Wasit Journal of Engineering Sciences

Journal homepage: https://ejuow.uowasit.edu.iq

Optimization of Vehicle Routing Problems Using GA for AL-Rasheed municipality, Baghdad, Iraq

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Received
10-October-2022
Revised
26-April-2023
Accepted
20-May-2023

DOI
10.31185/ejuow.Vol11.Iss2.387

Abstract

There are several problems with waste collection, transportation, processing, and disposal, particularly in major cities. The frequency of garbage collection is an important concern for municipal control. If waste is not disposed of properly, environmental problems such as air pollution and groundwater contamination may occur. This problem raises the concern for the need for specialized solutions for averting potential calamities that might occur throughout the world. Before deploying to actual situations, computer modeling and planning of waste collection are frequently performed to minimize the negative impact solid waste, that can have on the environment. As a result, choosing the optimal waste collection policy has a large effect on cost savings. The paper objective is to apply a Genetic Algorithm (GA) to reach the goals, illustrating the process of selecting the optimal route for the vehicle with the lowest time and greatest weight among several paths. The other goal is to create an improved time schedule for the vehicles, in order to minimize the number of used vehicles. This time schedule could minimize vehicle-related costs such as maintenance, gasoline, work staff salaries, and other vehicle-related costs. MATLAB simulation tool was used to simulate and model the practical data of 10 vehicles from the AL-Rasheed Municipality waste collection center, processing has been done for the collected data to be matched the input data format of the GA. Optimized time for routes and weights of lifted trash shows that the majority of the results has been improved dramatically. The final results reveal that the top five vehicles (8, 6, 7, 1, and 4) have a great percentage improvement in the number of collection points (133.3%, 100%, 100%, 66.7%, and 50%), respectively.

Keywords: Municipal Solid Waste, Genetic Algorithm, Waste Collection Vehicles, Routing Optimization

الخلاصـــة: هناك العديد من المشــكلات المتعلقة بجمع النفايات ونقلها ومعالجتها والتخلص منها ، لا ســيما في المدن الكبرى. يعد تكرار جمع القمامة مصدر قلق مهم للرقابة البلدية. إذا لم يتم التخلص من النفايات بشكل صحيح ، فقد تحدث مشاكل بيئية مثل تلوث الهواء وتلوث المياه الجوفية. تثير هذه المشـكلة ناقوس الخطر بشـأن الحاجة إلى حلول متخصـصــة لتجنب الكوارث المحتملة التي قد تحدث في جميع أنحاء العالم. قبل النشـر في المواقف الفعلية ، يتم إجراء نمذجة الكمبيوتر والتخطيط لجمع النفايات بشـكل متكرر لتقليل التأثير السـلبي الذي يمكن أن تحدثه النفايات الصـلبة على البيئة. نتيجة لذلك، فإن اختيار الســياســة المثلى لجمع النفايات له تأثير كبير على توفير التكاليف. تهدف الدراســة الحالية إلى تطبيق الخوارزمية الجينية للوصول إلى الأهداف، مما يوضح عملية اختيار المسار الأمثل للآلية ذو الوقت الاقل والوزن الاكبر بين عدة مسارات. الهدف الآخر هو إنشاء جدول زمني للآليات لتقليل عددها. سيقلل الجدول الزمني ايضا من التكاليف المتعلقة بالآلية مثل الصيانة والوقود ورواتب العمال والتكاليف الأخرى المتعلقة بالآلية. في الدراسة الحالية، تم استخدام برنامج ماتلاب لتطبيق بيانات حقيقية من 10 اليات من اليات جمع النفايات التابعة لبلدية الرشيد بعد معالجتها لتكون مقبولة لدى الخوارزمية الجينية. بعد تحسين وقت المسـارات وأوزان النفايات المرفوعة ، تحسـنت غالبية النتائج بشـكل كبير. تظهر النتائج أن أفضل خمس اليات هي (8 ، 6 ، 7 ، 1 ، 4) التي لديها نسبة تحسن مئوية كبيره في عدد نقاط التجميع وهي (133.3٪ ، 100٪ ، 100٪ ، 66.7٪ ، 50٪) على التوالي.

