Engineering and Applied Science Research 2023;50(2):155-162 Research Article

EASR

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Solving vehicle routing problem for waste disposal using modified differential evolution algorithm: A case study of waste disposal in Thailand

Narat Rattanawai[1)], Sirawadee Arunyanart*[1)] and Supachai Pathumnakul[2)]

[1)]Supply Chain and Logistics System Research Unit, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand
[2)]Academy of Science, Royal Society of Thailand, Bangkok 10300, Thailand

Received 1 February 2023
Revised 12 March 2023
Accepted 16 March 2023

Abstract

The aim of this study is to present a modified differential evolution (MDE) approach for solving the vehicle routing problem for waste disposal trucks by considering the routes that the vehicles take and their fuel consumption in order to obtain the lowest fuel consumption. The problem is complicated since there are several waste disposal sites, various waste types, various vehicle types, and various transport route speed specifications. In this study, three MDE techniques were employed: (1) the CR was set at 0.5 during the recombination phase and used the MDE-1 simulated annealing (SA) selection procedure, (2) the SA selection method was specified as MDE-2, and the self-adjusting CR value was adjusted from 0.9 to 0.1 in the recombination process, and (3) the recombination process was set up using a primitive selection process that is specified as MDE-3, and the CR value is set to automatically shift from 0.9 to 0.1. These three proposed models were tested with five small problems, five medium problems, and five large problems. The results showed that the proposed methods could solve the problem appropriately. In addition, three proposed models were tested with real data from a case study. The results showed that the MDE-1 method provided the best solution, followed by the MDE-2, MDE-3, and DE method, respectively.

Keywords: Vehicle routing problem, Waste disposal, Modified differential evolution, Algorithm

1. Introduction

The quantity of carbon dioxide in the atmosphere rose by 149% between 1983 and 2021, according to the World Meteorological Organization (WMO). Rising global temperatures are a result of the quantity of carbon dioxide reaching 415.7 trillion tons (ppm) in the year 2021 [1]. Thailand emitted 248.49 million tons of carbon dioxide in the year 2020, with 75 million tons of those emissions coming from the transportation sector, which accounted for 30% of the nation's overall emissions [2]. Carbon dioxide emissions from road transport are affected by the type of vehicle, vehicle load, vehicle load, etc., all of which are related to the length of the trip [3]. The issue of poor routing also leads to high transportation costs and longer travel times, which increase carbon dioxide emissions [4, 5]. Globally, there is concern about the rapidly rising levels of municipal solid waste, which are mostly caused by population expansion and ineffective garbage management [6]. The problem of inappropriate waste transportation routes consists of the distance of waste transportation, the frequency of garbage collection, the cost of waste management, and the flexibility in selecting waste disposal sites, all of which lead to high costs. Ways to increase efficiency in waste management are through routing, vehicle selection, and choosing the right waste disposal sites [7]. [8] stated that 70-80% of the overall cost of garbage disposal is incurred in the transportation of waste from its place of origin to its disposal site. According to the studies, the rate at which the area's population grows influences the amount of garbage produced. The amount of waste in each area is different due to the density of the population. Since waste is dispersed throughout the city and the amount of waste in each area varies owing to varied population density, using the shortest route possible for transportation can reduce transportation cost [9]. The cost of waste management can be kept as low as possible by using efficient waste transportation management [10]. Therefore, the issue of transportation for waste disposal is significant since, in the absence of an efficient waste management system, it will lead to greater fuel expenses for transportation.

According to the pollution control department [11], in 2021 there were 637 tons of solid garbage per day in the Phetchabun Province in Thailand. This garbage can be categorized into three groups: 1. waste that can be recycled, such as paper, plastic, glass bottles, aluminum, and metal; 2. the presence of infectious waste in huge amounts in both public and private hospitals or nursing homes, such as mucus, sputum, saliva, or blood; and 3. general waste, such as plastic bags, food tubes, sugar packets, coffee, etc., in large quantities in community houses. The local government agencies are responsible for collecting, moving, and disposing of garbage. Currently, the truck will take all three types of waste from various towns to the three types of waste disposal facilities: sanitary landfill, municipal solid waste incineration, and recycle waste disposal. Even though the construction of solid waste disposal and trash collection facilities is sufficient to handle the expected increase in trash production in the future [12], there are still issues with ineffective garbage transportation. Moreover, there are restrictions on transportation, such as driving speeds and the steepness of the terrain in Phetchabun. Therefore, a solid waste management system that is effective is thus required.

