Available online at : http://josi.ft.unand.ac.id/

Jurnal Optimasi Sistem Industri

| ISSN (Print) 2088-4842 | ISSN (Online) 2442-8795 |

Jurnal Optimasi Sistem Industri

Case Study

Application of Genetic Algorithms to Solve MTSP Problems with Priority (Case Study at the Jakarta Street Lighting Service)

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Article Information

Received : July 3, 2022
Revised : November 4, 2022
Available online : November 30, 2022

Keywords

Transportation, Multiple TSP, Priority Node, Genetic Algorithm, Neighbor Algorithm

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A B S T R A C T

Transportation is one thing that is very important and is the highest cost in the supply chain. One way to reduce these costs is to optimize vehicle routes. The Multiple Traveling Salesman Problem (MTSP) and Capacitated Vehicle Routing Problem (CVRP) are models that have been extensively researched to optimize vehicle routes. In its development based on actual events in the real world, some priorities must be visited first in optimizing vehicle routes. Several studies on MTSP and CVRP models have been conducted with exact solutions and algorithms. In a real case in the Jakarta City Street Lighting Section, the problem of determining the route in three shifts is a crucial problem that must be resolved to increase worker productivity to improve services. Services in MCB (Miniature Circuit Breaker) installation and maintenance activities for general street lights and priority is given to light points that require replacement. Because, in this case, the delivery capacity is not taken into account, the priority of the lights visited is random, and the number of street light points is enormous, in this study, we use the MTSP method with priority and solve by a genetic algorithm assisted by the nearest neighbor algorithm. From the resolution of this problem, it was found that the travel time reduction was 32 % for shift 1, 24 % for shift 2, and 23 % for shift 3. Of course, this time reduction will impact worker productivity so that MCB installation can be done faster for all lights and replace a dead lamp.

INTRODUCTION

Transportation in the supply chain is the movement of products from one location to another to get to the hands of consumers. Transportation is one of the most costly activities in the supply chain [1]. Therefore, the supply chain must minimize transportation costs [2]. One of the most common problems in transportation planning problems is the arrangement of the fleet used to carry out transportation activities. The operation of transportation activities is faced with several operational constraints, such as vehicle capacity, travel, and delivery time limits, or time windows limitations [3].

Several methods can reduce transportation costs. One way that can be done is by optimizing vehicle routes. A way that can be done is to find the minimum total distance, commonly known as the traveling salesman problem (TSP). Transportation routes start from the starting point to several places and return to that starting point, and delivery to each location is only once. In its development, several variations of the TSP model aim to represent the actual situation. In addition to model development, many variations of developing TSP solving algorithms. Several optimization methods used to solve TSP include Hill Climbing Method, Ant Colony System, Dynamic Programming, Greedy Algorithm, Brute Force Algorithm, and Genetic Algorithm [4]. Research on the TSP model with a priority level has been carried out by [5] and [6]. These two studies focus on disaster management with the level of delivery priority based on the location and radius of the natural disaster so that the delivery priority follows the severity of the impact of the disaster.

The other model is the Vehicle routing problem (VRP). VRP is one of the problems in transportation to design optimal delivery routes from one or several depots to some cities or consumers spread over a specific geographic area and must meet some operational limitations [7]. At the operational level, two kinds of decisions must be made. The first is the assignment of vehicles to serve several consumers. The second is to determine the order of consumers that will be visited by each vehicle. The number and size of available vehicles are a limitation at the operational level. At the tactical level, the decisions taken are how many, what size, and how many types of vehicles to have [3]. VRP is an essential supply chain optimization model to determine the shortest and optimal route. VRP is an extension model or

DOI: 10.25077/josi.v21.n2.p75-86.2022

variation of the Traveling Salesman Problem (TSP) [8]. The Capacitated Vehicle Routing Problem (CVRP) is also a development model of the basic VRP, which this model is created to solve problems in determining the optimal route in the presence of vehicle capacity limitations [9]. The VRP model development with delivery priority has been developed by [10] based on importance, [11] based on preference, [12] based on limited resources, [13] based on Emergency Response Plans, and [14] based on stochastic demand.

This study will discuss the determination of routes in the service sector in an urban environment inspired by the real problems faced by the Street Lighting Section in the City of Jakarta, which is responsible for the maintenance of street lighting in the City of Jakarta. The tasks that the Street Lighting Section must carry out are installing public street lights or carrying out maintenance activities on public street lights so that when carrying out their operational tasks, the problem of determining the route is often encountered by the Street Lighting Section.

Public street lighting systems throughout DKI Jakarta currently use smart system technology. Suppose some lights go out due to damage. In that case, there is a notification about this on the system monitor room screen so that the operator can immediately give work orders to operational officers to repair the lamp. Notifications that appear include the location of the lights that are out and the type of lights. The priority of the work carried out is handling the dead lights. After the dead lights are handled, then other work that has been planned will be carried out next.

There are three shifts in the Street Lighting Section. The first is at 00.00-08.00, the second is at 08.00-16.00, and the third is at 16.00-24.00. In the first and third shifts, the tasks are replacing the lights reported to be out and checking all the lights. In the second shift, apart from replacing the lights that were reported to be out on the second shift, the MCB Box was also installed. This research coincided with the installation of MCB Boxes for all existing lights. Complete activities for each shift can be seen in Appendix A.

Due to a large number of light points in the entire Central Jakarta Administrative City, approximately 2196, the research will be limited to Senen District. Senen is a sub-district in Central Jakarta that has all been installed with smart system lights when the data collection process is carried out Senen has 274 light points. The division of the operational vehicle fleet uses pick-up cars for the overall operational activities of the lights. The pick-up car is equipped with two ladders made of bamboo and fiber. While the ladder car is used for lamp maintenance that uses heavy equipment, such as the installation of generators.

Based on an interview with the Regional Leader for Senen Sub-district, the current productivity of workers can be said to be low. It is evidenced by workers who have returned from operational activities in the field one to two hours before the shift ends. This problem results in light points not being visited in day and night circles (shifts one and 3). It causes when there is damage that is not detected, it cannot be immediately handled. As for shift 2, there is no planning regarding the number of MCB Boxes, and light points are not visited. The cause of the low productivity is the absence of a standard route that is set to carry out operational activities in the field for the entire shift.

