Dynamic Waste Collection Strategy to Optimize Routes Using Open-Source Tool*

Adriano S. Silva[1,2,3,4], Thadeu Brito[1], Jose L. Diaz de Tuesta[2], José Lima[1], Ana I. Pereira[1], Adrián M. T. Silva[3,4], and Helder T. Gomes[2]

[1] Research Centre in Digitalization and Intelligent Robotics (CeDRI), Instituto Politécnico de Bragança, 5300-253 Bragança, Portugal

[2] Centro de Investigação de Montanha (CIMO). Instituto Politécnico de Bragança, 5300-253 Bragança, Portugal

[3] Laboratory of Separation and Reaction Engineering – Laboratory of Catalysis and Materials (LSRE-LCM), Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

[4] Associate Laboratory in Chemical Engineering (ALiCE), Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

{adriano.santossilva,brito,jl.diazdetuesta,apereira,htgomes}@ipb.pt, adrian@fe.up.pt

Abstract

Cities throughout the world occupy around 3% of land area, but they are responsible for 60-80% of greenhouse emissions [3]. The current scenario is about to become worse if more solutions were not implemented to improve overall sustainability in cities. According to the statistics, most of the global population will be living in cities by 2050 (*ca.* 70%). One of the most complex systems in cities that often doesn't receive much resources and attention is the Municipal Solid Waste Management System (MSWMS). The world generates about 2.01 billion tonnes of municipal solid waste annually, and in most cases the waste is collected in a traditional way, in which drivers decide the path to be followed. This approach can lead to inefficient spending of fuel and time, nonetheless problems with overfilled dumpsters or even visits to empty ones [1].

Most studies approaching waste collection problems begins considering the Vehicle Routing Problem (VRP) initial formulation, adding more constraints to the problem as an attempt to reaching higher similarity with real problems of waste collection. From this attempt, formulations as Capacicated Vehicle Routing Problem (CVRP), Vehicle Routing Problem with Time Windows (VRPTW), and Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) arouses. Most recently, authors dealing with this problematic are using another name for the problem: Waste Collection Problem (WCP). There is no significant difference between WCP and VRP, only that the first one was created to specifically address problems of waste collection routes [2].

The waste collection problem is ruled by the objective of finding the best route to visit a set of locations using multiple vehicles. Even for computers, the utilization of exact methods to solve the problem can be impracticable due to the high running times

* This work has been supported by FCT - Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/05757/2020, UIDB/00690/2020, UIDB/50 020/2020, and UIDB/00319/2020. Adriano Silva was supported by FCT-MIT Portugal PhD grant SFRH/BD/151346/2021, and Thadeu Brito was supported by FCT PhD grant SFRH/BD/08598/2020. Jose L. Diaz de Tuesta acknowledges the financial support through the program of Atraccion de Talento of Atraccion al Talento of the Comunidad de Madrid (Spain) for the individual research grant 2020-T2/AMB-19836.

(computation time). On the other hand, metaheuristic algorithms can find acceptable solutions with low execution times, and thus, become the most practical choice. Algorithms in this class can be classified as population-based (*i.e.*, genetic algorithms and ant colony optimization) and trajectory-based (tabu search and simulated annealing). Recently, Google OR-Tools has shown the potential application to solve different variants of VRP problems through different solvers. In this tool, some search algorithms are available as an option to solve VRP variants, such as Simulated Annealing (SA), Tabu Search (TS), and Guided Local Search (GLS).

Increasing efforts focused on this research field contribute to developing innovative strategies with highly efficient solutions. Despite the clear development observed with the strategy to optimize waste collection system, most works are focused on big cities, and no models are built considering small towns. Furthermore, there is no mention of an upper limit of waste used by the algorithms to decide if a dumpster should be collected or not. The scenario shows opportunities to optimize waste collection systems in small cities (commonly disregarded for ICT implementation). The sustainable impact of implementing a smart waste management system in small towns can be lower than in big cities, but it still represents a remarkable improvement for interior societies. The implementation cost of smart devices, such as IoT boards equipped with level or weight measurements, is the hardest step in research that will deal with MSWMS in small cities. Moreover, this process could be expensive, consequently, not interesting for the companies. However, this threat can be faced as a challenge for researchers to develop solutions considering both cost and efficiency.

Thus, in this work, 10 waste paper dumpsters in the city of Bragança were chosen to study the influence of waste level in finding the best route for waste collection using the GLS algorithm. The problem was formulated as a CVRP, in which truck capacities are the constraint that determines when trucks should go to the central depot to empty the load. Furthermore, the optimization was evaluated upon three different strategies of dumpster selection for collection: the first considering only levels (regular approach), the second taking into account the level after 2 days (dynamic approach), and the traditional one, in which trucks collect the waste once each 2 days. Paper waste dumpsters were chosen in this study because paper waste has the highest generation, according to data provided by the company in charge of MSW management. The simulation was performed considering waste changes during 30 days, in which 3 trucks were responsible for waste collection. Waste changes through days were determined upon analysis of 150 m around each dumpster in a static approach (waste change daily is the same on different days for the same dumpster). In this regard, if a dumpster has a high concentration of populated area, the nearby daily waste oscillation will be higher. Two strategies for dumpster selection (regular and dynamic) for collection take into account the upper threshold of waste, which was considered as 70%, 80%, and 90% in this work.

The optimization algorithm returned daily distances traveled and load carried in each selection strategy for different levels, and the parameter Collection Efficiency (CE) was considered for comparison purposes. This parameter is the division of total load carried by the total distance traveled, and he was noted necessary due to the misleading conclusions that could be reached by separate analysis of distances and loads. CE values were all higher considering 90% as maximum level in regular and dynamic strategy. For instance, traditional collection, regular, and dynamic approach were 0.0357, 0.0319, and 0.0537 m^3/km. The CE values shows that considering only levels for selection of dumpsters for collection is not enough since the best result in this approach did not overcome traditional collection result. On the other hand, considering waste level after 2 days to select dumpsters for collection resulted in a increase of about 50.42% in efficiency compared to traditional result. Analyzing daily distances and load carried revealed some key insights on why dynamic approach had better performance. The average load collected per collection day is 43.49% higher, and 47% less trips were done.

The results obtained in this work demonstrates the power of strategies for the proper selection of dumpsters to be collected. For future works, more sophisticated algorithms will be used for waste level forecast, using more realistic data of waste generation to create accurate models (*i.e.*, artificial neural network). Furthermore, the main goal is the assembly of a wireless sensor network to collect waste level in real-time, which can lead to a higher efficiency in decision-making regarding collection routes.

Keywords: Google OR-tools · Waste Collection Problem · Guided Local Search

References

1. Esmaelian, B., Wang, B., Lewis, K., Duarte, F., Ratti, C., & Behald, S. (2018). The future of waste management in smart and sustainable cities: A review and concept paper. Waste Management, 81, 177-195. doi: 10.1016/j.wasman.2018.09.047
2. Elshaer, R., Awad, H.A taxonomic review of metaheuristic algorithms for solving the vehicle routing problem and its variants. (2020). Computers & Industrial Engineering, 140, 106242. doi: 10.1016/j.cie.2019.106242.
3. O'Dwyer, E., Pan, I., Acha, S., & Shah, N. (2019). Smart energy systems for sustainable smart cities: Current developments, trends and future directions. Applied energy, 237, 581-597.