Expert Systems with Applications 41 (2014) 8062–8074

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Optimizing Municipal Solid Waste collection using Chaotic Particle Swarm Optimization in GIS based environments: A case study at Danang city, Vietnam

Le Hoang Son *

VNU University of Science, Vietnam National University, Viet Nam

ARTICLE INFO

Article history:
Available online 19 July 2014

Keywords:
ArcGIS
Chaotic Particle Swarm Optimization
Vehicle routing model
Heuristic algorithms
Municipal Solid Waste collection

ABSTRACT

Municipal Solid Waste (MSW) is an increasing concern at any municipality in the world, and is one of the primary factors that contribute greatly to the rising of climate change and global warming. MSW collection and disposal especially in the context of developing countries are indeed the urgent requirements for the sustainable development of environment and landscape, which rule over the quality-of-life and life expectancy of human being. In this paper, we concentrate on MSW collection at Danang city, which is one of four largest municipalities in Vietnam having high quantity of the average waste load per person and is bearing negative impacts of climate change such as severe weather conditions and natural disasters as a result. A novel vehicle routing model for the MSW collection problem at Danang city is presented. A novel hybrid method between Chaotic Particle Swarm Optimization and ArcGIS is proposed to generate optimal solutions from the vehicle routing model of Danang. Experimental results on the real dataset of Danang show that the proposed hybrid method obtains better total collected waste quantity than the relevant ones including the manual MSW collection procedure that is currently applied at this city.

1. Introduction

Municipal Solid Waste (MSW) is an increasing concern at any municipality in the world. Reports from some articles in Consonnia, Giuglianob, and Grosso (2005), Weitza et al. (2002) pointed out that MSW is one of the primary factors that contribute greatly to the rising of climate change and global warming. The bad side effects of MSW are not only limited to environmental pollution and hygiene but also indirectly affected to traffic jam, financial budget and quality-of-life. Nowadays, most of developing countries in the world are currently in the progress of urbanization and industrialization, resulting in the augmentation of various types of wastes that leave a burden to both the municipality's infrastructure and the community. MSW collection and disposal especially in the context of developing countries are indeed the urgent requirements for the sustainable development of environment and landscape, which rule over the quality-of-life and life expectancy of human being. Additionally, optimizing MSW collection in those countries brings much meaning in terms of environmental, landscape developments and economic savings. In the extent of this research, **our focus** is the *MSW collection problem at Danang city*, which is one of largest industrial zones of Vietnam. According to Harmeling (2009), Vietnam is one of 11 countries in the world that suffered greatest damage from climate change and sea-level rise. As a consequence, Danang has to cope with negative impacts of climate change such as severe weather conditions and natural disasters. Optimizing MSW collection at Danang both minimizes the vulnerability caused by climate change and ensures the sustainable ecological environments. Monre (2010) stated that Danang is one of four largest municipalities in Vietnam, having high quantity of the average waste load per person, approximately 0.84–0.96 kg/person/day, which is higher than that of Southeast Asia with the number being 0.85 kg/person/day. A summary from Danang Bureau of Statistics (2011) showed that the quantity of solid waste increases much larger than the number of households in the duration of years from 1995 to 2010. 91% of the solid waste quantity at Danang in that period came from the households whilst 7% and 2% were reserved for markets and hotels & restaurants, respectively. The total waste quantity per day at Danang is around 661.6 tons, and it tends to increase dramatically by years and can attain 550 thousands tons till 2020. Current manual MSW collection scenario at Danang involving the uses of