1. INTRODUCTION

Population expansion in cities leads to increased consumption per capita and industrial growth in the economy. They generate significant amounts of solid waste, resulting in a huge waste collection problem, particularly in urban areas [1][2]. Solid wastes produced by human activities cause environmental, communal, and vital issues in central living areas and cities [3]. Solid waste is becoming an increasing worry among governments [4][5]. According to the World Bank, global solid waste is currently over 1.3 billion tons and is expected to reach 2.2 billion tons per year by 2025 [2]. In developing countries, collection services account for 80-90% of municipal expenditures, despite reduced collection frequency and efficiency [6][7]. Waste management is a main problem in any city throughout the world to keep it clean, and it is expected to be a great challenge due to the quick growth of waste, finite processing capacities, high costs of waste collection, and environmental problems [8]. In this paper, a study for improving the Vehicle Routing Problem (VRP) of Municipal Solid Waste (MSW) collection in Baghdad, Iraq.

Baghdad, being the capital city of Iraq, has seen an increase in the amount of waste over the last few years. There are many problems in the waste collection, such as transportation, processing, and disposal of trash [9] [10]. The regularity of waste collection is an important issue for municipal control [11]. If waste is not disposed of properly, environmental hazards such as groundwater contamination and air pollution may occur [12]. This challenge raises the alarm about the requisition of specific strategies to prevent disasters that might occur on a global scale [13], [14]. There has been a lot of research done on waste management as a way to reduce these consequences, as in [12] [15-17]. To decrease the environmental consequence of solid waste, modeling and planning of solid trash collection are frequently performed processed before being deployed to real-world scenarios [18] [19]. The necessity of improving and developing the waste management systems are required. As a result, choosing the optimum waste collection strategy has a large effect on time and cost savings [20]. In highly populated urban areas, shorter streets may be more crowded and take longer to navigate than longer ones [21]. Since the traffic unpredictable on a particular day, average traffic days must be defined where relatively constant traffic loads remain across a user-specified time interval [22].

The objectives of this research are using, a Genetic Algorithm (GA) to find the optimal path for a vehicle that has the least trip time and the highest weight among other routes, and to produce a reduced timeline for the working vehicles. The optimized time schedule will reduce vehicle-related expenditures such as maintenance, fuel costs, working staff remuneration, and additional vehicle-related expenses.

The rest of this paper are organized as follows, the related works and the comparison with other researches' results are given in section 2. Additionally, the research methodologies, which are divided into data collection, formulation of the model, and development of the algorithm for solving the optimization model are presented in section 3. Furthermore, the results and discussion are shown in section 4. Finally, the conclusions are provided in section 5.

2. RELATED WORK

The modeling of MSW collection is split into two primary stages: producing an optimization model, and proposing a meta-heuristic approach for determining optimal collection routes for vehicles to reduce collected time and distance. This strategy has been used in several studies. Cruz et al. [18] designed a mixed integer optimization model for municipal solid waste collection. Yu et al. [23] proposed a bi-objective dynamic linear programming model that has recently been assigned to a meta-heuristic algorithm for finding optimal solutions. Many studies have used a mathematical formulation and a meta-heuristic algorithm to solve the waste collection route within a specified time limit. The research in reference [24] developed and mixed a Backtracking Search Algorithm (BSA) with the intelligent bin concept to obtain the best-structured garbage collection route solutions for Capacitated Vehicle Routing Problem (CVRP) models.

The research in reference [25] built a Particle Swarm Optimization (PSO) algorithm for the CVRP model to establish the optimal waste collection and route optimization options. [17] developed Mixed-Integer Linear Programming (MILP) for the multi-trip CARP to decrease overall cost. The depots and landfills were distributed through the model. To simplify decision-making for a total solution to the MSW collection system's capacitated vehicle routing matter, all advantages, especially economic, environmental, and social consequences, have been considered in recent years. PSO and Tabu Search (TS) are both meta-heuristic algorithms implemented in a two-phase algorithm by a study presented in reference [19] to provide an efficient solution. The research in reference [26] provides a framework that utilizes Internet of Things (IoT) technology to help waste collection bins and vehicles in waste collection systems, that were resulting in waste collection route optimization.