So referring to the background and problem identification, it is crucial for the Street Lighting Section, which is in charge of carrying out operational activities, to have a route for these activities. Problems in the Street Lighting Section can be modeled with the Multiple Traveling Salesman Problem with priority nodes for shift one at 00.00-06.00, shift two and shift three, and Multiple Traveling Salesmen Problem for shift one at 06.00-08.00. The problem that can be modeled with MTSP is the vehicle route problem, where the vehicle departs from the starting point, visits all points exactly once, and then returns to the starting point. There is no capacity limit on this problem. Therefore, MTSP is appropriate if it is used to solve the problems of the Street Lighting Section. The goal is to minimize the time taken at each light point. When travel time can be minimized, more light points will be visited, and the productivity of workers will increase.

METHOD

Multiple Traveling Salesman Problem (MTSP) is a generalization of the Traveling Salesman Problem (TSP), where more than one salesman travels [15]. Given several cities, one point location (location of m salesmen), and cost metrics. The purpose of MTSP is to determine the route of *m* salesmen so that the total cost of m routes can be minimized. Cost metrics can describe cost, distance, or time. The provision of the route used is for the entire route. It must start and end at the same location. Then, each location must be visited once by only one salesman.

MTSP can be formulated with integer linear programming problems. *n* represents a set of locations, *m* is the number of vehicles and is the weight of each side that connects location *i* to location *j*. And there is a decision variable worth 1 when the trip is made through the side connecting *i* and *j*. On the other hand, when the trip does not pass through that side, it will be worth 0. The objective and constraint functions are shown in equations 1-5.

$$Minimize\ \ z = \sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}\ \ Xij \tag{1}$$

$$\sum_{j=2}^{n} X_{1j} = m \tag{2}$$

$$\sum_{j=2}^{n} X_{j1} = m \tag{3}$$

$$\sum_{i=1}^{n} X_{ij} = 1, j = 2,3, \dots, n \tag{4}$$

$$\sum_{j=1}^{n} X_{ij} = 1, i = 2,3, \dots, n \tag{5}$$

According to [16], optimization problems can be solved using exact and approximate methods. The exact method is a solution where the resulting solution is the optimal solution. On the other hand, the solution resulting from the approximation method is not guaranteed to have an optimal solution.

The main disadvantage of the exact method is the long computational time. Computational time is the time used to obtain the optimal solution. When computational time is an exponential or factorial function as a dimension of the problem,

DOI: 10.25077/josi.v21.n2.p75-86.2022

then the dimensions of the problem are quite large, and as a result, the time required is very long. It encourages the use of an approach method. The approach method is a settlement method that uses the concept of trial and error. It causes the results obtained to be not necessarily optimal. The approach method can be divided into two, the approximation algorithm and the heuristic algorithm. The approximation algorithm guarantees the quality of the completion and the time. On the contrary, the heuristic algorithm does not ensure that a good completion will be obtained in the desired period. However, the advantage of the heuristic algorithm is that it is a good solution for problems that have a large scale.

In this study, algorithm development was carried out to solve the Multiple Traveling Salesman Problem with priority node with a real case from the Department of Industry and Energy in the City Lighting Section, DKI Jakarta Street Lighting Section. Two steps are carried out, firstly using the nearest neighbor algorithm to find routes for priority nodes and secondly using genetic algorithms to determine the combined route between the nearest neighbor priority nodes and non-priority nodes.

Nearest Neighbor

According to [17], making a path in the Nearest Neighbor method follows the following steps.

1. Start with an arbitrary node.
2. Find the node that has not been included in the route that is closest to the node that was just added and add that node to the route so that the two nodes can be connected.
3. When all the nodes have been included in the route, add a side that connects the starting node and the last node.
4. The nearest neighbor algorithm can be programmed to operate at a time proportional to n^2, where n is the number of all nodes. Linear time with the input of length if the input is a list of all distances.

Genetic Algorithm

According to [18], the genetic algorithm is a stochastic search technique for the optimum value that originates from the process of natural selection mechanisms. This algorithm was adapted based on Darwin's theory of evolution and theories in biology, so many biological terms have been adapted to this algorithm. The algorithm development process will be carried out three times based on the number of decisions totaling three.

The following are the steps usually carried out in the genetic algorithm process.

1. Formation of Initial Population
2. Individual Selection Process
3. Crossover Process
4. Mutation Process

The algorithm used in this study is a genetic algorithm, according to [19]. In this algorithm, there is a new method used. This method eliminates the crossover process because it is considered rare that it can increase the best solution for the resulting route. In addition, crossover events can sometimes occur where the same two individuals are selected as parents so that new individuals will not be formed [20].

According to [21], this process can be replaced by elitism and mutation. In this process, eight individuals are taken randomly, which have not been selected in the temporary population are. The elitism process is carried out by choosing the best individual from the group in the existing population. In each taking from a group of 8 individuals, one of the best individuals will be selected to experience elitism. These individuals will be retained in the next generation of the population. Then for the other seven individuals, a mutation process is carried out. The mutation is carried out using flip, swap, slide, breakpoint variation, swap+breakpoint variation, slide+breakpoint variation, and flip+breakpoint variation [20].

The algorithm development process will be carried out three times based on the number of decisions totaling 3. Each decision is used because the three shifts have different tasks, as explained in the introduction.

Decision 1 Algorithm

Decision 1 describes operational activities in the field for shift one at 00.00-06.00. Operating activities include relaying unfinished previous shift assignments and checking and installing lights and night checks. A flow diagram of a genetic algorithm that has undergone a modification process according to the actual case is shown in Appendix B. The algorithm flow chart is adjusted to the actual situation in decision 1.

Decision 2 Algorithm

Decision 2 describes operational activities in the field for shift one at 06.00-08.00. The operational activity carried out in the morning check for the protocol road. A flow diagram of a genetic algorithm that has undergone modification according to the actual case is shown in Appendix C. The algorithm flow chart is adjusted to the actual situation in decision 2.

