Time-dependent Capacitated Solid Waste Collection Vehicle Routing Problem with Time Windows

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1 Abstract

Solid waste collection is one of the most important axes of solid waste management because it affects social, environmental, and economic issues. Current literature frequently studies

economic and environmental dimensions such as costs, route length, environmental impact, total collection time, required vehicles, and the number of working teams using different solution methods. Yet, the real-life constraints are rarely studied and introduced. In this paper, to guarantee the reliability of the solid waste collection process under time-dependent travel times, we propose a generalized time-dependent capacitated vehicle routing model, including multiple transfer stations, gather sites, and non homogeneous vehicles with time windows for municipal solid waste collection, that aims to minimize the economic and environmental costs of the solid waste collection process, taking instances of the problem generated from real traffic data into consideration. A case study of Sfax, Tunisia, is given to illustrate the applicability of this model. Furthermore, this model could be applied to scenarios with similar vehicle aspects and node structures.

Keywords: Municipal solid waste collection, Capacitated vehicle routing problem, Time windows, Time-dependent.

3 Introduction

Improving solid waste management strategies is critical for municipalities. Identifying the best collection route would not only allow municipalities to provide more effective services to their people, but it would also help reduce significant costs. Furthermore, it would reduce transportation congestion, gasoline usage, carbon emissions, and environmental pollution [1]. The waste collection routing problem refers to the challenge of finding a route that serves all customers with the lowest total traveling distance or time, using the least number of vehicles, under some constraints like vehicle capacity. Optimization algorithms and GIS-based approaches are commonly used to find the most efficient waste collection routes. These methods consider factors such as the location of waste facilities, road networks, traffic patterns, and the volume of waste generated in different areas to create optimized collection routes. [2]. [3] The most frequent formulations used in waste collection problems are capacity and time window constraints. The Capacitated Vehicle Routing Problem (CVRP) was developed by [4] as an extension of the vehicle routing problem (VRP) that considers vehicle capacity constraints. The CVRP aims to deliver (or pick up) goods to customers with specific demands while taking the shortest possible route. An essential feature of this approach is that routes start and end at a central depot, and the vehicle's capacity is considered to decide whether a vehicle will continue collecting items or return to the central depot to unload the collected load. The Vehicle Routing Problem with Time Windows (VRPTW) is another common formulation for waste collection processes that assigns a specific time interval during which a customer must be visited. To more closely resemble real-world waste collection problems, some researchers include both capacity and time window constraints, leading to the development of the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) [5]. Another extension to waste collection routing problems, is the Time-Dependent Capacitated Vehicle Routing Problem with Time Windows (TDCVRPTW), which consider travel times or costs that depend on the time at which the

vehicle is moving. This feature is particularly helpful for modeling a vehicle route subject to traffic conditions. [6] proposed a waste collection routing problem that considers real-world time constraints and variable traveling speeds caused by time-dependent traffic conditions. In this problem, time windows are also considered, which means that nodes can only be visited within a certain period defined by opening and closing hours. Another variant, introduced by [7], includes lunch breaks and rest periods for drivers.

In this paper we propose a mathematical modeling and heuristic to solve (TDCVRPTW) problem and apply them to a real life problem

