Applied Mathematics and Computational Intelligence
Volume 12, No. 3, Oct 2023 [40-50]

Optimising Routes Scheduling of Garbage Truck for Waste Collection using Artificial Bee Colony Algorithm

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Received: 27 Oct 2022
Accepted: 8 Sept 2023

ABSTRACT

The issue of waste generation has attracted significant public attention in today's societies, not only because waste production is increasing quantitatively but also because some products and components are becoming more complex. The growing problem of municipal solid waste management has become the most serious environmental issue. Population growth has resulted in the increase in the generation of solid waste, which has become a serious issue that must be resolved. Optimised route planning is one of the most important components of a smart waste management system. Route planning is a technological approach to determining the shortest routes through optimisation. The route optimisation problem commonly referred to as the vehicle routing problem (VRP), has been thoroughly studied to find the best possible route for a vehicle. This study aims to find the optimal routes and reduce the distance travelled by the garbage truck when collecting waste using Artificial Bee Colony (ABC) algorithm. ABC algorithm is an optimization method based on the clever behaviour of honey bee swarms. The artificial bee colony in the ABC algorithm is divided into three groups which are employed bees, onlookers and scouts. To provide neighbouring solutions that are guaranteed to be possible, swap operator is used. Results show that by using 10 trucks in total as the vehicle, the optimal solution produced a total of optimal distance for 94.9542 km. The findings of this study fulfilled the intended objectives which are to find the optimal route and shortest distance for the vehicles

Keywords: Artificial Bee Colony, Optimisation, Vehicle Routing Problem, Distance, Waste Management

1 INTRODUCTION

Waste management or waste disposal consists of the processes and activities to handle garbage from its beginning to its last disposal. There are many types of waste which comprises of solid, liquid or gaseous with various disposal and management strategies for each. A major component of dealing with waste management is municipal solid waste, which is caused by domestic, industrial, commercial and household sectors [1].

Developing countries such as Malaysia face several issues in managing garbage in a sustainable manner due to fast-growing cities and a rising population. Malaysia has limited landfill space and the cost of disposal has been rising recently. Therefore, there is a greater pressure to handle the waste management problem and lessen the impact on the environment as well as the general well-being of the community.

Waste management plays an important role to minimize the harmful effect of waste on human health and maintaining a sustainable environment. According to a survey from the world bank website, waste management involves a high cost, accounting about 20% to 50% of municipal financial plan. Some stakeholders took their responsibility to empty the waste bins at certain intervals but still some waste collection processes are not always efficiently scheduled making some garbage containers fill up faster and becoming full before the next waste collection. This problem has effects in overflowing waste causing a bad view and smell, as well as hygiene and health risks. Thus, stakeholders have to maintain the cleanliness of the city from such situation.

Operating this important municipal function requires the development of integrated systems that are efficient, long-lasting, and socially beneficial. To handle this situation, one of the most significant aspects of a smart waste management system is optimised route planning. One of the elements is route planning for garbage truck which helps to find the best and shortest routes thus optimised schedule to know when the best time would be to collect waste. Real-time monitoring of waste fill levels and weight in bins gives up-to-date information that allows for optimum route optimization, resulting in increased collection efficiency [2]. The management system lack information of bin status that prevents proper route optimisation. The number of labours and size of the garbage trucks that will be needed for the waste collection are also some elements that can be optimized [3]. Other than that, the schedule or timing for waste collection should be considered to minimize the cost of transportation.

However, [4] found that the travel distance was the main factor in optimising the waste collection and transportation. Thus, this study is conducted to determine the optimal routes scheduling of garbage truck for waste collection using artificial bee colony algorithm.

2 LITERATURE

According to [5], waste collection can be defined as collection is the process in charge of taking-back wastes from the collection point to the disposal facility. In solving the waste collection problem, some researches try to find the shortest distance, find the most appropriate location for collection bins and disposal, and find the minimum number of vehicles needed for waste collection problem.