*Corresponding author.
Email address: sirawadee@kku.ac.th
doi: 10.14456/easr.2023.17

The objective of this research is to develop a method based on modified differential evolution (MDE) to determine the appropriate route for transporting waste disposal from the various sources of waste to various waste disposal points, i.e., landfills, mechanical and biological treatment (MBT) facilities, and recycling facilities, while taking into account the shortest route to reduce carbon dioxide emissions. The proposed method is presented through a real case study of waste transportation in Phetchabun Province, Thailand. During the peak season, when a large number of visitors visit the area, there is currently insufficient management for waste disposal. Traditional waste management systems are unable to cope with the increasing amount of waste by finding the optimal route to the site of disposal. Therefore, the proposed method intends to be used as a decision-support tool to find appropriate routes for waste disposal.

2. Literature review

The problem of solid waste management involves reducing the distance of logistics transportation. [9] presented a mathematical model to determine the route for municipal waste management in Canada. The objective was to reduce logistics costs and the total cost of municipal waste management, which considers the amount of waste generated at the point of origin and the cost of transporting waste from the source to the waste disposal site. [13] used a mathematical model for waste management to minimize direct transportation costs. Some studies focused on finding the location of waste sorting points to collect waste before bringing it to the waste disposal site [7]. However, when the problem of finding a suitable route for waste disposal is complicated, heuristics can be applied [14, 15].

Differential evolution (DE) has gained widespread popularity due to its advantages, as it can solve a wide range of problems and get the best results in a shorter amount of time. The method has been applied to solve a variety of problems, such as locating the signal distribution point inside a building [16], vehicle routing problem, and location-routing problem [17]. From the literature review, some research has used modified differential evolution (MDE) to solve the vehicle routing problem in order to increase the efficiency of solid waste management [17-22]. This research will develop a mathematical model to solve the vehicle routing problem for waste disposal and propose a modified differential evolution method to find the solution to the problem of solid waste management in Phetchabun Province, Thailand.

3. Problem statement

The optimal waste management routing issue in Phetchabun Province served as the study's main research challenge. It also considers the issue of properly assigning waste disposal sites to proper waste transportation routes. There are three types of trucks for transporting waste, namely: a four-wheeled truck with a maximum capacity of 2.5 tons and a fuel consumption of 0.08865 l/km, a modified four-wheeled truck with a maximum capacity of 4.0 tons and a fuel consumption of 0.11236 l/km, and a modified six-wheeled truck with a maximum capacity of 6.0 tons and a fuel consumption of 0.13158 l/km. There is only a certain quantity of each type of vehicle, and each type has a different maximum transit volume restriction. Since the location of this case study is a tourist destination with mountainous topography and heavy traffic, the speed of the truck depends on the type of road. The type of road is represented in terms of an increased fuel consumption rate for each route, which is divided into 3 ranges: road type A, speed between 42-55 km/hr, has an increased fuel consumption rate of 1.0455; road type B, speed between 56-63 km/hr, has an increased fuel consumption rate of 1.0382; and road type C, speed between 77-84 km/hr, has an increased fuel consumption rate of 1.0340. Moreover, the limitation of a waste disposal site is that each waste disposal site is only able to dispose of a certain kind of waste, and there is a limit on the daily maximum amount of waste that can be disposed, as shown in Table 1.

From the data survey, it was found that each route has a range of allowable driving speeds. Table 2 shows an example of a metric that takes both speed and distance into account.

Table 1 Information of the waste disposal site

No.	Types of waste disposal points	Amount of waste that can be disposed (ton/day)
1–5	Landfill	7.0, 6.0, 5.0, 7.0 and 6.8
6–7	Mechanical and biological treatment (MBT)	11.0 and 14.0
8–9	Recycling	10.0 and 9.0

Table 2 Example of road type metrics among 5 communities

Community	1	2	3	4	5
1	-	6.997A	15.656A	15.217C	20.304A
2	6.997C	-	8.659A	8.220A	13.306A
3	15.656B	8.659A	-	7.200B	12.287A
4	15.217B	8.220B	7.200B	-	5.087B
5	20.304B	13.306B	12.287C	5.087C	-

According to the aforementioned details, the model of the problem could be defined as a routing problem combined with an assignment problem for a suitable trash disposal site. Phetchabun is a tourist town with a large amount of waste that must be disposed of on a daily basis. The current method of garbage disposal is the use of trucks to transport garbage from each community to the waste disposal site, which can be presented as an assignment problem. The truck will travel from the municipality (a large community) to communities that request waste disposal. In the event that several communities submit their requests at the same time, the truck driver will randomly collect the garbage from one community and then take it to the nearest disposal site before returning to pick up the waste from the remaining communities. Consequently, the truck is required to transport garbage several times in one day. This study presents waste transportation routing and assignment of appropriate waste disposal sites by taking into account the newly explored waste disposal sites in conjunction with existing ones. Figure 1 provides an illustration of the problem.