4 Literature Review: An overview of Time-dependent VRP and VRP with time windows

In their research, [7] focused on a VRPTW for waste collection that considered the lunch and rest periods for drivers. The objective of their study was to minimize the total trip time and the number of vehicles required. [8] state that deterministic algorithms, such as those proposed by [9] and have been utilized to solve VRPTW. However, because of the NP-Hard problems, applying these deterministic algorithms to solve large-scale VRPTW problems can be very time-consuming. Thus, recently, researchers have shown great interest in developing heuristic and meta-heuristic algorithms to solve VRPTW problems. These techniques have been widely studied as potential solutions to this problem such as, Taboo Search (TS) [10], Particle Swarm Optimization (PSO) [11] Ant Colony Optimization (ACO) [12], and Genetic Algorithm (GA) [13]. The condition of the road network in urban areas has time-varying characteristics, affecting the speed at which vehicles can travel. Therefore, researchers have investigated the time-dependent vehicle routing problem (TDVRP) from various angles. The first reference to a time-dependent travel time model is credited to [14], who adapted the savings algorithm to incorporate two different periods of the planning horizon, each with distinct travel time values. [15] proposed a mathematical model to estimate solutions for time-dependent routing problems by constructing a hierarchical traffic network based on the frequency of road usage. [16] developed a bi-objective model for the time-dependent vehicle routing problem (TDVRP) that aimed to minimize both route cost and fuel consumption. They solved the model using particle swarm optimization with a greedy mutation operator and a time-varying acceleration coefficient. [17] developed a TDVRP planning model that aimed to minimize carbon emissions and maximize customer satisfaction. To solve the problem, they designed an improved version of the non-dominated sorting genetic algorithm. [18] introduced a novel variant of the time-dependent vehicle routing problem (TDVRP) with time windows, which considers that the paths between any two customers may differ at different times of the day due to varying traffic conditions. They developed a tabu

search algorithm to solve the problem. According to existing literature, time dependent vehicle routing problem TDVRPTW refers to a procedure used to determine the most efficient route for a vehicle, which aims to minimize the total travel time. This involves starting from the depot, servicing each customer until all have been attended to, and then returning to the depot. In the process, factors such as the speed of the vehicle, the distance between points, the vehicle's capacity, and the time frames for each customer are all considered. According to existing literature, time dependent VRPTW refers to a procedure used to determine the most efficient route for a vehicle, which aims to minimize the total travel time. This involves starting from the depot, servicing each customer until all have been attended to, and then returning to the depot. In the process, factors such as the speed of the vehicle, the distance between points, the vehicle's capacity, and the time frames for each customer are all considered. The TD-VRPTW has been applied to various fields, such as the distribution industry [19], courier services[20], and transportation [21]. The importance of vehicle travel speed in waste collection applications, was first highlighted by [6]. Their study aimed to enhance the TD-VRPTW in waste collection applications by taking into consideration changes in the vehicle's load (weight of collected waste) and speed during waste collection from customers.

5 Paper’s contribution

The aim of this study is to find an optimal routing plan for the efficient collection of solid waste by considering time windows and time-dependence constraints. Therefore, we propose a mathematical model and heuristic to solve this problem and apply them to a real-life problem, with comparison with existing work in the literature. Computational results will be reported.

6 Conclusion

In this paper, we considered a capacitated vehicle routing problem for MSW collection with time windows while considering real-world constraints. Computational results will be reported.

References

[1] H. S. Akdas, O. Demir, B. Dogan, A. Bas, and B. C. Uslu (2021): "Vehicle Route Optimization for Solid Waste Management: A Case Study of Maltepe, Istanbul". In: *13th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*, Pitesti, Romania, pp. 1–6.

[2] A. Sulemana, E. A. Donkor, E. K. Forkuo, and S. Oduro-Kwarteng (2018): "Optimal Routing of Solid Waste Collection Trucks: A Review of Methods". In: *Journal of Engineering*, pp. 1–12.

[3] C. A. Arribas, C. A. Blazquez, and A. Lamas (2009): "Urban solid waste collection system using mathematical modelling and tools of geographic information systems". In: *Waste Management & Research.* vol. 28, no. 4, pp. 355–363.

[4] G. Dantzig and J. Ramser (1959): "The Truck Dispatching Problem". In: *Management Science,* Vol. 6, No. 1, pp:80-91.

[5] A. S. Silva, F. Alves, J. L. D De Tuesta, A. M. Rocha, A. I. Pereira, A. M. Silva, H. T. Gomes (2023): "Capacitated Waste Collection Problem Solution Using an Open-Source Tool" In: *Computers*, vol. 12, no. 1, p. 15.