* Address: 334 Nguyen Trai, Thanh Xuan, Hanoi, Viet Nam. Tel.: +84 904171284; fax: +84 0438623938.
E-mail addresses: sonlh@vnu.edu.vn, chinhson2002@gmail.com

http://dx.doi.org/10.1016/j.eswa.2014.07.020
0957-4174/

some semi-automated vehicles such as the tricycles, the forklifts and the hook-lifts could not guarantee the operation if such huge waste quantities are present. Those facts raise the need of an effective optimization method for the MSW collection problem at Danang city. This is **our objective** in this paper. The MSW collection optimization problem can be described by a *vehicle routing* (VR) model including some basic components such as the vehicles, nodes and their relations in order to ensure pre-defined goals. Several VR models for different places and scenarios were presented in the literature. For example, Apaydin and Gonullu (2008) presented a VR model for Trabzon city, Turkey taking into account the exhaust emission of vehicles to minimize the environmental emission. Tavares, Zsigraiova, Semiao, and Carvalho (2009) integrated some factors such as the driving situations, vehicle load and road gradient to the VR models of the city of Praia, the capital of Cape Verde, and Santiago Island. Fan, Zhu, Zhang, He, and Rovetta (2010) proposed a VR model for Pudong city, China considering energy utilization with the supports of incineration in transfer stations. Shoba and Rasappan (2013) integrated the degree of industrialization and climate to waste generation rates for the VR model of Coimbatore town, India. Other examples of designing VR models could be referenced in Apaydin and Gonullu (2011), Arebey, Hannan, Basri, and Begum (2012), Arebey, Hannan, and Basri (2013), Aranda Usón, Ferreira, Zambrana Vásquez, Zabalza Bribián, and Llera Sastresa (2013), Faccio, Persona, and Zanin (2011), Gharaibeh, Haimour, and Akash (2011), Huang et al. (2001), Huang, Pan, and Kao (2011), Kanchanabhan, Mohaideen, Srinivasan, and Sundaram (2011), Nithya, Velumani, and Senthil Kumar (2012), Tai, Zhang, Che, and Feng (2011), Zhang, Huang, and He (2011). Nevertheless, the VR model for Danang city was not available in the literature, and we cannot utilize other models for the case study at Danang since each studied site has own MSW collection scenario. Thus, **our first contribution** in this paper is the design of a novel VR model for the MSW collection problem at Danang city. Once the VR model for Danang is constructed, the next step is to seek out an effective optimization method to find optima solutions of this model. There are several groups of methods proposed in the literature for the MSW collection problem. The first group so-called *Graph–Heuristic* (Kytojoki, 2007; Maniezzo, 2004; Tung & Pinnoi, 2000) represented a map as a graph where each node is an important site, e.g. depot, landfill and gather sites and each arc is a connected line between two neighbored nodes. Using greedy algorithms such as the well-known Solomon's I1 insertion heuristic, an initial solution is quickly found and improved in some next steps by the local search procedures, namely Or-opt and 2-opt*. The disadvantage of this group is the quality of the final solution since it depends on results of the greedy algorithm. Since all variables in a VR model are non-negative integers, the second group namely *Integer Programming* (Huang & et al., 2001; Maqsood & Huang, 2003; Wang, 2001) uses the chance-constrained programming and (fuzzy) linear integer programming such as Cutting Planes, Ellipsoid algorithm and Conic sampling to determine optimal solutions from a VR model. The activities of this group are often complicated and require large computational time when the graph is complex and the number of nodes is very large. The third group so-called *GIS-Functions* employs available routing algorithms such as Dijkstra in GIS softwares for the searching of optimal solutions. Some examples could be listed, to name but a few: Chalkias and Lasaridi (2009), Huong, Tuyet, Nga, and Huong (2012), Karadimas et al. (2007a) used ArcGIS Network Analyst (ESRI, 2009) to identify the best route for the municipal waste collection of large items; Badran and El-Haggar (2006) investigated Municipal Solid Waste management in Port Said, Egypt through MPL software V4.2 (Rosen, 2005); Apaydin and Gonullu (2008) relied