Decision 3 Algorithm

Decision 3 describes operational activities in the field for shift two at 08.00-16.00 and shift three at 16.00-24.00. Operational activities carried out in shifts two and three include :

a. relaying tasks from previous shifts that have not been completed
b. checking and installing lights
c. relaying MCB Box installations

Operational activities carried out in shift three are relaying the tasks of the previous shift that have not been completed, checking and installing lights, and night rings. A flow diagram of a genetic algorithm that has undergone a modification process according to the actual case shown in Appendix D. Algorithm flow chart adapted to the actual situation in decision 3.

Validation

Before being used in real cases, program verification is carried out to check whether the program that has been made using Matlab software can produce solutions to the problems of the Street Lighting Section. Program validation is then carried out to ensure that the results generated by the program are in accordance with the manual calculations. Calculations will be carried out using simple data. The case with simple data representing decision 1 and decision 3 will be called Case A. For example, Case A uses simple data with 8 light points. Table 1 shows the x and y coordinates of the light points for the 8 light points. The number of vehicles (salesmen) used are 2. The priority points used are 5 and 7 and Table 2 shows the time matrix between the light points.

To determine the population size and the number of generations to produce the optimal solution, an experimental design was carried out using population sizes of 8, 16 and 32, and the number of generations of 500, 1000, and 1500. The number of populations used were multiples of 8, adjusted for elitism and mutations carried out. For each population, the program runs 5 times. After that, the ANOVA test was conducted to determine the effect of population size and number of generations on the independent variables.

Based on this experimental design, it was obtained that the objective value had the minimum value at a population size of 8 and the number of generations of 1500 and based on the ANOVA test it was found that these two parameters had an effect on the objective value. Based on this, the vehicle route calculation process will use these parameters. Using Matlab software, calculations are made to generate routes for two vehicles. Table 3 shows the route results obtained using the Matlab program.

After that, it is compared with the manual calculation of Case A based on the coordinates of 8 points and the time between those 8 points. The route results obtained between calculations using software and manual calculations are the same. Thus, it can be said that the algorithm that has been made in the program in the Matlab software is valid and can be used to perform calculations using real data.

Table 1. X and Y Coordinates of Simple Data Case A

Point	X Coordinates	Y Coordinates
1	6331,5221	172,163435
2	6335,67952	182,503946
3	6336,00873	181,39103
4	6330,26359	170,07671
5	6329,65834	168,476903
6	6332,61818	139,059904
7	6332,56681	175,562479
8	6333,94278	178,359185

RESULT AND DISCUSSION

There are two pieces of data to be processed using a genetic algorithm. The first is data on the location of the lights in the form of x and y coordinates. The second data is the time matrix data between lights with the number of rows and columns of 274x274. Furthermore, data processing will be carried out for each predetermined decision. In each decision, parameter determination, an ANOVA test, and the resulting vehicle route are based on previously determined best parameters. The parameters used are the effect of the number population and the effect of the number of generations on the objective value, on the objective value.

Decision 1 Result

Decision 1 describes operational activities in the field for shift 1 at 00.00-06.00. Operational activities carried out include relaying unfinished previous shift assignments, checking and installing lights, and night rings. The data needed in decision 1 is the location of the lights in the form of x and y coordinates, the lamp time matrix measuring 274x274, the number of vehicles, the population, the number of generations, and the priority light points. Working hours are limited to 345 minutes for each vehicle (6 hours minus 15 minutes for apple activities).

Table 2. Simple Data Time Matrix Case A (minutes)

	1	2	3	4	5	6	7	8
1	0	2,2907	2,4286	0,6419	0,9598	1,7396	0,5840	1,3206
2	2,2907	0	0,1649	2,9314	3,2500	3,0849	1,7086	0,9702
3	2,4286	0,1649	0	3,0703	3,3884	3,1499	1,8492	1,1113
4	0,6419	2,9314	3,0703	0	0,3189	1,7999	1,2230	1,9612
5	0,9598	3,2500	3,3884	0,3189	0	1,8830	1,5417	2,2798
6	1,7396	3,0849	3,1499	1,7999	1,8830	0	1,9561	2,3517
7	0,5840	1,7086	1,8492	1,2230	1,5417	1,9561	0	0,7385
8	1,3206	0,9702	1,1113	1,9612	2,2798	2,3517	0,7385	0

Table 3. Results of the Matlab Program Route Case A

Vehicle	Detailed Route & Time Traveled							Service Time(min)	Total Time(min)
1	Route	1	7	8	2	3	1	30	34,8863
	Time(min)		0,584	0,7385	0,9702	0,1649	2,4286		
2	Route	1	5	4	6	1		30	34,8182
	Time(min)		0,9598	0,3189	1,7999	1,7396			

 DOI: 10.25077/josi.v21.n2.p75-86.2022

In this case, as shown in Table 4, the priority light points are 45, 123, 82, 60, 100 and 43. The number of priority light points is 6, so there are 6 light points that need to be checked and repaired. Each 1 light point takes 30 minutes so that the total time used is 180 minutes. The number of vehicles used is 2, according to real cases. The number of population and the number of generations will be determined later.

To determine the population size and the number of generations to produce the optimal solution, an experimental design was carried out using population sizes of 32, 64 and 128, and the number of generations of 500, 1000, and 1500. The number of populations used was multiples of 8, adjusted for elitism and mutations carried out. For each population, the program was run 10 times. After that, the ANOVA test was conducted to determine the effect of population size and number of generations on the independent variables.

Based on this experimental design, it was obtained that the objective value had the minimum value at a population size of 128 and the number of generations of 1500 and based on the ANOVA test, it was found that these two parameters had an effect on the objective value. Based on this, the vehicle route calculation process will use these parameters. The total time obtained is 381.5754 minutes with total details for vehicle 1 of 255.2954 minutes and vehicle 2 of 126.28 minutes.
The following is the result of running the program for decision 1 in the form of total time and number of iterations as well as a fitness graph for each iteration. The fitness graph shown in Figure 1 is for the average fitness value and the best fitness value for each iteration.