Table 1 Comparison between the results with the other researches

Author Name with used technique	Number of lifting nodes	Transmission Efficiency	Weight	Route Distance	Number of sub-paths	Fuel cost	TWL	Emission
Cruz et al. (2015) [18]/ TSP	-	-	-	30%	-	-	-	-
Qiao et al. 2020 [19] / PSO-TS	-	-	-	-	21.39%	-	-	-
Zhang et al. 2022 [23] / GA	-	23%	-	-	-	-	-	-
Akhtar et al. (2017)[24] / BSA	-	36.78%	-	36.80%	-	47.77%	-	44.68%
Hannan et al. 2018 [25] /PSO	-	-	-	-	-	-	75%	-
Assaf and Saleh 2017 [28] / GA	-	-	-	66%	-	-		-
Proposed method	64.95%	-	62.48%	-	-	-	-	-

3. RESEARCH METHODOLOGY

The goal of this work is to minimize overall vehicles routing distances by finding optimal routes for all trips. Regarding this topic, a three-phase technique has been suggested, which are listed below:
First, a data collection procedure from a geographical location (AL-Rasheed Municipality as a case study).
Second, the optimization model's formulation process.
Third, the GA used for resolving the optimization model is created.
Figure 1 shows the proposed strategy for improving the waste collection vehicle route.

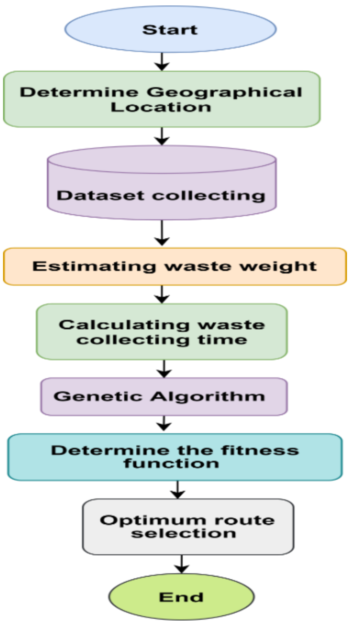

Figure 1 Diagram of the proposed approach.

Phase 1: Data Collection from a Geographical Location

The data collection begins by determining the geographic locations of all n∈ {1…,10} nodes (where n is the vehicle) [27]. The actual distances of the shortest routes between the nodes are considered, to enhance the accuracy of the solutions in the presented study. The GPS data for the vehicles operated by Al-Rasheed Municipality (as a case study) to collect waste from the streets within its borders was used in the presented research. As seen in Fig. 2, they use many vehicles and staff to collect bins of garbage from the streets.

Figure 2 collecting waste from the street of AL-Rasheed Municipality.

To better the data collection procedure, Al-Rasheed Municipality has partnered with a company that offers to monitor the vehicle's routing and gather information from the GPS devices linked to them [15]. As shown in Fig. 3, all of the roads were plotted in a Geographic Information System (GIS) application to cover the whole region where the vehicles collect waste.

Figure 3 Distributed vehicles on a GIS Raster captured by the web application

Al Rasheed Municipality relies on a pre-drawn path in the GIS application and creates a schedule for each vehicle that must visit a specific area to lift waste [11]. They use (10) vehicles to execute this work in one or two work shifts depending on the type of waste; some waste may be medical, while others may be organic. The amount and weight of the wastes are different [2]. The duration of one shift is 7 hours. The collected data will be formulated in the next phase.

