehicle routes. It is evident that since integrated waste management is a high-cost activity the relevance of vehicle routing systems cannot be stressed in coherent decision making. Technologies such as the Geographic Information System (GIS) which is proficient in utilizing and handling geographic and spatial data can be employed in optimizing routes for solid waste management (Tavares et al., 2009). A GIS routing optimal model was proposed by Ghose et al., (2006) in the collection of solid waste putting in consideration the location of collection bins, road networks and types and vehicle load balance for efficient waste transport and fuel utilization.

In the article “Optimization of fuel consumption for municipal solid waste collection in Al Ain city, UAE”, Maraqa, Aldahab, Ghanma, & Kaabi (2018) made use of ArcGIS Network tool in determining an optimal route for the collection municipal solid waste with the main aim of minimizing fuel consumption. The ArcGIS Network tool which makes use of the Dijkstra’s Algorithm executes network-based spatial analysis, routing as it enables the modelling of realistic network conditions to consider speed constraints, traffic rules and turn policies (Karadimas, Doukas, Kolokathi, & Defteraiou, 2008).

In the article "Optimizing route choice for lowest fuel consumption - Potential effects of a new driver support tool" by Ericsson, Larsson, & Brundell (2006), a model was presented that optimized routs in determining the decrease in fuel consumption when compared to the shortest time or distance travelled. It has been observed that road slopes and terrain are relevant when optimizing routes as they greatly affect the performance of the engine which in turn influences the engine power demand resulting in variable fuel consumption and greenhouse gas emission (Tavares et al., 2008).

Emphasis has been put on shortest distance rather than minimization of fuel consumption as scenarios such as terrain relief, road slopes and weight of the vehicle have not been considered in the effective route optimization in the collection and transportation process of Integrated Solid Waste Management (Tavares et al., 2009). It is evident that the rate at which fuel is utilized is dependent on operating conditions of the vehicle and distance travelled (Tavares et al., 2009; Tavares et al., 2008).

Tavares et al., highlight the facts that in Integrated Solid Waste Management (ISWM), the collection vehicle is influenced by the gradient and length of the roads which affect fuel consumption due to the power utilization and conversion (2008). It's observed that when routes are optimized in terms of reduced fuel consumption relative to the shortest distance, there is a 52% decrease in fuel consumption (from 125, 471 to 60, 584 g/trip) when compared to a 34% increase in total distance travelled (104 to 140 km). Moreover, in terms of fuel consumption, routes can be optimized based on the average vehicle speed as an increase in average speed of 20 to 50 km/h can lead to a subsequent decrease in fuel consumption by 36% (18.5 to 11.8 kg) (Tavares et al., 2008).

Maraqa et al., developed a GIS model modified from GPS tracking of collection routes and container placements in the stipulated area. The routes were optimized using ArcGIS with relation to four different conditions to attain an efficient collection and transportation process in integrated solid waste management. The first and second case was based on route optimization in determining fuel consumption under certain context (enforcing traffic rules and not adhering to traffic rules respectively). The third focused on route optimization for relocated container placement while observing the 40-m service zone of the stipulated area and fourth focused on waste generation & land use while infringing the 40-m service zone. Maraqa's investigation supports Tavares' argument of optimizing routes with regards to minimal fuel consumption (2018).

Maraqa et al., observed that Case 1 and Case 2 recorded a 5% & 14.3% decrease in the fuel consumption respectively and a corresponding 6% and 14.1% decrease in travel time when compared to the current routing system. It was also observed that Case 2 and Case 3 also recorded a similar 6.5% & 8.1% decrease in the fuel consumption respectively and a corresponding 9.7% and 17.3% decrease in travel time when compared to the current routing system. Comparing Case 4 to Case 3 it is observed that Case 4 indicated a lofty advantage over Case 3 in terms of fuel utilization (2018).