In waste management, route optimisation is a frequent topic that has a variety of consequences on collection efficiency, collection costs and pollutant emissions. [6] focused on solving the problem of determining the most efficient or optimal route of garbage trucks for waste disposal in daily operations. Rational waste management should consider both ecological demands and logistics principles in the planning, organising, and performing of essential actions. This optimisation problem is formulated using an evolutionary algorithm which resembles natural evolution's mechanism and performed on 36 calculations. The problem was also solved by the artificial immune systems that were based on living organisms' defence mechanisms which obtained the shortest path amounts 217.92 km. The study revealed a reduction of up to 60% in the weight and volume of waste in landfills.

However, [7] state that in order to solve the waste collection problem, Vehicle Routing Problem (VRP) can be applied. A vehicle routing problem, or often known as VRP, is about route optimisation that was introduced by Dantzig and Ramser in 1959, and has been applied in the field of waste collection and transportation [8]. VRP is a problem that has been extensively investigated to minimize the total driving cost of vehicles from a depot to customers and then back to the depot via an optimal routing [9].

[10] proposed a unique sort of share-a-ride problem (SARP) that used online car-hailing as a transporter to transport customers to the distribution centre and courier stations to pick up and deliver parcels. By applying an improved genetic algorithm (GA), the issue is resolved in order to achieve the objective of minimizing the total cost of the three parties such as for drivers, passengers and courier services as well as the time penalty costs.

Other than that, [11] used bus routing problem (SBRP) for transporting elementary school pupils which was solved using an exact solution approach. An associated integer linear programme is described for the issue that is characterised as a capacitated and distance-constrained open vehicle routing problem. A few well-known inequities from the vehicle routing issue are acquired by the integer programming and it showed that these inequities also apply to the SBRP under analysis. The proposed formulation is used to calculate the problem's optimal solution and the result showed that it can save on travel expenses overall by up to 28.6% compared to the present implementation that used more buses and the total distance that the bus travel is higher.

3 ARTIFICIAL BEE COLONY ALGORITHM

Artificial Bee Colony (ABC) algorithm is one of the most defined algorithms by Dervis Karaboga in order to solve real-world and numerical problems [12]. ABC algorithm is based on swarm intelligence and imitates the process by which honey bee swarms search for food. This algorithm uses the quality of nectar of the food source as a fitness assessor and each selected solution reflects the position of the food source in the search space.

The process of this algorithm is the same as bees leaving their hive to find food and collect nectar. After that, they return to the hive, and perform dance, which means the bees provide information about what they explored of the food source to the onlookers. The onlookers search for new food and abandon the food with low fitness value thus becoming an employed bee. When their food source is abandoned, they turn into a scout bee that finds food source in the search space. This process is repeated until they reach the optimal food source.