Table 4. Example of Job Description for Shift 1

No.	Task	Point
1	3rd shift duty relay	45
2	3rd shift duty relay	123
3	Fix light off (data from system)	82
4	Fix light off (data from system)	60
5	Fix light off (data from costumer report)	100
6	Fix light off (data from costumer report)	43

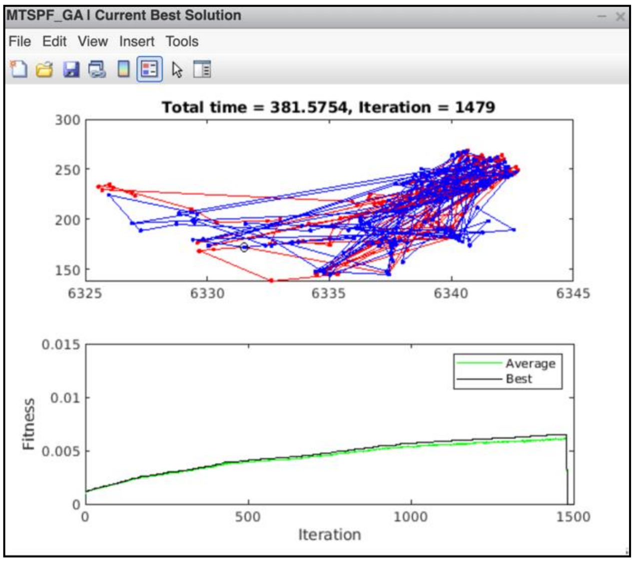

Figure 1. Results of Running Programs for Decision 1

Decision 2 Result

Decision 2 describes operational activities in the field for shift 1 at 06.00-08.00. The operational activity carried out is the morning circle for the protocol road. The data needed in decision 2 is the location of the lights in the form of x and y coordinates, the lamp time matrix measuring 130x130, the number of vehicles, the number of populations, and the number of generations. Because there is no repair process or lamp change, there is no priority point.

Working hours are limited to 120 minutes (2 hours). The number of vehicles used is 2, according to real cases. The number of population and the number of generations will be determined later. To determine the population size and the number of generations to produce the optimal solution, an experimental design was carried out using population sizes of 32, 64 and 128, and the number of generations of 500, 1000, and 1500. The number of populations used was multiples of 8, adjusted for elitism and mutations carried out. For each population, the program was run 10 times. After that, the ANOVA test was conducted to determine the effect of population size and number of generations on the independent variables.

Based on this experimental design, it was obtained that the objective value had the minimum value at a population size of 128 and the number of generations of 1500 and based on the ANOVA test, it was found that these two parameters had an effect on the objective value. Based on this, the vehicle route calculation process will use these parameters.

The total time obtained is 75.8606 minutes with total details for vehicle 1 of 37.7864 minutes and vehicle 2 of 38.0742 minutes.
Figure 2 shows the result of running the program for decision 2 in the form of total time and number of iterations as well as a fitness graph for each iteration. The fitness graph shown in Figure 2 is for the average fitness value and the best fitness value for each iteration.

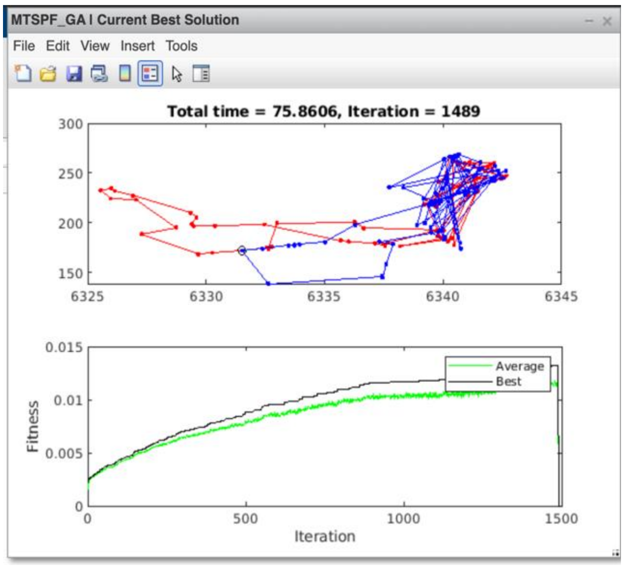

Figure 2. Running Program Results for Decision 2

Decision 3 Result

Decision 3 describes operational activities in the field for shift 2 at 08.00-16.00 and shift 3 at 16.00-24.00. Operational activities carried out in shift 2 include relaying tasks from previous shifts that have not been completed, checking and installing lights, relaying MCB Box installations and day rings. Operational activities carried out in shift 3 are relaying the tasks of the previous shift that have not been completed, checking and installing lights, and night rings.

The data needed in decision 3 is the location of the lights in the form of x and y coordinates, the lamp time matrix measuring 274x274, the number of vehicles, the population, the number of generations, and the priority light points. Working hours are limited to 465 minutes (8 hours minus 15 minutes of apple activity).

In this case, as shown in Table 5, the priority light points are 18, 159, 99, 173, 149, 200, 193, and 22. The number of priority light points is 8, so there are 8 light points that need to be done. checked and repaired. Each 1 light point takes 30 minutes so that the total time used is 240 minutes. The number of vehicles used is 2, according to real cases. The number of population and the number of generations will be determined later.

To determine the population size and the number of generations to produce the optimal solution, an experimental design was carried out using population sizes of 32, 64 and 128, and the number of generations of 500, 1000, and 1500. The number of populations used was multiples of 8, adjusted for elitism and mutations carried out. For each population, the program was run 10 times. After that, the ANOVA test was conducted to determine the effect of population size and number of generations on the independent variables.

Table 5.

No.	Task	Point
1	2nd shift duty relay	18
2	2nd shift duty relay	159
3	Fix light off (data from system)	99
4	Fix light off (data from system)	173
5	Fix light off (data from system)	149
6	Fix light off (data from costumer report)	200
7	Fix light off (data from costumer report)	193
8	Fix light off (data from costumer report)	22

Based on this experimental design, it was obtained that the objective value had the minimum value at a population size of 128 and the number of generations of 1500 and based on the ANOVA test, it was found that these two parameters had an effect on the objective value. Based on this, the vehicle route calculation process will use these parameters.