It is apparent that when routes are optimized for shortest distance, certain conditions such as the road inclination are not put into consideration and this results in a higher utilization of the fuel used in the collection and transportation process of the ISWM, unlike when route optimization is executed specific to fuel utilization. Despite attaining an increase in travel distance and time when optimizing routes for minimal fuel consumption, the use of geographical information systems such as the ArcGIS in Integrated Solid Waste Management limits activities on inclined and congested roads while considering average speed and the load of the collection vehicle to ensure that less fuel is consumed so as to attain a cost-effective process (Maraqa et al., 2018).

Hence, the terrain relief, container placement and route optimization are relevant with the reduction of fuel consumption, but it must be noticed that the shortest distance or shortest time will not necessarily decrease the consumed fuel in rout optimization of Integrated Solid Waste Management (ISWM).

3. ArcGIS and Network Analyst

Municipal Solid Waste (MSW) collection and transportation activities contribute to a big portion of solid waste management activities' expenses (Tavares et al., 2008). In addition to labor costs, depending on fuel cost in each country and geological properties of the location, fuel consumption plays a pivotal role in determining total budget for Municipal

Solid Waste Management System (MSWMS) (Zsigraiova, Semiao, & Beijoco, 2013). Moreover, greenhouse gases, including CO2, emission is another parallel problem related to fuel consumption in Municipal Solid Waste collection's fleet. Therefore, optimizing collecting rout will lead to reduce the environmental effects of greenhouse gases as well (Tavares et al., 2009). Since municipalities have the major role in MSWMS activities, and in contrast with private companies, reducing the cost maybe as a result of fuel conservation is not the primary goal of the system. Inevitably, municipalities may be triggered to reduce the fuel consumption by considering the climate change effects of greenhouse gases (Tavares et al., 2009).

In addition to distance that each vehicle should be traveled, other features such as road inclination, vehicle load and speed can affect the fuel consumption in MSWMS, therefore, to overcome this issue, optimizing the vehicle routing will give a substantial view to decision makers (Zsigraiova et al., 2013).

Geographic Information System (GIS) is the best available software for analyzing broad spatial data and providing a reliable technology to display and interpret geographic and spatial data to optimize collecting route (Tavares et al., 2008).

According to ESRI's explanation, Network Analyst is one of the useful extensions of ArcGIS software for optimizing the routes. Providing a network-based spatial analysis, ArcGIS Network Analyst is a powerful extension to dynamically model routing according to accurate network conditions and traffic restrictions. The extension is useful for modeling efficient routing in a wide range of activities, including business deliveries, school bus routes, best routing network for emergency situation in metropolitans, transportation, as well as MSW collecting routes (ESRI, 2019).

An optimal collecting route will not essentially be the shortest travelled distance and it would be picked based on less fuel consuming route. Sometimes based on the slope of the streets and choosing a proper start and ending point, in spite of selecting a longer route, fuel consumption would be minimized (Tavares et al., 2009).

Minimizing the fuel consumption by the mean of ArcGIS could be implemented in three stages:

First, by using ArcGIS 3D Analyst extension a 3D road network should be created. The 3D model based on contours reveals the earth elevation as polylines. ArcGIS is one of the most powerful software technologies which has substantial advantages in modeling urban networks. Urban network in GIS visualize the points and their connecting lines including the road characteristics such as slope, traffic, driving direction and weight load restriction, etc. (Ericsson et al., 2006; Ghoseet al., 2006; Salhofer, Schneider, & Obersteiner, 2007; Tavares et al., 2009; Zsigraiova et al., 2013).

Second, fuel consumption for different situation of road network, travelled distance and real operating condition of vehicles should be calculated. To calculate mentioned effects, COPERT, a computer program which calculates emissions by road vehicles is used. The effect of vehicle load depending on different amount of MSW which is collected is considered in COPERT calculations. Obviously, the lower vehicle weight will lead to less load to the engine and consequently results in less fuel consumption. Road gradient is considered in the fuel consumption in different load and vehicle speed situations as well (Ericsson et al., 2006; Ghose et al., 2006; Salhofer et al., 2007; Tavares et al., 2009; Zsigraiova et al., 2013).