[6] N. A. Mat, A. M. Benjamin, and S. Abdul-Rahman (2018): "Enhanced heuristic algorithms with a vehicle travel speed model for time-dependent vehicle routing: A waste collection problem" In: *Journal of Information and Communication Technology*, vol. 17, no. 1.

[7] B.-I. Kim, S. Kim, and S. Sahoo, "Waste collection vehicle routing problem with time windows," *Comput. Oper. Res.*, vol. 33, no. 12, pp. 3624–3642, Dec. 2006, doi: 10.1016/j.cor.2005.02.045.

[8] Q. Wu, X. Xia, H. Song, X. Xu, Y. Zhang, F. Yu, H.Wu. (2023): "A neighborhood comprehensive learning particle swarm optimization for the vehicle routing problem with time windows" In: *SSRN 4316940*.

[9] R. Baldacci, A. Mingozzi, and R. Roberti (2012): "Recent exact algorithms for solving the vehicle routing problem under capacity and time window constraints" In: *European Journal of Operational Research*, vol. 218, no. 1, pp. 1–6

[10] S. C. Ho and D. Haugland (2004): "A tabu search heuristic for the vehicle routing problem with time windows and split deliveries". In: *Comput. Oper. Res.*, vol. 31, no. 12, pp. 1947–1964, Oct. 2004, doi: 10.1016/S0305-0548(03)00155-2.

[11] Y.-J. Gong, J. Zhang, O. Liu, R.-Z. Huang, H. S.-H. Chung, and Y.-H. Shi (2012): "Optimizing the Vehicle Routing Problem with Time Windows: A Discrete Particle Swarm Optimization Approach". In: *IEEE Transactions on Systems Man and Cybernetics Part C (Applications and Reviews)* vol. 42, no. 2, pp. 254–267..

[12] C. G. Gómez S., L. Cruz-Reyes, J. J. González B., H. J. Fraire H., R. A. Pazos R., and J. J. Martínez P.(2013): "Ant colony system with characterization-based heuristics for a bottled-products distribution logistics system". In: *Journal of Computational and Applied Mathematics*, vol. 259, pp. 965–977.

[13] J. Nalepa and M. Blocho, (2015): "Co-operation in the Parallel Memetic Algorithm" In: *International Journal of Parallel Programming* vol. 43, no. 5, pp. 812–839.

[14] J. E. Beasley, (1981): "Adapting the savings algorithm for varying inter-customer travel times" In: *Omega*, vol. 9, no. 6, pp. 658–659.

[15] M. Okude and E. Taniguchi (2014): "Hierarchical Traffic Network for Heuristic

Approximation Method of Vehicle Routing Problems". In: *Procedia- Social and Behavioral Sciences*, vol. 125, pp. 262–274.

[16] G. Poonthalir and R. Nadarajan (2018): "A Fuel-Efficient Green Vehicle Routing Problem with varying speed constraint (F-GVRP)" In: *Expert Systems with Applications* pp 131–144.

[17] Z. Xu, A. Elomri, S. Pokharel, and F. Mutlu (2019): "A model for capacitated green vehicle routing problem with the time-varying vehicle speed and soft time windows" In: *Computers & Industrial Engineering*, vol. 137, p. 10601.

[18] M. Gmira, M. Gendreau, A. Lodi, and J.-Y. Potvin (2021): "Tabu search for the time-dependent vehicle routing problem with time windows on a road network" In: *European Journal of Operational Research*, vol. 288, no. 1, pp. 129–140.

[19] Y. Kuo, C.-C. Wang, and P.-Y. Chuang (2009): "Optimizing goods assignment and the vehicle routing problem with time-dependent travel speeds" In: *Computers & Industrial Engineering*, vol. 57, no. 4, pp. 1385–1392.

[20] J. Y. Potvin, Y. Xu, and I. Benyahia (2006): "Vehicle routing and scheduling with dynamic travel times" In: *Computers & Operations Research* vol. 33(4), pp. 1129-1137.

[21] A. Goel and V. Gruhn (2005): "Solving a Dynamic Real-Life Vehicle Routing Problem" In: *Operations Research Proceedings.*