Scientific Journal of Informatics
Vol. 10, No. 4, Nov 2023

p-ISSN 2407-7658 http://journal.unnes.ac.id/nju/index.php/sji e-ISSN 2460-0040

Enhancing Transportation Route Optimization Through Genetic Algorithm-Based Vehicle Routing Problem Method

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Abstract.
Purpose: The purpose of this study is to identify effective and efficient waste collection route for cost savings. The focus is on Tembalang District, where waste management has been compromised due to inefficient transportation.
Methods: The study employs genetic algorithm to ascertain the optimal routes for waste collection vehicles. This method seeks to design an improved transportation system, taking waste from transfer stations (TPS) to landfills.
Results: The devised waste transport model from the study demonstrated an optimized route for Tembalang Sub-District, with a total distance of 17.90 km and took 49 minutes. This contrasts with the existing route defined by the Sanitation Department, which spans 18.20 km and requires 1 hour and 15 minutes.
Novelty: Innovative application of the Vehicle Routing Problem method coupled with the Genetic Algorithm. This approach resulted in a significant reduction of time (by 35%) compared to traditional routing systems, and thus minimizing the number of waste collection vehicles required and enhancing overall waste management in Semarang.

Keywords: Algorithm, Vehicle routing, Transport route optimization, Waste transportation routes
Received August 2023 / **Revised** October 2023 / **Accepted** November 2023

INTRODUCTION

Computational systems in waste management have become a major issue in various countries. The amount of waste and solid waste produced in any region is proportional to population growth and commercial and industrial activities [1], [2]. The global community agrees on the adverse effects of waste on the environment, natural resources (e.g. groundwater), and human health if not treated effectively; therefore, it is inevitable that local authorities will have to determine effective and efficient waste and solid waste management systems [3].

Many researchers have studied truck routing problem, well-known as a vehicle routing problem (VRP) in the optimization literature. As defined in [4], VRP is mainly concerned with optimization problems that aims to identify efficient and optimal vehicle (truck) routes (with minimal mileage) [5].

In 2022, Semarang's waste volume reached 1.150 tons per day, which were transported to the final disposal location in Jatibarang landfill (TPA). The refuse came from 266 transfer stations (TPS) scattered in 13 districts. To regulate waste management, Semarang City Regulation No. 6 of 2012 concerning Waste Management consists of waste reduction and handling. Waste reduction includes limiting waste generation, recycling, and reuse of waste [6]. Meanwhile, waste handling includes compartment and sorting, collection, transportation, processing, and final processing. However, the collection and transportation of refuse are currently limited to handling of solid waste starting from storage to final processing, without the schedule and distribution of the nearest refuse collection route from the TPS to the TPA [7], [8]. The current problem is separate waste management at the sub-district level without an integrated management system in Semarang City [9].

Judging from these problems, it is necessary to have a plan for developing systematic waste management in Semarang city area to optimize the operational technical sub-system supported by other non-technical sub-systems [10]. The problem of vehicle routing problem (VRP) can be defined as the problem of selecting an optimal route which results in the most efficient use of cost of a garbage disposal or TPS to

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DOI: 10.15294/sji.v10i4.47049

other transfer stations with several different requests [11]. In this route, discharge of refuse by a collection vehicle to a waste depot is expected to be made only once. The description of problems in the process of garbage collection is the existence of intermediate facilities that each collection vehicle must pass in the route before returning to the depot [12].

The collection process starts from the depot, then to the TPS, and afterward to the TPA as an intermediate facility, and finally returns to the TPS. If the allowed period of time has ended, the collection truck must return to the depot. This research combined the facilities between (intermediate facilities) and multiple trips, which is the development of vehicle routing problem (VRP) [13]. VRP was developed by adding intermediate facilities to solve the problem of waste collection routes using genetic algorithms.
The formulation of the problem in the study found that the current transportation of waste in the city of Semarang is still ineffective because the transportation level is below 80% of the transported waste [14]. This research implements an effective and efficient waste scheduling and route collection system using genetic algorithms [15], [16] and MATLAB. This is because, at present, we believe that there is no optimal and effective scheduling and collection system in terms of waste collection, which may certainly affect cost efficiency [13].