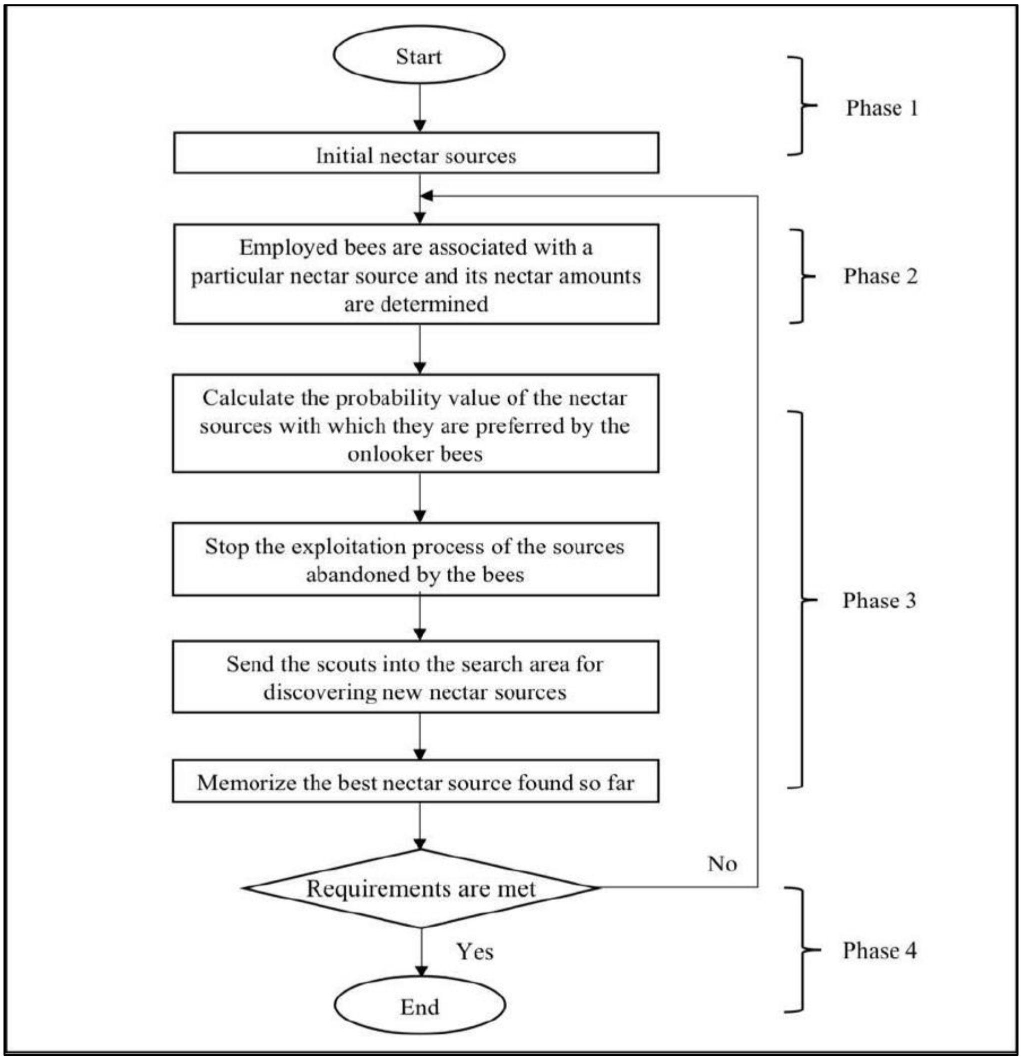

Figure 1: Flowchart of ABC Algorithm
(Source: [13])

Based on the flowchart in figure above, ABC algorithm can be classified into four phases which are; initialization phase, employed bee phase, onlooker bee phase, and scout bee phase.

3.1 Initialization Phase

In this phase, scout bees initialize the vectors in the population of the food source, x_q ($q = 1 \ldots SN$, where *SN* is the population size) and set the control parameters. Every food source, x_q is a vector that represents a solution to the optimization problem and each vector contains n variables and n is the dimension of searching space that needs to be optimized in order to minimize the objective function.

The following Eq. (1) is used for the calculation for initialization of the food source:

$$x_{qm} = c_m + rand(0,1)(d_m - c_m) \tag{1}$$

where x_{qm} is food source of n variables ($m = 1 \ldots n$), $rand(0,1)$ is a random number between 0 and 1 based on the normal distribution while c_m and d_m are the lower and upper bound of the solution space.

The initial food source obtained in Eq. (1) are randomly produced.

3.2 Employed Bee Phase

In this phase, employed bees look for new food sources, d_{qm} that contain more nectar within the location area of the food source, x_q. When they locate a neighbour food source, they evaluate its profitability (fitness). If the amount of nectar for the new food source is lower than the previous one, they will abandon the latter.

The following Eq. (2) is used to calculate the neighbour food source:

$$d_{qm} = x_{qm} + \phi_{qm}(x_{qm} - x_{lm}) \tag{2}$$

where x_{lm} is chosen at random of food source, m is chosen at random of parameter index and ϕ_{qm} is a random number between the range of -1 and 1. After done produce the new food source d_{qm}, new fitness is calculated.

The fitness value of the solution, $fitval_q(x_q)$ is calculated for the minimization problem by using the following Eq. (3):

$$fitval_q(x_q) = \begin{cases} \dfrac{1}{1 + f_q(x_q)} & \text{if} \quad f_q(x_q) \geq 0 \\ 1 + abs(f_q(x_q)) & \text{if} \quad f_q(x_q) < 0 \end{cases} \tag{3}$$

where $f_q(x_q)$ is the objective function value for the solution x_q which is symbolized as total distance for this study.