on MapInfo (Daniel, Loree, & Whitener, 2002) to find optimized routes in Trabzon city, Turkey. Nevertheless, the quality of solutions achieved by this group is not high since the built-in routing algorithms in GIS softwares are either simple or obsolete. The last group of this topic namely *evolutionary algorithms* (EA) uses some sorts of Ant Colony Optimization (ACO) Ismail & Loh, 2009; Karadimas, Papatzelou, & Loumos, 2007b, Particle Swarm Optimization (PSO), Genetic Algorithm (GA) Fan et al., 2010 and Fuzzy Clustering (Son, 2014a, 2014b; Son, Cuong, Lanzi, & Thong, 2012; Son, Cuong, & Long, 2013; Son, Lanzi, Cuong, & Hung, 2012; Son, Linh, & Long, 2014) to determine approximate solutions in polynomial time instead of exact solutions which would be at intolerably high cost. Mimicking the evolution natural process such as selection, mutation, cross and inheritance, the quality of final solutions and the computational time are somehow better than those of other groups. The only limitation is that the outcomes are not accompanied by a GIS-based interface so that viewers could not validate whether or not the optimal paths are valid according to the structure of streets on a map. For example, an optimal route founded by GA may not be opted since it travels through many construction places or playgrounds that are likely to cause the traffic jam and unsafe situations for drivers. Another example is routes crossing over historical places should not be selected. Besides these four groups, there are still some standalone/hybrid EA algorithms such as the heuristic-based algorithm (Ai & Kachitvichyanukul, 2009), the tabu search-based algorithm (Brandão, 2011), the hybrid discrete PSO (Chen, Yang, & Wu, 2006), the hybrid GA-PSO (Marinakis & Marinaki, 2010), the hybrid PSO and multi-phases neighborhood search (Marinakis, Marinaki, & Dounias, 2010), the hybrid electromagnetism-like algorithm (Yurtkuran & Emel, 2010) and other ones (Banos, Ortega, Gil, Fernandez, & De Toro, 2013; Kuo & Wang, 2012; Tarantilis, Stavropoulou, & Repoussis, 2012; Yu, Yang, & Yao, 2011; Yücenur & Demirel, 2011; Zachariadis & Kiranoudis, 2011; Zarandi, Hemmati, & Davari, 2011). Nevertheless, those algorithms are designed for the general VR models or other applications but not for the MSW collection problem, which requires special components, architectures and operations so that they could not be applied herein. Based upon the advantages of the third and fourth group, **our idea for the new optimization method** is integrating evolutionary algorithms with GIS softwares. In the other words, the built-in routing algorithms in GIS softwares are replaced with an EA algorithm so that the limitations of those groups could be handled. More specifically, a modification of *Chaotic Particle Swarm Optimization* (CPSO) Gholipour et al., 2012 incorporation with the binary gravitational search algorithm (Rashedi, Nezamabadi-Pour, & Saryazdi, 2010) is presented and integrated to the ArcGIS software (ESRI, 2009). The hybrid approach is used to generate optimal solutions from the VR model of Danang. This is our **second contribution** in this paper. The *advantages and the novelty* of the hybrid method between CPSO and ArcGIS (a.k.a. CPSO-ArcGIS) in specific and our whole contributions including the VR model for Danang and the hybrid method in general are expressed as follows. *Firstly*, the hybrid method utilizes the advantages of both an EA algorithm and GIS software presented in the survey above into the activities of the new algorithm. This means that an optimal solution derived by the CPSO algorithm is modified according to the status quo in a map expressed by GIS software; thus giving a better, more optimal and adaptable solution than those of the built-in GIS functions in GIS software of the third group and the single EA algorithm of the fourth group. *Secondly*, the hybrid method employs CPSO incorporation with the binary gravitational search algorithm (Rashedi et al., 2010), which have never been used for the MSW collection problem in the literature, to produce the list of optimal solutions. As being mentioned above, CPSO relying on the basis of Chaos theory (Ott, 2002) is a strong EA tool and is capable to overcome some limitations of current variants of PSO (Gholipour et al., 2012). Therefore,