The objectives of this study are to obtain an optimal scheduling system and garbage collection route from one TPS to another, and then to TPA by overcoming the obstacles that occur to produce cost-efficient process by using the genetic algorithm method.

METHODS

The research methodology has a role in helping to solve the problem more directly and systematically. In the research methodology, the stages are as follow: creating an initial map of the waste transport network, data collection, data processing and analysis, verification of results, validation of results, conclusions, and suggestions [17].

The process of this study involved several stages and procedures which could help answer the research problems [18]. The research process is illustrated in Figure 1 below.

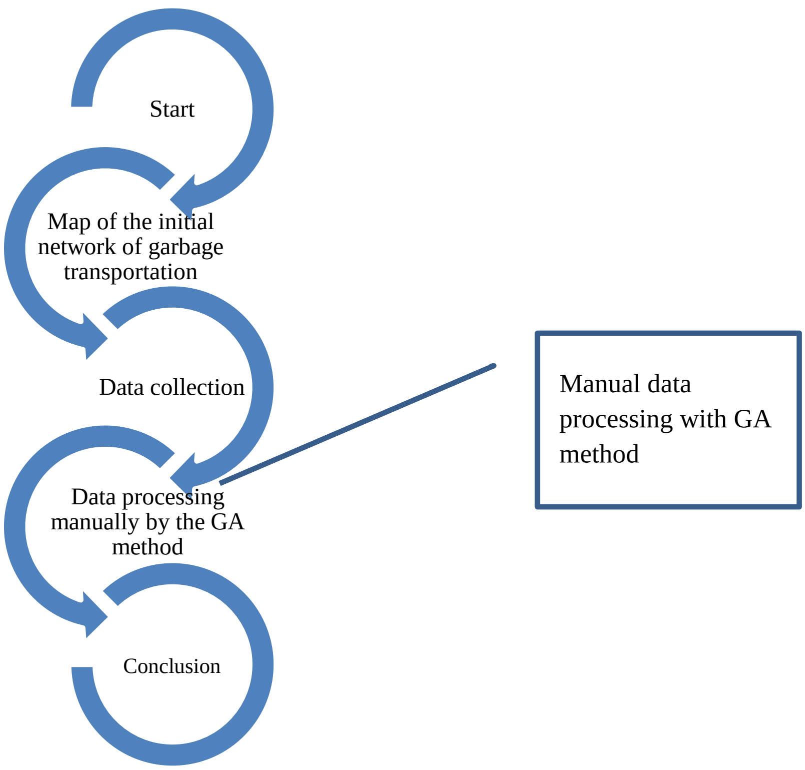

Figure 1. Research process

Research Data

In this research, the data was collected from the database of the Department of Sanitation and Parks of Semarang City. The data used in the data analysis include: (a) waste volume data, (b) TPS location data, (c) transportation fleet data and capacity, (d) transportation route data that has been implemented by the current Sanitation Department (SOP), and (e) map of Semarang City. Data was collected through literature study, observation, and interview [12], [19].

Data Analysis

The data analysis and testing stage were the two stages of determining the optimal route of waste transportation using MATLAB. The next stage was interpreting the results of the route determination [20].

RESULTS AND DISCUSSIONS

Initial network mapping

This study aims to determine the shortest optimal route for the waste transportation network from each transfer station (TPS) to Jatibarang final disposal site (TPA) located in Kedungpane Village, Mijen Sub-District, Semarang City. The genetic algorithm was used as a path-finding method to find the optimization because of its ease of implementation. Data on the location of the distribution of TPS were obtained from the Environment Agency (DLH) of Semarang City and road network data from Google Maps. Then the data was arranged in graph network drawings that illustrated the points of TPS, TPA, and crossroads likely to be passed by collection trucks [7].

Study samples were taken from three sub-districts: West Semarang Sub-District, Central Semarang Sub-District, and East Semarang Sub-District. To identify the map of the transportation route network, network map data was compiled using the data based on the SOP of the Environment Agency of Semarang City.