Finally, optimization of fuel consumption can be performed by applying ArcGIS Network Analyst (NA) extension. The extension would be able to create a network dataset (NDS) and carry out analysis on it and save it as a NDS which is contain sources' features in network attributes. Attributes for example are including fuel consumption for a specific street, time required to travel in a given distance of a road, speed limit and location of driving restricted street such as one-way ones. In addition to minimizing the travel distance or travel time, fuel consumption is one of the cost attributes of the network dataset, which can be optimized. Using Visual Basic for application (VBA) and ArcObject a distinct module will be developed for each stage and saved in a spatial database and facilitate input and output data combination. The Network Analyst (NA) extension module compute the minimum impedance between groups of collection points and the final destination. Route display commands is carry out to view the resulting rout (Ericsson et al., 2006; Ghose et al., 2006; Salhofer et al., 2007; Tavares et al., 2009; Zsigraiova et al., 2013).

4. Discussion

In this section the most remarkable results of the indicated resources are summarized as fallow:

Tavares et all., optimize municipal solid waste collection rout of Praia city and Santiago Island, Portugal, by developing a (GIS) 3D route modelling software (2009). In compare with simple shortest route, in Praia city and Santiago Island the 3D model reduced the fuel consumption 8% and 12% respectively. Also, they concluded in the cities with significant road slopes 3D modeling reveals more reliable results in compare with 2D modeling (Tavares et al., 2009).

Ghose et all., proposed a GIS based MSW routing optimization model for Asansol municipality, for collecting and transporting MSW to landfill (2006). They estimated fixed cost for storage bins, sanitary landfill and vehicles is around 80 million rupees, plus approximately 8.4 million rupees annually operating costs. While, the city at that time spent around 25 million rupees per year just for collecting MSW without any sanitary landfill. For a period of 15 years roughly, it will be around 50 percent reduce in the collection system, plus building a sanitary landfill on top of that (Ghose et al., 2006).

Karadimas et al., applied ArcGIS Network Analyst to model the best route for collecting Bulky item in municipal waste collection system, therefore 20 % optimization is achieved during their model (2007). The need for developing a model for MSW collecting route in the municipality of Athens is one important result of their work (Karadimas et al., 2007).

Desai, Shah, & Zaveri conducted a modeling by using ArcGIS Network Analyst to optimize the MSW collecting route for municipality of Nagpur and the model takes less time compare the existing route, in addition , the cost is reduced up to 14 % per month (2018).

5. Conclusion

In this paper municipal solid waste route optimization with the help of ArcGIS network analyst has been reviewed. Proposed resources shows that:

- Optimization of collection rout in solid waste management can be done from different aspects, one of which is fuel consumption.
- Operating conditions of the vehicle, distance, road slopes and terrain influence the vehicle performance which leads to variable fuel consumption in route optimization. So, fuel consumption for different situation of road network, travelled distance and real operating condition of vehicles should be calculated.
- ArcGIS provides urban network model which can visualize the points and their connecting lines including the road characteristics such as slope, traffic, driving direction and weight load restriction, etc.
- ArcGIS Network analyst is a powerful extension in ArcGIS software that provides spatial analysis. It enables the model to consider speed constraints, traffic restrictions, turn policies and network conditions.
- ArcGIS Network Analyst can create a network dataset (NDS) which includes attributes to analyse fuel consumption for a specific street, time required to travel in a given distance of a road, speed limit and location of driving restricted street, etc.

However, what is mentioned in this literature review might not be overgeneralized to all contexts, developing an ArcGIS network analyst, which take road and vehicle specifications and limits in to account, is required to deal with the existing system of MSW collection system. Nevertheless, there are too many examples of successful models, some of which are mentioned above. Modeling with ArcGIS network analyst provide a supporting tool for decision makers to reduce the fuel consumption, and consequently reduce the greenhouse gases emission and their environmental impact during daily operation. While sometimes based on models it is required to travel longer distance, fuel consumption is decreased substantially which is a proof to rely on driven models and take them into account.

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