Phase 2: Formulation of the Optimization Model

The real data includes the path that each vehicle follows when collecting waste from the streets, as well as the time that it takes to lift the waste between two points. The original data's route from point to point describes the titles of these points and streets, therefore we transform them into integers beginning with 1 and ending with the last moment. The garage is represented by number one, while the landfill is represented by number five. There are three steps to the formulation process as follows:

A. Unifying the time variation

Because the data was taken for two months in a case study, the duration among every two points the vehicle requires to collect waste is not equal, as seen in the collected dataset. In this situation, time is affected by various factors, including traffic, the number of packed bins, vehicles collected, vehicle condition, and so on [28], [29]. As a result, we had to average the time for every two points by summing the time in the same two points and would then divide it by the number of repeated paths in 60 days. As an outcome, we have a standard for the time among every two points, which represents the time required. This was accomplished through the use of the Visual Basic Application (VBA), as demonstrated in the steps below:

Step 1: Create a VBA query that forms groups for each action (start and end), sums the total time, and counts the repetitions.
Step 2: Splitting the summing time into (hours, minutes, and seconds).
Step 3: Converting the summation to seconds ((hour ×3600) + (minute ×60) + seconds) and dividing the result by the number of repeats for each step.
Step 4: Divide the result of step (3) by 3600 to get the integer number that represents (hour).
Step 5: Subtract the results of steps 3 and 4 and get the integer number to obtain the value of (minute).
Step 6: Subtract the results of steps 4 and 5 and get the integer number to obtain the value of (second).
Step 7: Finally, we organize the results from steps 4 through 6 in the form (00.00.00) in order.

B. Calculating waste weight

In this case study, there were no intelligent bins that contain a sensor to monitor the level of garbage in the bin or a sensor to determine the weight of waste in the vehicles, therefore this work created a technique to calculate it. We were able to obtain an approximate amount for the weight of waste collected in each street from the specialist departments of Al-Rasheed Municipality, ranging between (200 and 250) kg. We utilize this range Rand, where Rand is really from (0 to 10) kg, to calculate the final weight and redistribute it on the original data's old pathways.

C. Calculating waste collecting time

To calculate how much the collected waste for each minute was, we get the summation for the weight in each route and the outline for time, and then we divide the weight over time. Then we multiply the weight for each minute we get by the time for each path and add a small random amount to reach the weight for each track in the route. The optimum time we get from the 48 routes will be the summation, and then we divide it by the shift time equal to 7 hours or (420) min, as shown in Equation 1.

$$V_{total} = (\sum_i T_i) \div T_{sh} \qquad (1)$$

where V_{total} is the number of actual (optimal) need for vehicles, T_i is the optimal time for the vehicle i, and T_{sh} is the shift time (fixed at 420 min), $1 < i < 48$ is the total number of vehicles.
As a result, we will determine the number of vehicles required to accomplish waste collection. Using this method, we can meet the actual need that vehicles may have without wasting time or incurring additional costs, lowering emissions and reducing unnecessary spending on fuel, maintenance, and workers. The final findings will be utilized in the optimization algorithm to determine the optimal route for vehicles in the following phase.

Phase 3: Development of the algorithm for solving the optimization model

The optimization model's goal is to minimize activity and related costs, such as total distance travelled by collection vehicles or overall collection cost [13], [30], [31]. Some basic constraints should be addressed, like the period of the collection route, the number of vehicles within the fleet, vehicle capacity, viability conditions, the number of bins, the amount and types of garbage, and sanitary and aesthetic effects. The current study offers a GA for reducing the minimum-path function. GA is commonly employed in optimization problems and is widely acknowledged to be efficient with difficult challenges [9] and [32] to [34]. It finds the optimal solution to a specific computing problem by maximizing or minimizing a certain function. Other optimization algorithms operate well in some cases, but GA is the most spectacular alternative for optimization in complex multimodal problems with many changes in nature. The genetic algorithm starts by choosing the most suitable individuals/chromosomes from a random population [35]. During the crossover phase, elite chromosomal pairs mate and produce offspring. A certain fraction of the offspring's chromosomes is changed during the crossover. The children's chromosomes then replace the poorest in the existing population, producing a better population [13]. To evaluate the quality of a solution, the model may determine each individual's fitness level. To calculate a chromosome's fitness function, the objective function (in this example, time) must be specified [27], [36]. The fitness shows not just how great the solution is, but also how close the chromosome is to be optimal. The fitness function is the same as the objective function in maximizing issues; there are a limited number of such transformations in minimization problems. In most cases, the fitness function in equation 2 is used:

$$\mathbf{F(i)} = \frac{\mathbf{1}}{\mathbf{objective\ function\ (i)}} \quad \mathbf{(2)}$$