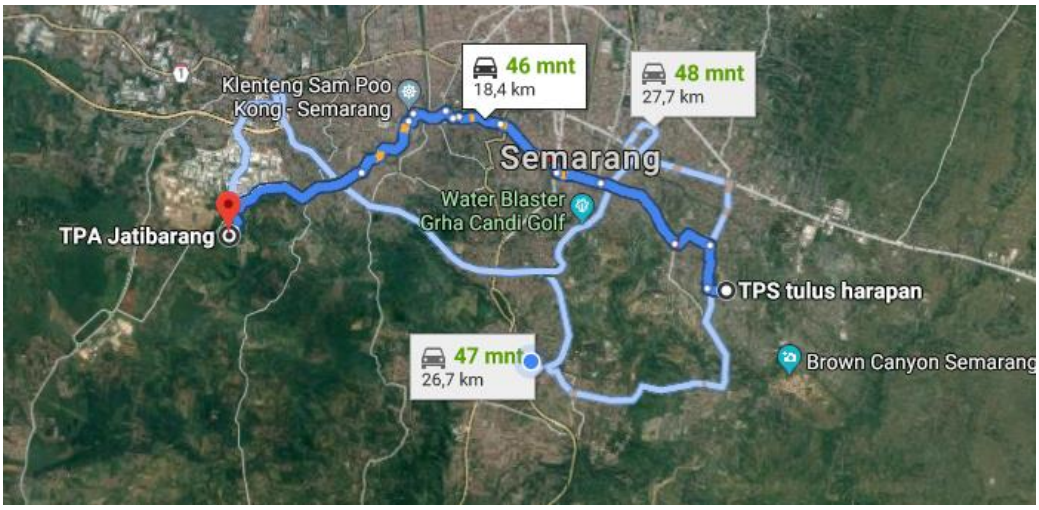

Figure 2. Key object of research: Tembalang

Map of Waste Transport Network

The first stage carried out in this research was to create a garbage transport route in Semarang City. The route included roads passed by collection trucks from a TPS to TPA Jatibarang according to the permitted route traversed by collection vehicles set by the Semarang City Transportation Agency [21]. The road network started with a starting point, a TPS in a sub-district, and ended with an endpoint, which was TPA Jatibarang.