The fitness value obtained is essential in order to find the global optimal value.

3.3 Onlooker Bee Phase

Employed bees notify and share their information of food sources with onlooker bees waiting in the hive of their food sources. Onlooker bees then probabilistically choose their food sources based on this information. In the ABC algorithm, an onlooker bee selects a food source according to the probability values calculated using the fitness values provided by employed bees.

The probability value, T_q with which x_q has been chosen by an onlooker bee can be calculated by using the following Eq. (4):

$$T_q = \frac{fitval(x_q)}{\sum_{q=1}^{SN} fitval(x_q)} \quad (4)$$

where SN is the population size, A neighbourhood source, d_q has been determined by using Eq. (2) after the food source, x_q has been chosen by the onlooker, and its fitness is computed.

3.4 Scout Bee Phase

The unemployed bees that choose their own food sources are called scouts. Employed bees whose solutions are not improved after a predetermined number of trials as specified by the user of the ABC algorithm and referred to as the "limit" or "abandonment criterion" herein, turn into scouts and their solutions are abandoned. After that, the transformed scouts begin to look for new solutions randomly. For instance, if the solution x_q has been abandoned, the scout who was the employed bee, x_q of will discover a new solution, defined by Eq. (1). As a result, sources that are initially poor due to exploitation are abandoned, and negative feedback behaviours arise to balance the positive feedback.

4 RESULTS AND DISCUSSIONS

In this study, secondary data was adopted from [14] where ten vehicles will be in charge of collecting rubbish from 30 waste bins that need to be collected during a waste collection activity. The waste collection vehicle must return to the disposal facility once it has finished collecting rubbish or when it is fully loaded in order to upload the waste. The waste bins are assumed to be the nodes and for the disposal centre, it was assumed to be node 0. X-coordinate and Y-coordinate refer to the location of each waste bin and disposal centre. The specifics information of the data such as the locations and amount of each waste bin are shown in Table 1 below:

Table 1: Information About the Disposal Centre and Bins

Point	X-coordinate	Y-coordinate	Amount of Waste (kg)
Disposal Center,0	4.8	4.78	-
1	0.98	0.08	626.87
2	3.6	1.05	566.31
3	3.35	2.68	772.5
4	1.92	4.27	913.9
5	2.46	4.55	918.5
6	3.87	1.67	916.67
7	0.74	2.35	601.86
8	2.43	0.01	772.21
9	0.36	1.55	937.47
10	3.94	2.43	560.5
11	1.97	1.31	928.18
12	1.18	3.42	949.89
13	0.4	4.56	608.93
14	0.4	2.85	538.49
15	4.64	1.33	737.11
16	1.02	4.64	917.51
17	4.78	0.32	734.7
18	1.7	3.13	706.88
19	0.3	0.54	751.37
20	1.72	2.58	562..72
21	3.02	4.78	566.14
22	3.06	1.36	935.24
23	2.78	2.63	801.48
24	2.73	3.56	632.65
25	1.01	1.07	932.4
26	3.94	4.13	529.05
27	1.74	0.69	728.88
28	4.86	2.19	861.1
29	0.58	3.88	669.5
30	3.56	3.52	700.61

(Source: [14])

From the data in above table, the minimum total distance (TD) will be obtained as in Eq. (5) by using ABC algorithm:

$$TD = \sum_{i=1}^{n} \sum_{j=1}^{n} x_{ij}^{k} d_{ij} \tag{5}$$

where x_{ij}^{k} represents whether a vehicle *k* goes from bin *i* to *j*, while d_{ij} represents as distance between bin *i* and *j*. Since the above data has 30 points, therefore the value of *n* will be set as 30.

For the ABC algorithm, the parameter settings have been summarized in Table 2 as shown below where the total number of vehicles and maximum capacity has been set as in [14]. For the maximum number of iterations is 200, the population size is 100, and there are exactly as many onlooker bees as there are populations that are 100. These parameters will be used in getting the total distance.