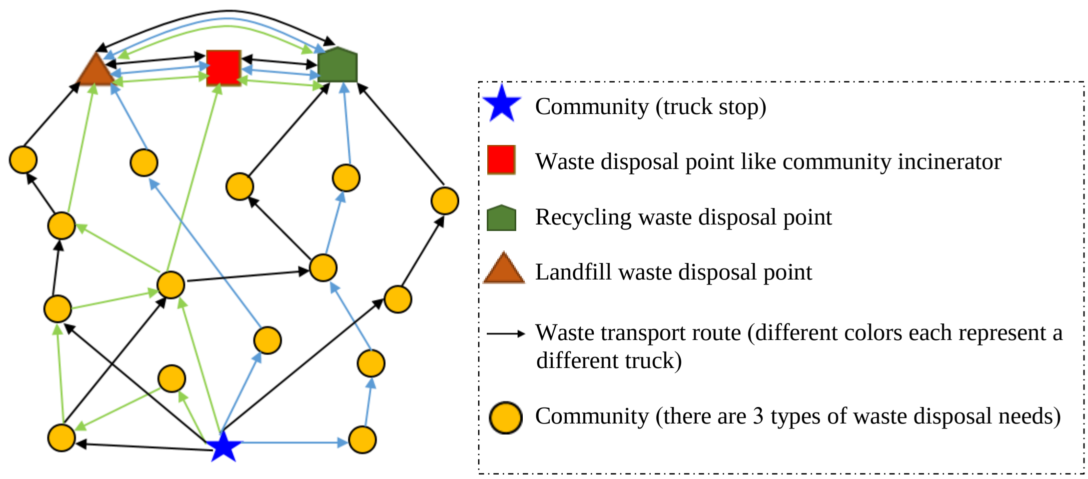

Figure 1 Form of the problem

4. Mathematical model formulation

Indices:

i and j the set of communities and waste disposal points for the case study: i and j numbered 1–9 indicate waste disposal points, and 10–31 indicate communities 1–22 respectively.

t the set of trucks for the case study: t = 1–3 represent 4-wheeled trucks, t = 4–7 represent 4-wheeled trucks (modified), and t = 8–10 represent 6-wheeled trucks (modified).

p the set of garbage types

d a truck stop; $d = 10$

Parameters:

D_{ij} the distance from i to j (in km)

F_t^c the fuel consumption rate of the truck t (in liters per km)

F_{ij}^r the increased fuel consumption rate when traveling from i to j

Q_{ip} the amount of waste type p that needs to be disposed of at point i (in tons)

V_t the maximum loading capacity of the truck at t (in tons)

C_{jp} the maximum capacity to dispose of garbage type p at waste disposal point j (in tons)

$$Y_i \begin{cases} 1 \text{ when } i = 1\text{–}9 \text{ garbage disposal point } i, \\ 0 \text{ in other cases or communities} \end{cases}$$

Decision variables:

$$x_{ijt} \begin{cases} 1 \text{ when truck t travels from point i to point j with truck t} \\ 0 \text{ in other cases} \end{cases}$$

$$y_{it} \begin{cases} 1 \text{ when truck t serves point i} \\ 0 \text{ in other cases} \end{cases}$$

u_{it} the amount of garbage accumulated to prevent sub-path formation (in tons)

$$v_t \begin{cases} 1 \text{ when truck t is used} \\ 0 \text{ in other cases} \end{cases}$$

g_{jpt} the amount of type p waste that truck t disposes of at point j

Objective function:

$$\min = \sum_{i \in I} \sum_{j \in J} \sum_{t \in T} F_t^c F_{ij}^r D_{ij} x_{ijt} \tag{1}$$

Constraints:

Equation (2) ensures that any truck will leave the truck stop on no more than 1 round; when the truck stop is point 10 ($i = d = 10$).

$$\sum_{j \in I} x_{djt} \leq 1 \qquad ; \forall_t \tag{2}$$

Equation (3) ensures that any truck traveling to point i must leave that point.

$$\sum_{j\in I} x_{ijt} = \sum_{j\in I} x_{jit} \quad ;\forall_{i,t} \tag{3}$$

Equation (4) ensures that each truck will not be transported to the maximum capacity of the load.

$$\sum_{i\in I}\sum_{p\in P} Q_{ip} y_{it} \leq V_t \quad ;\forall_t \tag{4}$$

Equation (5) indicates that the community must be served by at least one truck.

$$\sum_{t\in T} y_{it} \leq 1 - Y_i \quad ;\forall_i \tag{5}$$

Equation (6) specifies that the truck will not be allocated to any i community if it is not routed.

$$y_{it} = \sum_{j\in I} x_{ijt} \quad ;\forall_{it\ and\ i\neq d} \tag{6}$$

Equation (7) ensures that the community is served by passing trucks.