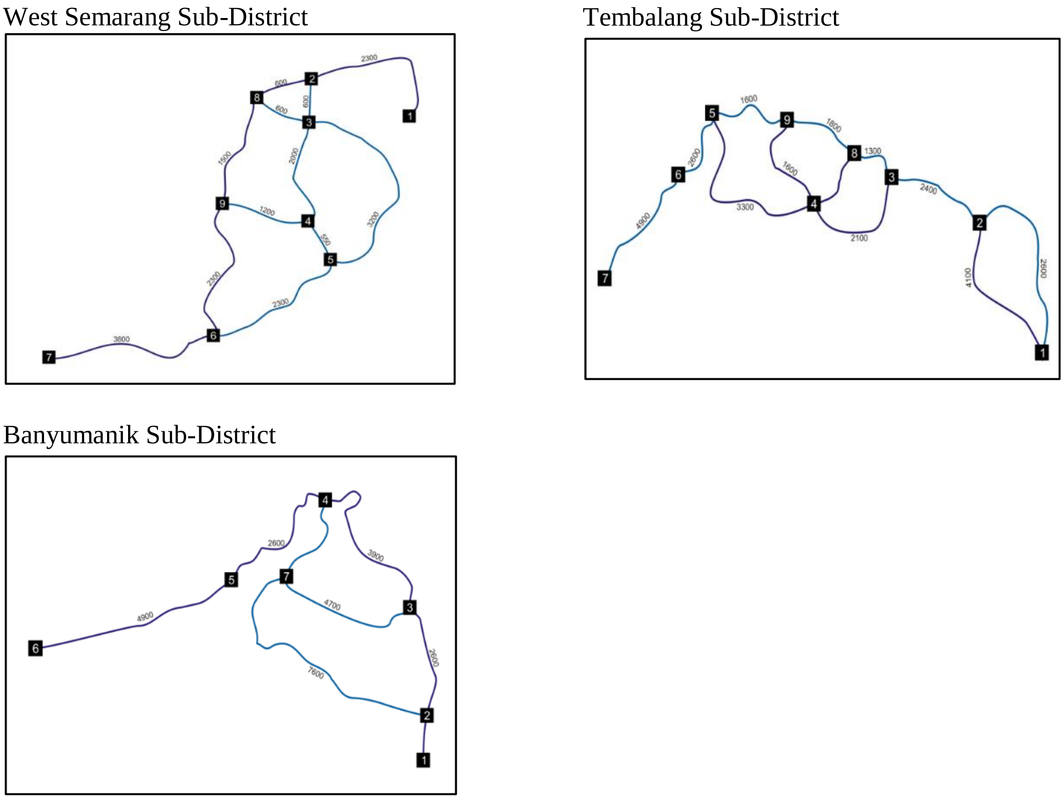

Figure 3. Map of waste transport network

Genetic Algorithm Calculation

Table 1. Gene determination

	Tembalang Sub-District	Banyumanik Sub-District	West Semarang
Gen 13	TPS Tulus Harapan	TPS Kel. Nyesrep	TPS Kel. Bojongsalaman
Gen 2	Ketileng Raya	Setiabudi	Siliwangi
Gen 3	Kedungmundu	Karangrejo	Jend. Sudirman
Gen 4	Tentara Pelajar	Teuku Umar	Abdurrahman Saleh
Gen 5	Sriwijaya	Sultan Agung	Puspowarno
Gen 6	Veteran	Letjen S.Parman	Puspogiwang
Gen 7	Dr.Wahidin	Pawyatan Luhur	Pamularsih
Gen 8	Diponegoro	Papandayan	W.R Supratman
Gen 9	Letjen S.Parman	Kelud Raya	Suratmo
Gen 10	Kaligarang	Kaligarang	Srirejekiraya
Gen 11	Simongan	Simongan	Simongan
Gen 12	Untung Suropati	Untung Suropati	Untung Suropati
Gen 1	Jatibarang	Jatibarang	Jatibarang

There were 13 genes in the chromosome that formed a route that started and ended simultaneously.

Table 2. Determination of Individuals

Individual 1	13 8 9 10 11 5 6 12 4 3 1 2 7
Individual 2	8 9 10 11 5 6 12 4 3 2 7 13 1
Individual 3	13 1 2 7 8 10 11 9 5 6 12 4 3
Individual 4	5 13 8 9 10 11 6 12 4 3 1 2 7
Individual 5	12 4 3 1 2 7 13 8 9 10 11 5 6
Individual 6	9 10 11 6 5 12 4 13 8 3 1 2 7
Individual 7	13 1 2 7 8 9 10 11 5 6 4 3 12
Individual 8	6 12 4 3 13 1 2 7 8 9 10 11 5
Individual 9	12 4 3 1 2 7 13 8 9 10 11 5 6
Individual 10	6 12 4 3 10 13 1 2 7 8 9 11 5
Individual 12	9 10 11 5 6 12 4 3 1 2 7 13 8
Individual 13	5 6 12 4 3 7 13 8 1 2 9 10 11

The initial population generation in this study produced a population size of 13 individuals. These individuals were then calculated for the value of each fitness.

Table 3. Fitness score

Fitness Value	Tembalang Sub-District	Banyumanik Sub-District	West Semarang
Individual 1	0.0571	0.0492	0.0952
Individual 2	0.0529	0.0555	0.0865
Individual 3	0.0584	0.0534	0.0819
Individual 4	0.5154	0.0520	0.0900
Individual 5	0.0552	0.0549	0.0840
Individual 6	0.0558	0.0502	0.0925
Individual 7	0.0574	0.0537	0.0833
Individual 8	0.0546	0.0531	0.0854
Individual 9	0.0578	0.0512	0.0913
Individual 10	0.0534	0.0546	0.0884
Individual 11	0.0564	0.0523	0.0934
Individual 12	0.0537	0.0498	0.0862
Individual 13	0.0561	0.0515	0.0826

After calculating the fitness value of each individual, we obtained three best fitness values from the population above: Tembalang Sub-District was the third with a fitness value of 0.0584, Banyumanik Sub-District the second with 0.0555, and West Semarang Sub-District the first with 0.0952. The individual with the best fitness value from this generation's population would be propagated to the next generation. The next step is to select individual as the parent [22], [23].