Table 2: Parameter Settings

Parameter	Value
Number of Vehicles	10
Maximum Capacity	3000
Number of Decision Variables, *n*	2
Maximum Number of Iterations	200
Population Size, *SN*	100
Number of Onlooker Bees	100

In this study, swap operator from [15] is used for neighbourhood structure in ABC algorithm. This operator produces a neighbour by swapping two randomly selected tasks at different positions at workstations while satisfying the precedence constraints. This swap random has been applied in the employed bees and the onlooker bees phases. Operation swap selects two tasks at random from the line sequence, swaps their positions, and returns a new feasible solution.

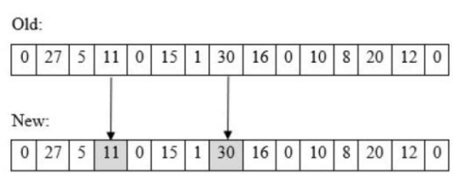

Figure 2: Example of Random Swap

Based on the Figure 2 above, two waste bins that need to be collected in this research were selected randomly. Then, checked the capacity of the vehicle, either the total capacity exceeds the maximum capacity or not. If capacity of the vehicle less than the maximum capacity, the waste bins will not change or swapped between vehicles.

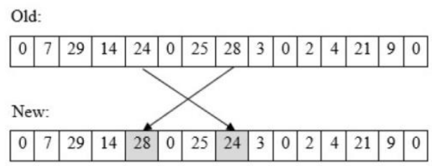

Figure 3: Example of Random Swap (2)

For Figure 3 above, the process of swap same as before but since the capacity of the vehicle exceeds the maximum capacity, the waste bins are swapped.

The result of the total nodes or waste bins collected, total capacity and the optimal value of distance by each vehicle used as shown in the Table 3 below:

Table 3: Nodes, Capacity and Distance for Each Vehicle

Vehicle	Nodes	Capacity	Distance (km)
1	0-24-17-25-13-0	2908.68	12.45
2	0-15-30-8-0	2209.93	9.2692
3	0-6-23-7-0	2320.01	8.9185
4	0-4-3-19-10-0	2998.27	13.7573
5	0-11-29-21-0	2163.82	10.6307
6	0-0-12-9-5-0	2805.86	8.8193
7	0-20-18-16-2-0	2753.42	12.8455
8	0-28-22-26-0	2325.39	8.4637
9	0-27-14-1-0	1894.24	9.7999
10	-	-	0

Based on the above results, the vehicle number 10 did not have any waste bin to collect, means that the number of vehicles is minimized to only nine vehicles to collect all of the waste bins from each location. Thus, the optimal solution resulted in a total distance of 94.9542 km is obtained by using 9 trucks as the vehicle.

Based on the result obtained from [14], the minimum value of the distance is 103.7554 km. Since the optimal value of total distance for this study is 94.9542 km, it shows that the ABC algorithm performs better than the suggested model with 8.4826% of difference error.

5 CONCLUSION AND RECOMMENDATIONS

Solid waste generation has increased due to population expansion, making it an urgent problem that must be resolved. Waste collection is the step in the process known as responsible for returning waste to the disposal facility. A waste collection could be applied as a Vehicle Routing Problem (VRP) which is an optimization that concerns determining the optimal routes travelled by vehicles. The main purpose of this study is to use an Artificial Bee Colony (ABC) algorithm to find the best paths and reduce the distance of the garbage trucks travelled when collecting waste. Data used for this study was collected from previous study by [14].

The capacity of the bins and the distance between 31 nodes are taken into consideration. The result shows the best optimal solution used by 10 trucks total is 94.9542 km of the total distance. The optimal distance for each of the ten vehicles has been computed based on the parameter settings used in this algorithm.

As for future work, Green House Gas (GHG) Emissions and total cost could be determined to compare the results with [14]. Other than that, other neighbourhood operators such as relocation, 2-Opt or else can be applied in the ABC algorithm to find a new feasible solution.

ACKNOWLEDGEMENT

We would like to express our appreciation to the ISTEC-CoSQA 2023 for the opportunity to present our research findings.

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