$$\sum_{j\in I}\sum_{t\in T} x_{ijt} \leq \sum_{t\in T} y_{it} \quad ;\forall_{i\ and\ i\neq d} \tag{7}$$

The routing of waste transportation from the community to the waste disposal point, or from the waste disposal point to other waste disposal points, will occur when the amount of waste is generated as in Equation (8).

$$\sum_{p\in P} g_{jpt} \leq M \sum_{i\in I} x_{ijt} \quad ;\forall_{jt\ and\ j<d} \tag{8}$$

Equation (9) ensures that any truck will travel to service point i when that truck is being used.

$$Mv_t \geq \sum_{i\in I\ and\ i>d} y_{it} \quad ;\forall_t \tag{9}$$

Equation (10) ensures that when any truck is used it must travel to the waste disposal point.

$$v_t \leq \sum_{j\in I\ and\ j<d} y_{jt} \quad ;\forall_t \tag{10}$$

The amount of each type of waste that trucks pick up from different communities is equal to the amount of waste brought to the waste disposal point, as specified in Equation (11):

$$\sum_{i\in I\ and\ i>d} y_{it} Q_{ip} = \sum_{j\in I\ and\ j<d} y_{jt} g_{jpt} \quad ;\forall_{pt} \tag{11}$$

Equation (12) indicates that the amount of waste disposed of at any site j must not exceed the maximum waste disposal capacity of that site.

$$\sum_{t\in T} g_{jpt} \leq C_{jp} \quad ;\forall_{jp} \tag{12}$$

Equation (13) prevent minor path occurrences.

$$u_{it} - u_{jt} + \sum_{p\in P} Q_{ip} \leq V_t(1 - x_{ijt}) \quad ;\forall_{ijt\ and\ i\neq j} \tag{13}$$

5. Modified Differential Evolution (MDE)

The differential evolution algorithm generally comprises 5 steps: The first step is generating the initial set, the second step is a mutation process, the third step is a recombination process, the next step is a selection process, and the final step is to repeat steps 2–4 and stop at the end of the specified number of rounds. The modified differential evolution algorithm is explained stepwise in the following section.

5.1 Generating the initial set

A target vector containing an M-dimensional array of numbers, each of which may have a value with two decimal places between 0 and 1, serves as the representation of the answer value. The entire number of trucks plus the total number of communities plus the total number of garbage disposal locations may be added to determine the dimensional number of the vector or M value for this problem. As an illustration, consider the original set of 5 sets of data with 5 trucks, 2 points for trash disposal, and 6 points for the community, which finds M, or the number of dimensions of the target vector, equal to 5 + 2 + 6 = 13, i.e., each vector (j) has 13 dimensions, which are encoded as follows. Dimensions 1–5 represent the order of all 5 trucks, respectively, dimensions 6–7 represent the order of the waste disposal at both points, and dimensions 8–13 represent the order of the communities at all 6 points. However, if the vector 1 random values are sequentially 0.29, 0.16, 0.05, 0.03, 0.20, 0.08, 0.60, 0.80, 0.67, 0.74, 0.11, 0.28, and 0.92, the truck's decoding is done in the vector ($j=1$), where the random values for dimensions 1 through 5 are 0.29, 0.16, 0.05, 0.03, and 0.20, respectively. The dimensions will be 5, 3, 2, 1, and 4 when arranged according to dimension (i) in ascending order. Consequently truck 4 will be given priority, followed by trucks 3, 2, 5, and 1 accordingly. Additionally, the community's proportions and the trash disposal facility's dimensions are the same.

5.2 The mutation process

Mutation is the second process of the DE mechanism. Equation (14) is called the mutant vector, presented as follows: DE/rand/1.

$$V_{ijG} = X_{r1jG} + F(X_{r2jG} - X_{f3jG}) \quad [17\text{-}20] \tag{14}$$

where r1, r2, …, rN are the mutual integers that are random within the range 1, 2, ..., N, and F is a mutation scaling factor as 0.5 [17].

5.3 The recombination process

Inbreeding, or the exchange of values from U_{ijG} vector trials, will be recommended for this study in order to provide new results that will be both better and worse than the original results. However, two different CR configurations have been proposed, namely a fixed recombination configuration of 0.5, because there were some experiments with fixed CR values equal to 0.6 and 0.8 and the answer was found to be worse [17]; changing the CR in the solution from 0.9 to 0.1 cycles meant that the initial mass exchange was approved, and remains unmodified until the execution cycle is complete (known as adaptive recombination), as in Equation (15).

$$U_{ijG} = \begin{cases} V_{ijG} & \text{if rand ()} \leq \text{CR} \\ X_{ijG} & \text{otherwise} \end{cases} \tag{15}$$