The solution with the highest fitness value would be the best, while the one with the lowest fitness value is the worst. If we wish to reduce the cost, the high-cost answer will be low fitness (like the weight in this study), and the low-cost solution will be high fitness (like the time in this study). The outcomes of performing the algorithm and obtaining the results will be the ideal route for each vehicle based on the lowest time and highest weight, as indicated in the following section.

4. RESULTS and DISCUSSION

The data were obtained for ten vehicles; each one has its paths for an average of 60 days and one shift. The shift is 7 hours long, and we just used the path from the garage to the landfill as a starting point and an endpoint for the trip. The optimal method was found to have the lowest time cost and the highest weight cost. To demonstrate the improvement in results, the optimized results will be compared here to the data before the optimization. Table 2 shows the optimum weight, time, and number of nodes, as well as the average nodes and weights for vehicle routes before optimization.

Table 2 Results before and after the algorithm.

Vehicles number	Number of routes for	The optimum route	The optimum time	The optimum weight	The number of nodes for	The average nodes (active)	The average weights

	each vehicle				the optimum route	before the algorithm	before the algorithm
1	35	15	75	975	5	3	617
2	49	36	146	2920	10	7	1389
3	22	17	109	872	4	3	653
4	30	11	104	1248	6	4	945
5	26	18	157	1413	7	5	1176
6	22	12	146	1606	8	4	863
7	50	28	208	3120	14	7	1502
8	14	6	63	1260	7	3	625
9	55	48	100	1700	8	6	1296
10	35	14	75	1950	9	6	1352

When we compare data from 10 vehicles (before and after optimization), we notice that the most improved in both average active point (nodes of collecting) and waste transported weights, as shown in Tables 3 and 4.

Table 3 Improvement in percentage for nodes in route for the vehicle.

Vehicle number	Nodes for the route before optimization	Nodes for route after optimization	Node improvement percentage
8	3	7	133.3 %
6	4	8	100 %
7	7	14	100 %
1	3	5	66.7 %
4	4	6	50 %
10	6	9	50 %
2	7	10	42.9 %
5	5	7	40 %
3	3	4	33.3 %
9	6	8	33.3 %

As seen in Table 3, the first five vehicles (8, 6, 7, 1, and 4) have a large percentage improvement in the amount of collecting points (133.3%, 100%, 100%, 66.7%, and 50%), respectively. The number of paths for vehicle 8 is (14) paths. The ideal path (6) is illustrated in Fig. 4 and it begins from point 1 (garage) to point 5 (landfill) as (1, 600, 77, 60, 56, 68, and 5) with both the lowest time of 63 minutes and highest weight of 1260 kg. The path between points indicates a street or streets with waste bins that need to be collected.