The total time obtained is 460.1197 minutes with total details for vehicle 1 of 299.3866 minutes and vehicle 2 of 160.733 minutes. The following is the result of running the program for decision 3 in the form of total time and number of iterations as well as a fitness graph for each iteration. The fitness graph shown in Figure 3 is for the average fitness value and the best fitness value for each iteration.

Comparison of Vehicle Routes between Initial and Proposed Conditions

After obtaining the entire proposed route and the total time required to take the route, a comparison will be made with the initial conditions at the Department of Industry and Energy for the City Lighting Section of the DKI Jakarta Street Lighting Section. Comparisons were made for three decisions: decision 1, decision two, and decision 3. Table 6 shows the comparison of the number of light points visited and the total time taken for the initial and proposed conditions.

The job description in decision 1 follows the job description in Table 4. Example of Job Description for Shift 1 where the priority

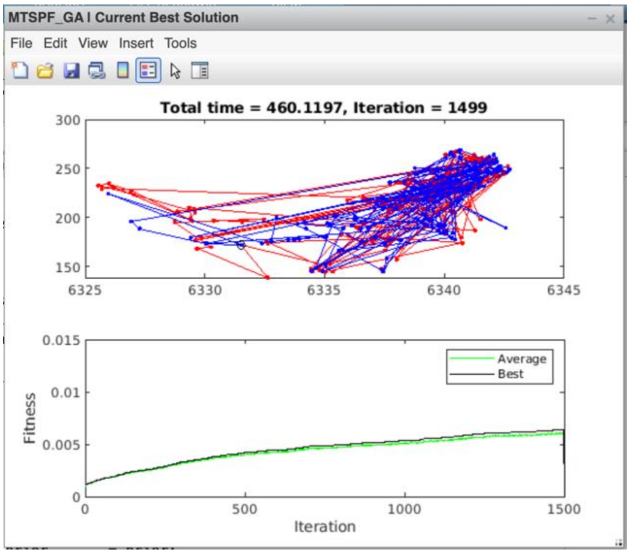

Figure 3. Results of Running Programs for Decision 3

Table 6. Comparison of the Total Time of Initial and Proposed Conditions

Decision	Initial Condition: Number of point	Initial Condition: Vehicle 1	Initial Condition: Vehicle 2	Initial Condition: Total Time (min)	Proposed Condition: Number of point	Proposed Condition: Vehicle 1	Proposed Condition: Vehicle 2	Proposed Condition: Total Time (min)
1	130	280	280	560	274	255	126	381
2	130	75	75	150	130	76	38	114
3	135	300	300	600	274	299	161	460

DOI: 10.25077/josi.v21.n2.p75-86.2022

points visited are 45, 123, 82, 60, 100, and 43. In the initial conditions of decision 1, the team tasked with operational activities at the Street Lighting Section of DKI Jakarta carries out repairs and checks for damaged lamps. It is either from the results of the previous shift relay or those assigned to the shift. The night check is only on the protocol road. It is rare to do a night check for the whole point. Then, all priority points are indeed on the protocol road. Therefore, the number of lights visited was 130, some light points on the protocol road. The time needed to carry out operational activities for each vehicle is considered the same because the task of repairing and checking the lights is divided equally for both vehicles.

In decision 2, the tasks performed between the initial and proposed conditions are the same, and there is no difference. It is because the task is to carry out the morning check and the light points visited are some protocol street light points totaling 130. In the initial conditions, the time required to carry out operational activities for each vehicle is considered the same because the route taken for the morning circle is divided equally for both vehicles.

Energy in the City Lighting Sector, the Street Lighting Section of DKI Jakarta, to repair and check the damaged lamps, either from the results of the previous shift relay or indeed those assigned to the shift, relay installation of MCB Boxes and daytime rings which are on the road protocol only. It is rare to do a day circle for the whole point. Therefore, the number of lights visited was 135, the number of light points on protocol roads (amounted to 130) plus priority points outside the protocol road that had to be checked and repaired or fitted with MCB Boxes (amounted to 5, namely points 159, 173, 149, 200 and 193). The time required to carry out operational activities for each vehicle is considered the same because the task of repairing and checking the lights is divided equally for both vehicles.

From this result, MTSP with priority can be used to solve this routing problem. The priority for repairing the lamps has been prioritized. After that, the vehicle will follow the inspection route for all lamp points and install the MCB, especially in shift 2. Compared to the results of previous studies, MTSP with priority is more appropriate in this case because there is no limit regarding the vehicle's capacity and the random priority of repairing the dead lights. The solution is also more precise with the genetic algorithm considering the running time is not too long compared to the exact solution.

Implications can be made real by inputting data at the beginning of the shift and then running the program, and workers follow the suggested route. The data at the beginning of the shift is in the form of data on reports of blackouts that will be a priority, data on work that has not been completed in the previous shift, and point lamps that have not been installed MCB.

CONCLUSION

After conducting research related to the application of the genetic algorithm method and the nearest neighbor method to the real problems of the Department of Industry and Energy in the City Lighting Section of the Street Lighting Section of DKI Jakarta, the following conclusions can be drawn:

1. The genetic algorithm assisted with the nearest neighbor algorithm has successfully solved the MTSP with priority node case.
2. There is a 32 % reduction in time for shift 1, 24 % for shift 2, and 23 % for shift 3. Time reduction will impact worker productivity. It means more light points will be visited, MCB installation can be done faster for all lights, and more dead lights can be fixed.

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APPENDICES

Appendix A

Complete Shift Task

1. Shift 1 (00.00-08.00)
   a) The evening call at the office.
   b) Carry on the task of the previous shift if the problem is too complex, so it cannot be installed on the shift.
   c) Check and install lights when lights go out on the shift.
   d) Do a night check to find out if lights are off but not detected. Checks for undetected dead lights can be carried out until 06.00 because, after that time, the lights will turn off automatically.
   e) At 06.00, a morning check was carried out by checking the lights were still on. It is because the lights should have turned off automatically at that time. However, due to the limited time, 2 hours, only checking the road.
2. Shift 2
   a) Morning meetings at the office.
   b) Carry on the task of the previous shift to install lights when there were lights off, which were too complex, so they couldn't be installed on the shift.
   c) Check and install lights when there are lights out on the shift.
   d) Install the MCB (Miniature Circuit Breaker) Box if there is a relay from the previous day, and conduct the MCB Box check. The MCB box serves to protect the lamp from lightning. When there is an MCB Box, the lightning will not damage the lights but only the MCB Box. It aims to save costs because the price of smart system lamps reaches 7 million, while the price of MCB Boxes is only 200 thousand. Installation of the MCB Box cannot be done immediately. When it is found that there is an MCB Box that has not been installed, it will be relayed to the next day's task in the second shift.