5.4 The selection process

Three equations are taken into account for picking the target vectors for the subsequent round, the original DE equation calls for choosing the target vector with the best solution out of the old target vectors (X_{ijG}) and the new target vector. As a result of the adjustment of the trial vector (U_{ijG}), where $X_{ij(G+1)}$ is the target vector at i, the j coordinate in cycle G+1 is equal to a vector with a solution value or fitness function that is better between the value of the target vector and the value of the trial vector in cycle G. Nevertheless, selecting of replies in the subsequent cycle of the original DE leads in the possibility of discovering low response values locally, or local minima. Therefore, the selection process consequently resolves this issue by including acceptance of the answer with P_{accept} in Equation (16).

$$X_{ij(G+1)} = \begin{cases} U_{ijG} & \text{if } f(U_{ijG}) > f(X_{ijG}) \\ U_{ijG} & \text{if rand () } > P_{accept} \\ X_{ijG} & \text{otherwise} \end{cases} \tag{16}$$

Equation (16) reveals that this research will accept scenarios where there is a chance of accepting larger than a random value between 0 and 1 and accepting a worse response in a specific number of cycles T, in addition to accepting the value of the trial vector if the answer is better, and returning to the initial response, which provided the local target vector's reverse's maximum value, where P_{accept} stands for the likelihood of acceptance. This study suggests and evaluates the effectiveness of obtaining the correct response using the P_{accept} value and probability in the form SA as in Equation (17).

$$P_{accept} = exp^{-\frac{f(U_{ijG}) - f(X_{ijG})}{T \cdot K}} \tag{17}$$

where $f(U_{ijG})$ is the solution value obtained from the vector U_{ijG}
$f(X_{ijG})$is the solution value obtained from the vector X_{ijG}
T is the temperature drop of the SA process, where $T = 1/G$
K is a constant value; in this study, K represents the mean distance of 50 km.

5.5 Repeat steps 2–4 and stop at 100,000 iterations [17]

The procedure of the proposed heuristics is shown in Figure 2.

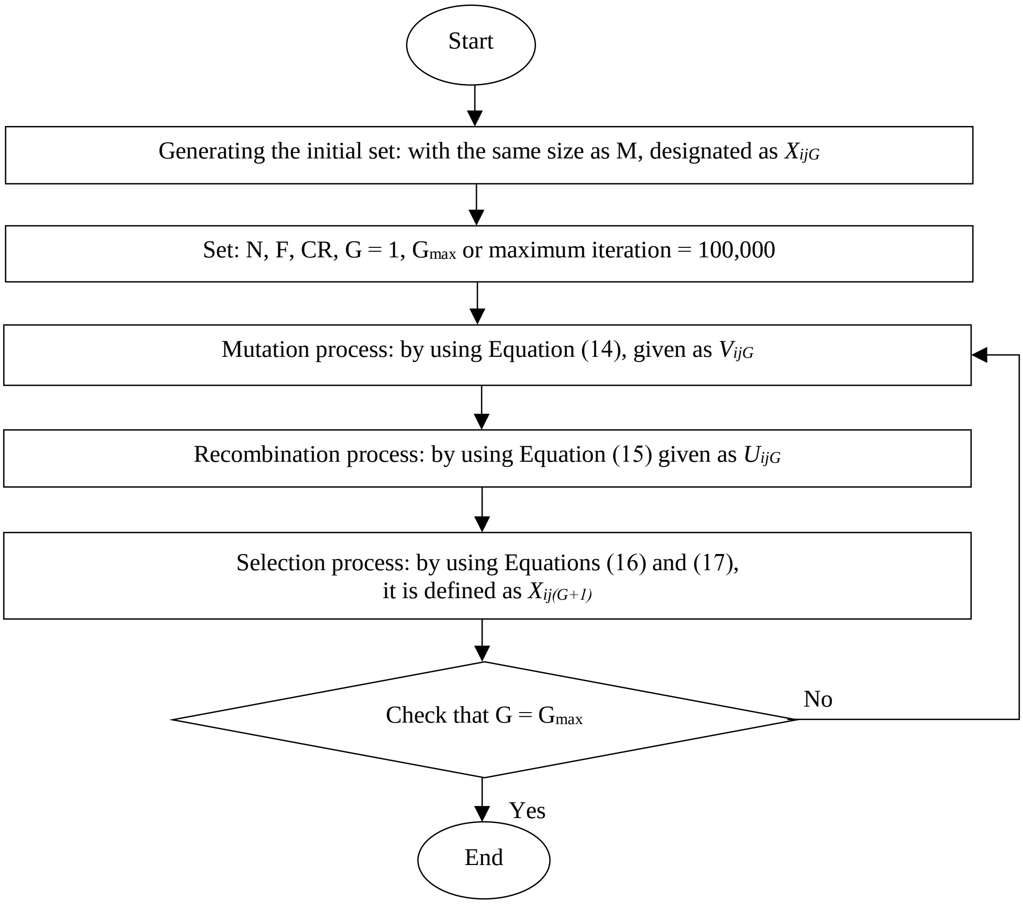

Figure 2 The pseudo code of the modified DE

This led to the establishment of three experimental techniques from the traditional DE development, giving rise to a total of four experimental methods, as follows:

1) Traditional DE method
2) The CR value is fixed at 0.5 in the MDE-1 method's recombination process, and an equation or procedure is used to choose the SA (17).
3) The MDE-2 method is in the recombination process with adaptive CR from 0.9 to 0.1, and there is an SA selection process or Equation (17).
4) Recombination using the MDE-3 approach has an adjustable CR ranging from 0.9 to 0.1, and has a conventional selection process according to Equation (16).

6. Computation experiments

The mathematical model and the adaptive differential evolution algorithm were tested with 18 randomly generated datasets that have different numbers of trucks, types of waste, and communities, as shown in Table 3.

Table 3 Defining the sample sizes

Sample size	Problem code	No. of trucks	No. of waste disposal sites	No. of types of waste	No. of communities
Small	S1–S5	5	2–3	1–2	10
Medium	M1–M5	10	4–5	2–3	20
Large	L1–L5	40	6–9	3	80–100
Case study	C1–C3	10	9	3	22

From Table 3, the numbers of vehicles, waste disposal sites, and types of waste were used to categorize the data into small, medium, and large problems. For example, large problem consists of 40 trucks, 6-9 waste disposal sites for three different waste types, and 80-100 communities. The proposed methods were tested with these problems to find an efficient solution. The results of the lowest fuel consumption obtained from the exact solution, MDE-1, MDE-2, MDE-3, and the original DE, and time used for calculation are shown in Table 4.

Table 4 Result of the experiment comparing the performance of the proposed heuristics

Problem code	Exact solution			DE		MDE-1		MDE-2		MDE-3		% Diff of fuel between exact solution and MDE-1
	Status	Lowest fuel (liters)	Duration (hh:mm:ss)	Lowest fuel (liters)	Duration (hh:mm:ss)	Lowest fuel (liters)	Duration (hh:mm:ss)	Lowest fuel (liters)	Duration (hh:mm:ss)	Lowest fuel (liters)	Duration (hh:mm:ss)	
S1	Optimal	8.69	00:00:01	8.69	00:01:21	8.69	00:01:24	8.69	00:01:14	8.69	00:01:19	0.00
S2	Optimal	10.76	00:00:17	10.76	00:01:15	10.76	00:01:19	10.76	00:01:22	10.76	00:01:18	0.00
S3	Optimal	6.97	00:00:01	6.97	00:01:09	6.97	00:01:21	6.97	00:01:15	6.97	00:01:12	0.00
S4	Optimal	27.21	00:00:08	27.21	00:01:35	27.21	00:01:42	27.21	00:01:35	27.21	00:01:39	0.00
S5	Optimal	24.88	00:00:22	24.88	00:00:59	24.88	00:01:02	24.88	00:01:01	24.88	00:00:55	0.00
M1	Feasible	102.28	24:00:00	83.35	00:05:35	82.82	00:05:32	82.82	00:05:42	83.21	00:05:37	+19.03
M2	Feasible	105.59	24:00:00	90.40	00:06:02	88.18	00:06:11	89.13	00:05:52	89.03	00:06:21	+16.49
M3	Feasible	156.75	24:00:00	124.53	00:05:46	124.43	00:05:36	126.42	00:05:44	125.45	00:05:41	+20.62
M4	Feasible	160.58	24:00:00	150.30	00:05:48	150.21	00:05:52	150.47	00:06:01	150.29	00:05:57	+6.46
M5	Feasible	158.41	24:00:00	142.06	00:04:59	143.40	00:05:21	142.06	00:05:09	143.70	00:05:12	+9.48
L1	Bound	510.74	120:00:00	656.45	00:43:54	540.04	00:46:24	583.54	00:47:07	551.58	00:45:21	-5.74
L2	Bound	527.06	120:00:00	594.84	00:38:33	568.07	00:36:47	636.71	00:38:33	565.73	00:40:27	-7.78
L3	Bound	765.97	120:00:00	925.44	00:50:26	945.10	00:53:44	999.28	00:54:03	899.54	00:53:13	-23.39
L4	Bound	807.07	120:00:00	1070.11	00:52:12	916.26	00:51:18	922.48	00:51:57	1032.88	00:50:52	-13.53
L5	Bound	812.07	120:00:00	1147.44	00:55:14	1099.17	00:57:31	987.67	00:59:38	1147.33	00:56:08	-35.35
C1	Feasible	93.33	24:00:00	63.20	00:08:22	57.63	00:08:45	58.61	00:08:59	60.64	00:08:52	+38.25
C2	Feasible	55.45	24:00:00	37.71	00:07:38	38.20	00:07:54	39.06	00:08:10	40.08	00:08:02	+31.11
C3	Feasible	90.27	24:00:00	66.93	00:08:49	64.13	00:09:13	64.24	00:09:21	65.98	00:09:02	+28.96
Average		245.78		290.63		272.01		275.61		279.66		+4.70