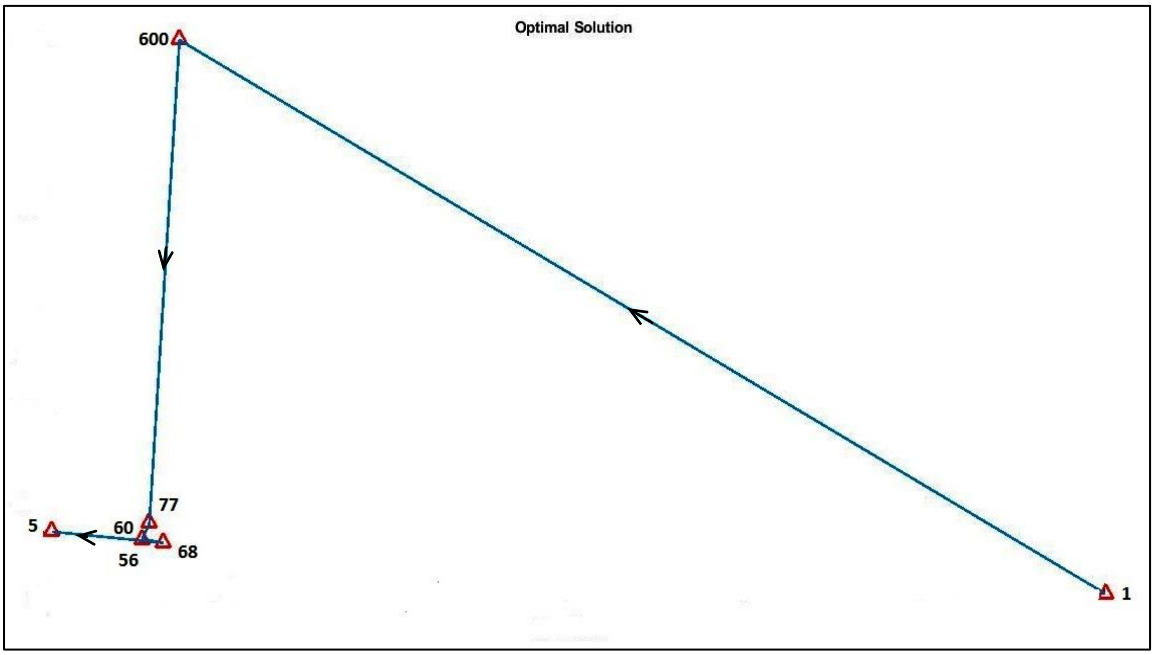

Figure 4 The optimal route for vehicle number 8

Table 4 Improvement in the percentage of weight in route for a vehicle

Vehicle number	Weights for the route before optimization	Weights for route after optimization	Weight improvement percentage
2	1389	2920	110.2 %
7	1502	3120	107.7 %
8	625	1260	101.6 %
6	863	1606	86.1 %
1	617	975	58 %
10	1352	1950	44.2 %
3	653	872	33.5 %
4	945	1248	32.1 %
9	1296	1700	31.2 %
5	1176	1413	20.2 %

Table 4 shows that the first 5 vehicles (2, 7, 8, 6, and 1) own a high percentage of waste lifted weight improvement (110.2%, 107.7%, 101.6%, 86.1%, and 58%), respectively. Table 2 shows the optimal time for 10 vehicles, and the result of a summing operation for it equals (1183) minutes. And when the entire optimal time is divided by the duration of one working shift, which is (420) minutes, the result is 3; this number represents the total number of vehicles necessary to work. Our method helps us in reducing the number of operating vehicles and, as a result, the costs associated with them, which is the fundamental purpose of our research.

5. CONCLUSIONS

To reduce the negative environmental effects of solid waste, solid trash collection is commonly modelled and planned on a computer before being deployed in real-world circumstances. As a result, implementing the most effective waste collection program has a significant impact on cost savings. The goal of this research is to use a genetic algorithm-based optimization approach to find the optimum path for a vehicle that takes the least amount of time and transports the highest weight among multiple routes. The results of the algorithm showed an improvement for all vehicles by 64.95% for the number of waste removal points (the activity of vehicles) compared to the points before the optimization, and an improvement in collecting vehicles by 62.48% for the amount of waste lifted compared to the amount of waste lifted before the optimization. The major contribution of this research is that it uses reliable data collected from municipal vehicles for two months and optimizes it by applying an optimization algorithm to find the optimum route for each vehicle based on the lowest time and the highest weight for the collection method. A similar technique was suggested to be used in other cities. Although the solution is static and cannot be used if certain unanticipated conditions (such as a truck being out of service or a truck driver being absent) occur, the technique can be used with sufficient time to generate near-optimal solutions. The author recommends that a distinct municipal division is in charge of controlling and optimizing solid waste collection matters based on daily data collection.

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