Table 4. Ranking selection

1)	Parent 1 = Individual 12 =	9 10 11 5 6 12 4 3 1 2 7 13 8
	Parent 2 = Individual 3 =	13 1 2 7 8 10 11 9 5 6 12 4 3
2)	Parent 1 = Individual 1 =	13 8 9 10 11 5 6 12 4 3 1 2 7
	Parent 2 = Individual 3 =	13 1 2 7 8 10 11 9 5 6 12 4 3
3)	Parent 1 = Individual 6 =	12 4 3 1 2 7 13 8 9 10 11 5 6
	Parent 2 = Individual 2 =	8 9 10 11 5 6 12 4 3 2 7 13 1
4)	Parent 1 = Individual 1 =	9 10 11 5 6 12 4 3 1 2 7 13 8
	Parent 2 = Individual 4 =	5 13 8 9 10 11 6 12 4 3 1 2 7
5)	Parent 1 = Individual 10 =	12 4 3 1 2 7 13 8 9 10 11 5 6
	Parent 2 = Individual 10 =	12 4 3 1 2 7 13 8 9 10 11 5 6
6)	Parent 1 = Individual 12 =	9 10 11 5 6 12 4 3 1 2 7 13 8
	Parent 2 = Individual 1 =	13 8 9 10 11 5 6 12 4 3 1 2 7

The individuals above were selected as parents by a ranking process for seven times, which produced 14 parents. Then, 14 mains were selected, and 15 new populations were obtained with one additional population, namely a copy of the individual with the best fitness value in the previous generation. The first parent and second parent were then moved to the cross to get new children or offspring.

Table 5. Cross over

1)	Child 1 =	4 3 1 2 7 13 8 10 11 9 5 6 12
	Child 2 =	8 10 11 9 5 6 12 4 3 2 7 13 1
2)	Child 1 =	3 1 2 7 8 10 11 9 5 6 13 12 4
	Child 2 =	8 10 11 9 5 6 12 4 3 1 2 7 13
3)	Child 1 =	13 8 9 10 11 5 6 12 4 3 1 2 7
	Child 2 =	2 7 13 1 8 9 10 11 5 6 12 4 3
4)	Child 1 =	11 5 6 2 7 12 4 3 1 13 8 9 10
	Child 2 =	5 13 8 9 10 11 6 12 4 3 1 2 7
5)	Child 1 =	5 13 8 9 10 11 6 12 4 3 1 2 7
	Child 2 =	5 8 9 10 11 6 12 4 3 1 2 7 13
6)	Child 1 =	9 10 11 5 6 12 4 3 1 2 7 13 8
	Child 2 =	9 10 11 5 6 12 4 3 1 2 7 13 8
7)	Child 1 =	13 8 9 10 11 5 6 12 4 3 1 2 7
	Child 2 =	9 10 11 5 6 12 4 3 1 2 7 13 8

Children resulting from the cross-transfer process above then underwent a mutation process. The mutation process was carried out on children from crossing to obtain new individuals as candidates for solutions in the next generation with better fitness and, over time, towards the desired optimum solution [24].