Table 4 shows that, when compared to other MDE methods, the MDE-1 method could provide the lowest average value of fuel consumption (272.01 litters) for solving the vehicle routing problem for waste disposal. More specifically, the fuel consumption was only 57.63 liters for the real case study of C1. According to the current waste disposal transportation survey in case study C1, it uses 112.16 liters of fuel. Therefore, the proposed MDE-1 method can reduce fuel consumption by 54.53 liters, or 48.62%. The fuel consumption of the four proposed methods can be described as a graph of the behavior in finding the solution, as in Figure 3.

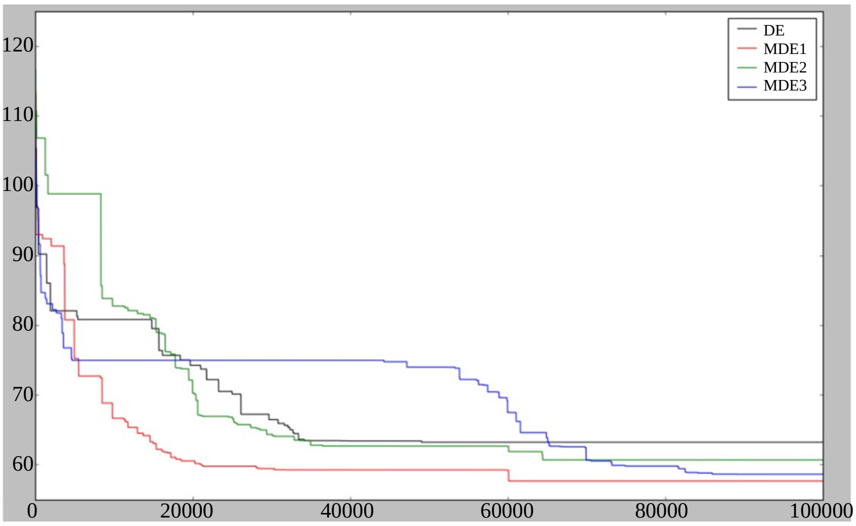

Figure 3 Best solution plot of the case study (C1) with 100,000 iterations

From Figure 3, the MDE-1 method was found not to have the best initial solution value out of the proposed methods, but it was quickly able to find the solution value. This is due to the efficiency of the possibility of finding a solution before narrowing the scope of the solution, according to Equation (17). Moreover, from Table 4, the results obtained from MDE-1 were then compared to the results obtained from the exact solution in order to make sure that the results were accurate and useful for problem solving. The comparative findings indicate that the fuel difference between MDE-1 and the exact solution is, on average, 4.70%. All the problems with a positive (+) sign in the column if %Diff of fuel show that the MDE-1 approach offers a more effective solution than the exact solution. The computation time for solving the problems using the MDE-1 method were also faster than the exact method. The answer value of the exact solution is lower than the MDE-1 for the large problems. However the value obtained from the exact solution is merely a bound value, which is not an exact answer value.

7. Conclusions

This research presents the modified differential evolution method for solving the vehicle routing problem for waste disposal. The method takes into account the characteristics of different transport routes and the fuel consumption rates of vehicles based on real data from the case study in Phetchabun Province, Thailand.

The case study problem is classified as a medium-sized problem that is considered complex and difficult to solve using traditional method. The exact method could take up to 24 hours to find a potential solution, with the best solution not yet found in some problems. In order to tackle this problem, the differential evolution method is modified by using different recombination and selection processes. MDE-1 performs a recombination process by using a fixed CR value of 0.5 and using SA for the selection process. MDE-2 performs a recombination process by using adaptive CR from 0.9 to 0.1 and using SA for the selection process. MDE-3 performs a recombination process by using adaptive CR from 0.9 to 0.1 and conventional DE for the selection process. It has been found that the most effective method is MDE-1.

The vehicle routing problem for waste disposal presented in this study is a complex problem involving several factors, i.e., several waste disposal sites, multiple types of waste, multiple truck types, and different speed limits for different routes. The results showed that the developed DE gave a solution that satisfied all existing conditions and limitations and took no more than 10 minutes to find the appropriate solution for the case study problems. It can be concluded that the solution obtained from MDE-1 is different from the mathematical model at 14.23% for all types of problems. However, the MDE-1 is able to find a solution 99.45% faster for medium- and large-sized problems.