3. Shift 3
   a) Afternoon apples at the office.
   b) Carry on the task of the previous shift to install lights when there are lights off which are too complex so that they cannot be installed on the shift.
   c) Check and install lights when there are lights out on the shift.
   d) Do the night check, which is carried out to find out if there are undetected dead lights.
   e) There are no installation and maintenance activities on the third shift using a ladder car, so the ladder car driver only works on two shifts. Although there are no daily operational activities using ladder cars, there is a ladder driver on duty for both shifts (morning and afternoon).

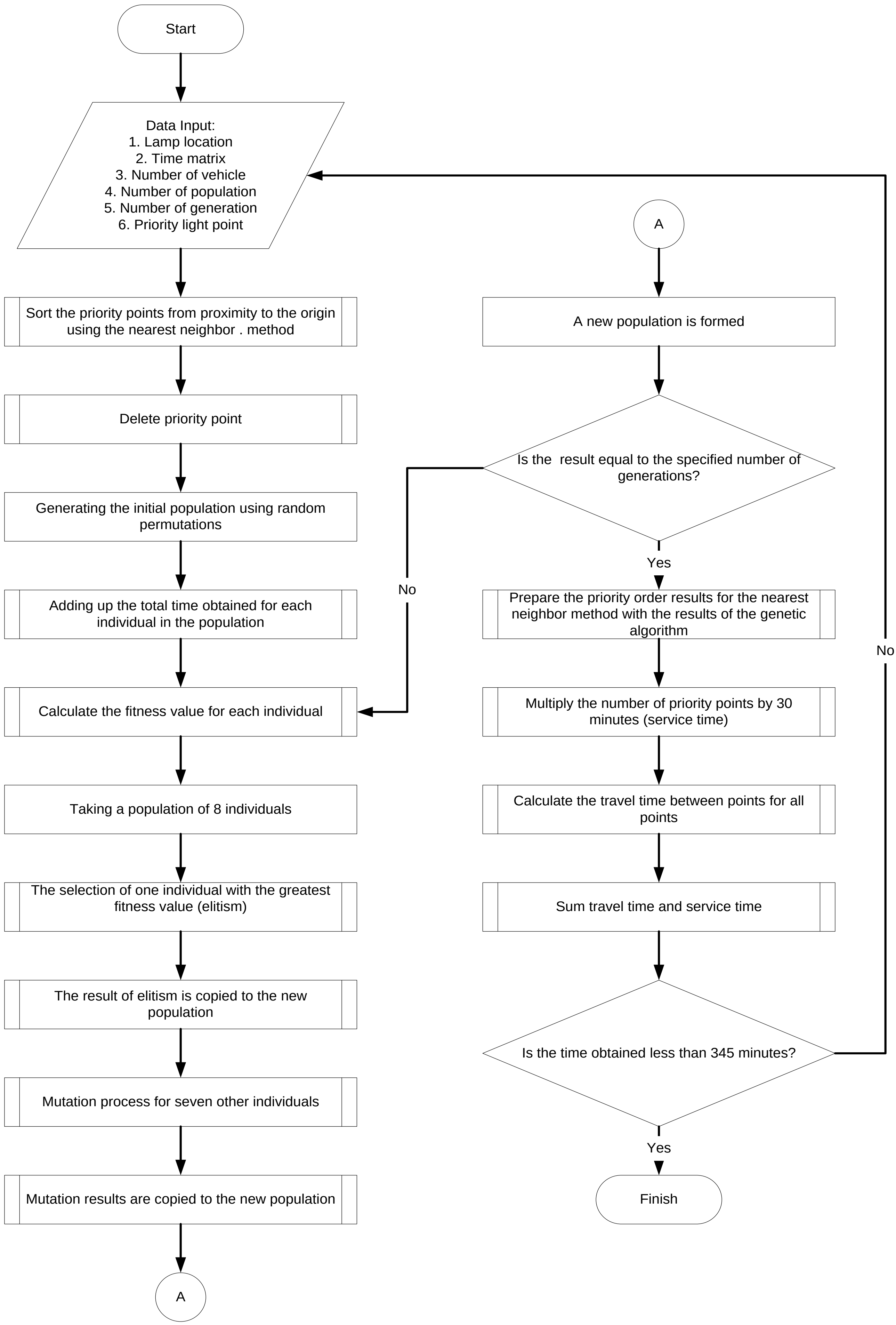
Appendix B

The first step is to collect the necessary data as input to the genetic algorithm. The data used are lamp location data in the form of x and y coordinates, time matrix between light points in minutes, the number of vehicles (salesmen) used, the number of populations used, and the number of generations (iterations) used for the genetic algorithm calculation process. The population used in the first step is a multiple of 8 so that it can be adjusted in the fourth step.

The second step is to sort the priority points using the nearest neighbor method. The priority points that have been entered in Step 1 are reviewed based on the shortest time from the starting point of departure (the office). Then the priority point will then be reviewed again for its proximity based on the priority point that has been visited with the starting point so that vehicle routes can be divided for all existing vehicles. Proximity is seen in two ways, namely at the location at the x and y coordinates and based on the minimum travel time.

The third step is to delete the priority point. After finding the order of priority points that has been carried out in Step 2, temporarily deletion is carried out at those priority points. This is

 DOI: 10.25077/josi.v21.n2.p75-86.2022



DOI: 10.25077/josi.v21.n2.p75-86.2022

so that the priority points are not included in the next calculation step. The next calculation step has been entered into the genetic algorithm. Priority points are not included in the calculation process using the genetic algorithm.