Table 6. Mutation

1)	New individual child 1 =	4 3 1 2 7 13 8 10 11 9 5 6 12
	New individual child 2 =	8 10 11 9 5 6 12 4 3 2 7 13 1
2)	New individual child 1 =	3 1 2 7 8 10 11 9 5 6 13 12 4
	New individual child 2 =	8 10 11 9 5 6 12 4 3 1 2 7 13
3)	New individual child 1 =	13 8 9 10 11 5 6 12 4 3 1 2 7
	New individual child 2 =	2 7 13 1 8 9 10 11 5 6 12 4 3
4)	New individual child 1 =	11 5 6 2 7 12 4 3 1 13 8 9 10
	New individual child 2 =	5 13 8 9 10 11 6 12 4 3 1 2 7
5)	New individual child 1 =	5 13 8 9 10 11 6 12 4 3 1 2 7
	New individual child 2 =	5 8 9 10 11 6 12 4 3 1 2 7 13
6)	New individual child 1 =	9 10 11 5 6 12 4 3 1 2 7 13 8
	New individual child 2 =	9 10 11 5 6 12 4 3 1 2 7 13 8
7)	New individual child 1 =	13 8 9 10 11 5 6 12 4 3 1 2 7
	New individual child 2 =	9 10 11 5 6 12 4 3 1 2 7 13 8

In individual 2, the new individual child, 1 result from a swapping mutation of the sixth chromosome, exchanged with the eighth chromosome. The new individuals produced will be used to form new populations in the second generation [22].

After the above steps are carried out, the next population is formed in the second generation [21]. The best individual with the highest fitness value in the initial population is taken to the next population. This process is called elitism [25].

Table 7. New population

	Tembalang Sub-District	Banyumanik Sub-District	West Semarang
Individual 1	13 8 9 10 11 5 6 12 4 3 1 2 7	12 4 3 1 2 7 13 8 9 10 11 5 6	9 5 6 12 4 3 2 7 13 1 8 10 11
Individual 2	4 3 1 2 7 13 8 10 11 9 5 6 12	9 10 11 5 6 12 4 7 1 2 3 13 8	8 10 11 9 5 6 13 12 4 3 1 2 7
Individual 3	8 10 11 9 5 6 12 4 3 2 7 13 1	9 10 11 5 6 12 4 3 1 2 7 13 8	9 5 2 12 4 3 1 6 7 13 8 10 11
Individual 4	3 1 2 7 8 10 11 9 5 6 13 12 4	11 9 5 6 13 12 4 3 1 2 7 8 10	5 6 12 4 3 1 2 7 13 8 9 10 11
Individual 5	8 10 11 9 5 2 12 4 3 1 6 7 13	3 1 2 7 13 5 8 9 10 11 6 12 4	8 9 10 11 5 6 12 4 3 2 7 13 1
Individual 6	13 8 9 10 11 5 6 12 4 3 1 2 7	10 11 6 12 4 3 1 2 7 5 13 8 9	7 12 4 3 1 13 8 9 10 11 5 6 2
Individual 7	2 7 13 1 8 9 10 11 5 6 12 4 3	3 1 2 7 5 13 8 9 10 11 6 12 4	10 11 6 12 4 3 1 2 7 5 13 8 9
Individual 8	11 5 6 2 7 12 4 3 1 13 8 9 10	12 4 3 1 13 8 9 10 11 5 6 2 7	13 8 9 10 11 6 12 4 3 1 2 7 5
Individual 9	5 13 8 9 10 11 6 12 4 3 1 2 7	8 9 10 11 5 6 12 4 3 2 7 13 1	10 11 6 12 4 3 1 2 7 13 5 8 9
Individual 10	5 13 8 9 10 11 6 12 4 3 1 2 7	3 1 2 7 13 8 9 10 11 5 6 12 4	12 4 3 1 2 7 13 8 9 10 11 5 6
Individual 11	5 8 9 10 11 6 12 4 3 1 2 7 13	3 1 6 7 13 8 10 11 9 5 2 12 4	5 6 12 4 3 1 2 7 13 8 9 10 11
Individual 12	12 4 3 1 2 7 13 8 9 10 11 5 6	8 10 11 9 5 6 13 12 4 3 1 2 7	12 13 8 9 10 11 5 6 4 3 1 2 7
Individual 13	9 10 11 5 6 12 4 3 1 2 7 13 8	4 3 2 7 13 11 9 8 10 1 5 6 12	6 12 4 7 1 2 3 13 8 9 10 11 5

The procedures for determining the value of fitness, selection, cross-over, and mutation were carried out in the second generation to determine the population in the next generation. Iteration is carried out to obtain optimum and convergent fitness values in certain generations [26]. The most optimum and convergent fitness was in the 134th generation. The new population of the 134th generation is as follows.