8. References

[1] Japan Meteorological Agency. The state of greenhouse gases in the atmosphere based on global observations through [Internet]. Tokyo: World Meteorological Organization; 2021 [cited 2020 Nov 11]. Available from: https://reliefweb.int/country/wld.

[2] Energy Policy and Planning Office (EPPO). Carbon dioxide (CO2) emissions from energy [Internet]. Bangkok: Ministry of Energy; 2020 [cited 2020 Nov 15]. Available from: https://www.eppo.go.th/index.php/en/en-energystatistics/co2-statistic.

[3] Heinold A, Meisel F. Emission rates of intermodal rail/road and road-only transportation in Europe: a comprehensive simulation study. Transp Res D Transp Environ. 2018;65:421-37.

[4] Khamjan W, Khamjan S, Pathumnakul S. Determination of the locations and capacities of sugar cane loading stations in Thailand. Comput Ind Eng. 2013;66(4):663-74.

[5] Willemse EJ, Joubert JW. Efficient local search strategies for the mixed capacitated Arc routing problems under time restrictions with intermediate facilities. Comput Oper Res. 2019;105:203-25.

[6] Ayeleru OO, Okonta FN, Ntuli F. Municipal solid waste generation and characterization in the city of Johannesburg: a pathway for the implementation of zero waste. Waste Manage. 2018;79:87-97.

[7] Yadava V, Bhurjee AK, Karmakar S, Dikshit AK. A facility location model for municipal solid waste management system under uncertain environment. Sci Total Environ. 2017;603-604:760-71.

[8] Yadav V, Karmakar S, Dikshit AK, Bhurjee AK. Interval-valued facility location model: an appraisal of municipal solid waste management system. J Clean Prod. 2018;171:250-63.

[9] Eiselta HA, Marianov V. Location modeling for municipal solid waste facilities. Comput Oper Res. 2015;62:305-15.

[10] Das S, Bhattacharyya B. Optimization of municipal solid waste collection and transportation routes. Waste Manage. 2015;43:9-18.

[11] Pollution Control Department. Report on the situation of municipal solid waste disposal sites in Thailand for the year 2021 [Internet]. Thailand: Ministry of Natural Resources and Environment; 2021 [cited 2022 Mar 1]. Available from: https://www.pcd.go.th/publication/26832.

[12] Pollution Control Department. National waste management action plan (2022-2027) [Internet]. Thailand: Ministry of Natural Resources and Environment; 2021. [cited 2022 Mar 1]. Available from: https://www.pcd.go.th/wp-content/uploads/2021/10/pcdnew-2021-10-16_05-41-25_882141.pdf.

[13] Asefi H, Lim S. A novel multi-dimensional modeling approach to integrated municipal solid waste management. J Clean Prod. 2017;166:1131-43.

[14] Boonmee C, Arimura M, Asada T. Location and allocation optimization for integrated decisions on post-disaster waste supply chain management: On-site and off-site separation for recyclable materials. Int J Disaster Risk Reduct. 2018;31:902-17.

[15] Asefi H, Lim S, Maghrebi M, Shahparvari S. Mathematical modelling and heuristic approaches to the location-routing problem of a cost-effective integrated solid waste management. Ann Oper Res. 2019;273:75-110.

[16] Goudos SK, Plets D, Liu N, Martens L, Joseph W. A multi-objective approach to indoor wireless heterogeneous network planning bases on biogeography-bases optimization. Comput Netw. 2015;91:564-76.

[17] Supattananon N, Akararungruangkul R. Modified differential evolution algorithm for a transportation software application. J Open Innov Technol Mark Complex. 2019;5(4):84.

[18] Sethanana K, Pitakaso R Differential evolution algorithms for scheduling raw milk transportation. Comput Electron Agric. 2016;121:245-59.

[19] Moonsri K, Sethanan K, Worasan K. A novel enhanced differential evolution algorithm for outbound logistics of the poultry industry in Thailand. J Open Innov Technol Mark Complex. 2022;8(1):15.

[20] Zou D, Liu H, Gao L, Li S. A novel modified differential evolution algorithm for constrained optimization problems. Comput. Math. Appl. 2011;61(6):1608-23.

[21] Moonsri K, Sethanan K, Worasan K, Nitisiri K. A hybrid and self-adaptive differential evolution algorithm for the multi-depot vehicle routing problem in egg distribution. Appl Sci. 2022;12(1):35.

[22] Gonwirat S, Surinta O. Optimal weighted parameters of ensemble convolutional neural networks based on a differential evolution algorithm for enhancing pornographic image classification: Eng Appl Sci Res. 2021;48(5):560-9.