The fourth step is to generate an initial population of as many routes as the population size at random. Initialization of the population using the random permutation method to generate individuals representing routes between 1 and the number of points, as many as 8. Point 1 is not included because it is the starting and ending point of the route.

The fifth step is to add up the total time obtained from the initial population generation process for each individual in the newly formed population.

The sixth step is to calculate the fitness value to find the best individual. The process of calculating the fitness value is dividing 1 by the objective function. The objective function in this case is time, so the value of 1 will be divided by the total time obtained for each individual.

The seventh step is to take a population of 8 individuals who have never been selected further. The population used in the first step is a multiple of 8 so that it can be adjusted in this fourth step. In the eighth step, the best individual will be selected based on the greatest fitness value. In the ninth step, the best individual will be retained in the next generation population. This process is called elitism.

In the tenth step, the other seven individuals, will undergo a mutation process. The mutation process for each individual is carried out in a different way, namely one of 7 ways: flip, swap, slide, modify breaks, flip then modify breaks, swap then modify breaks, and slide then modify breaks. In the eleventh step, the mutation results will be copied to the new population.

The twelfth step is to obtain a new population resulting from the elitism and mutation processes. The thirteenth step is to repeat the calculation starting from the sixth step, which is to calculate the return fitness value for the new population. This step is repeated until the number of calculations matches the number of generations entered in the first step. This is because the stopping criteria used in this genetic algorithm is that the number of generations entered in the first step has been reached.

The fourteenth step is the insertion of the priority point with the minimum time obtained using the nearest neighbor method (second step) with the results of the genetic algorithm obtained in the eighth step. The insertion process is by combining the most recent priority point on the route with the earliest population obtained from the results of genetic algorithm calculations. The insertion process considers the minimum time.

The fifteenth step is to multiply the number of priority points by 30 minutes. This is because, the priority point is the point where work is done, both installing and checking lights or installing MCB Boxes. Each job is done for 30 minutes.

The sixteenth step is to calculate the travel time between points for all existing points. By using the existing time matrix, the travel time between points for the route that has been generated is calculated. Obtained the overall time in the seventeenth step. The total time is a combination of the travel time of the entire point with the service time at the priority point.

The eighteenth step is to compare the total time gained with the hours worked. In this case, the working hours used are 345 minutes. 345 is obtained from 6 hours of work converted into minutes, which is 360 minutes and then reduced by 15 minutes for apples.

Appendix C

The first step is to collect the necessary data as input to the genetic algorithm. The data used are lamp location data in the form of x and y coordinates, time matrix between light points in minutes, the number of vehicles (salesmen) used, the number of populations used, and the number of generations (iterations) used for the genetic algorithm calculation process. The population used in the first step is a multiple of 8 so that it can be adjusted in the fourth step.

The second step is to generate an initial population of as many routes as the population size at random. Initialization of the population using the random permutation method to generate individuals representing routes between 1 and the number of points, as many as 8. Point 1 is not included because it is the starting and ending point of the route.

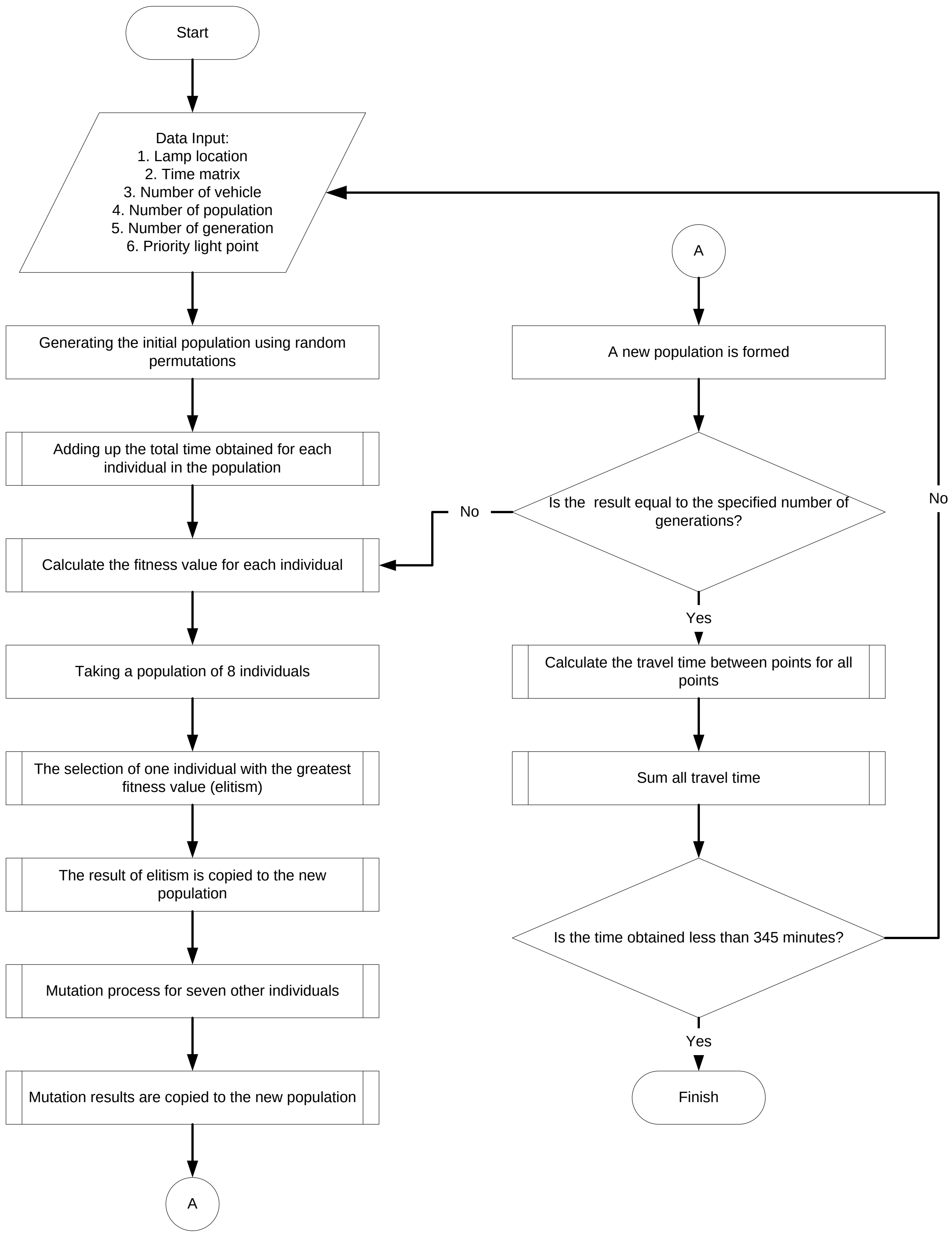
The third step is to add up the total time obtained from the initial population generation process for each individual in the newly formed population.
The fourth step is to calculate the fitness value to find the best individual. The process of calculating the fitness value is dividing 1 by the objective function. The objective function in this case is time, so the value of 1 will be divided by the total time obtained for each individual.