Table 8. New population

	Tembalang Sub-District	Banyumanik Sub-District	West Semarang
Individual 1	1 2 7 13 8 9 10 11 12 5 6 4 3	2 4 13 1 12 7 3 8 9 10 11 5 6	2 5 6 12 4 3 9 7 13 1 8 10 11
Individual 2	11 3 1 2 7 12 13 8 9 10 5 6 4	9 1 11 5 6 12 4 7 13 2 3 10 8	8 10 11 7 5 6 9 12 4 3 1 2 13
Individual 3	4 12 13 8 9 10 11 5 6 3 1 2 7	9 10 13 5 6 12 4 3 11 2 7 1 8	7 5 2 12 8 3 1 6 4 13 9 10 11
Individual 4	5 6 4 12 13 8 9 10 11 3 1 2 7	1 9 5 6 13 12 4 3 11 2 7 8 10	5 6 2 4 3 1 12 7 13 8 9 10 11
Individual 5	8 9 10 11 6 4 3 1 12 5 2 7 13	3 1 12 7 13 5 8 9 10 2 6 11 4	8 1 10 12 5 6 11 4 3 2 7 13 9
Individual 6	11 5 6 12 4 3 1 2 7 13 8 9 10	10 11 6 13 4 3 1 12 7 5 2 8 9	4 12 5 3 1 13 8 9 10 11 7 6 2
Individual 7	5 6 12 4 3 13 8 9 10 11 1 2 7	3 1 2 7 5 13 4 9 10 11 6 12 8	10 11 6 7 4 3 1 12 2 5 13 9 8
Individual 8	7 5 6 12 4 3 13 8 9 10 1 2 11	12 4 13 11 3 8 9 10 1 5 6 2 7	13 8 9 10 11 6 12 4 3 1 2 7 5
Individual 9	7 12 3 1 2 13 8 9 10 11 5 6 4	8 9 1 10 11 5 6 12 4 3 2 7 13	5 10 6 12 4 3 1 2 7 13 11 8 9

Individual 10	11 5 6 9 4 3 1 2 7 12 13 8 10	3 11 2 7 13 8 9 1 12 5 6 10 4	12 13 3 1 2 7 6 8 9 10 11 5 4
Individual 11	11 3 1 2 7 9 12 5 6 4 13 8 10	3 1 6 7 13 8 10 11 9 5 12 2 4	9 6 5 4 3 1 2 7 13 8 12 10 11
Individual 12	8 9 10 11 5 13 6 12 4 3 1 2 7	8 10 11 5 6 13 12 4 3 1 2 9 7	12 13 11 9 10 6 5 8 4 3 1 2 7
Individual 13	5 6 12 13 8 9 10 11 4 3 1 2 7	4 3 12 7 13 11 9 8 10 1 5 6 2	12 4 7 5 2 3 13 8 6 9 10 11 1

Based on the fitness results of the new population above, an individual could be obtained as a solution in 3 (three) sample districts in Tembalang Sub-District; individual 6 was the solution because it had the highest fitness value of 0.0561. In Banyumanik Sub-District, individual 2 was the solution because it had the highest fitness value of 0.0689. Finally, individual 1 was the solution in West Semarang Sub-District because it had the highest fitness value of 0.0952.

CONCLUSION

The results of the calculations with genetic algorithms showed the solution to the problem of transporting waste in Semarang City research samples. Tembalang Sub-District illustrates this point clearly. In this sub-district, the shortest route to TPA Jatibarang was from TPS Harapan, passing Jl. Ketileng Raya, Jl. Kpapanmundu, Jl. Tentara Pelajar, Jl. Diponegoro, Jl. Papandayan, Jl. Kaligarang, Samongan Raya, and Jl. Surung Suropati. The distance of the route was 17.90 km and took about 49 minutes. Compared to the standard used by DLH which used a conventional routing model, with total travel time of 1 hour and 15 minutes and total distance of the route of 18.20 km, the proposed route could increase efficiency and reduce wasted time by up to 35%.

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