The fifth step is to take a population of 8 individuals who have never been selected further. The population used in the first step is a multiple of 8 so that it can be adjusted in this fourth step. In the sixth step, the best individual will be selected based on the greatest fitness value. In the seventh step, the best individual will be retained in the next generation of population. This process is called elitism.

In the eighth step, the other seven individuals, will undergo a mutation process. The mutation process for each individual is carried out in a different way, namely one of 7 ways: flip, swap, slide, modify breaks, flip then modify breaks, swap then modify breaks, and slide then modify breaks. In the ninth step, the mutation results will be copied to the new population.

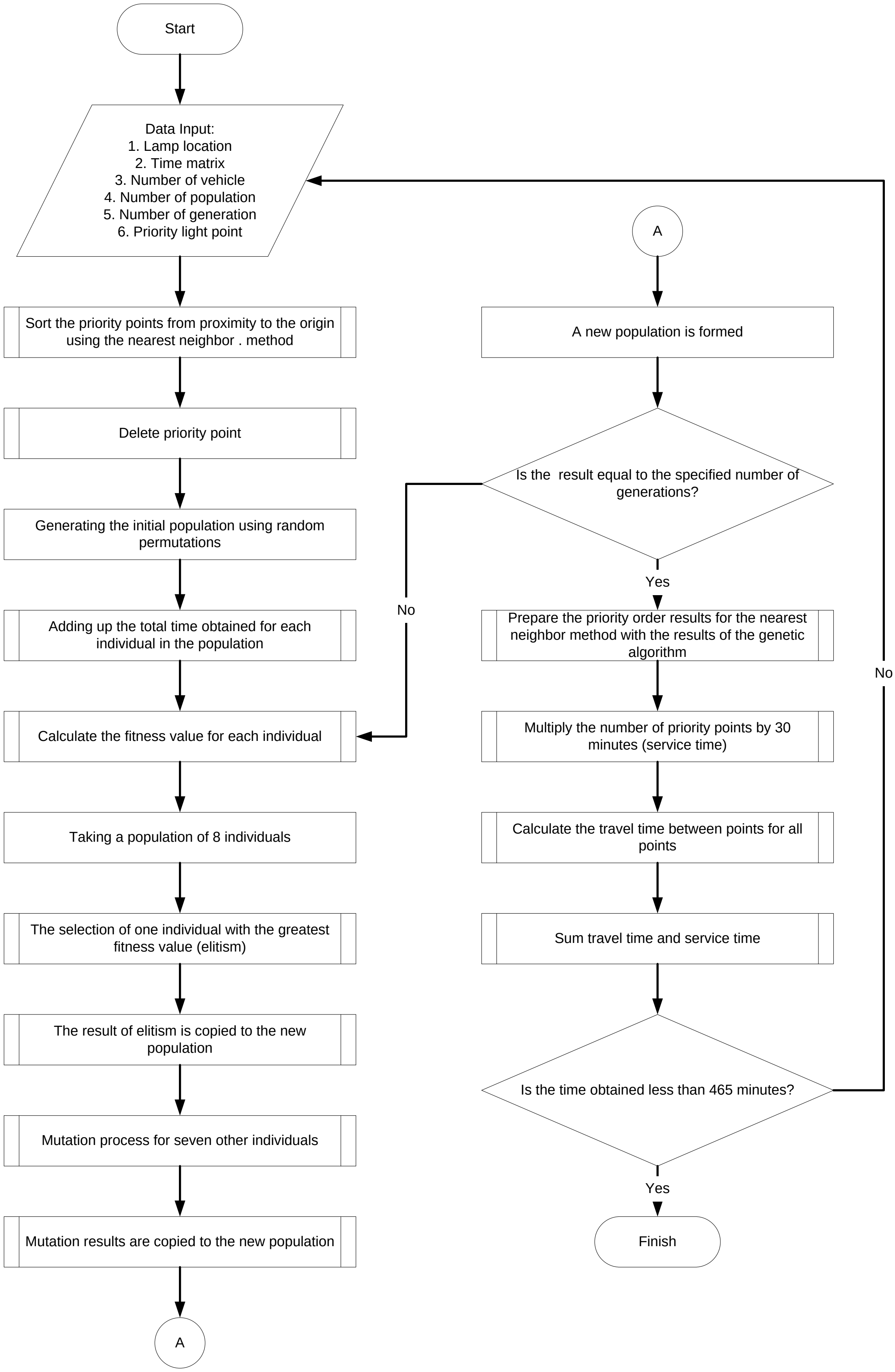
The tenth step is to get a new population resulting from the elitism process and the mutation process. The eleventh step is to repeat the calculation starting from the sixth step, which is to calculate the return fitness value for the new population. This step is repeated until the number of calculations matches the number of generations entered in the first step. This is because the stopping criteria used in this genetic algorithm is that the number of generations entered in the first step has been reached.

DOI: 10.25077/josi.v21.n2.p75-86.2022



The twelfth step is to calculate the travel time between points for all existing points. By using the existing time matrix, the travel time between points for the route that has been generated is calculated. Obtained the total time in the thirteenth step. The fourteenth step is to compare the total time obtained with the hours worked. In this decision, the working hours used are 120 minutes.

Appendix D



The steps in decision 3 are exactly the same as the steps in decision 1, except for the last step, which is the eighteenth step. The eighteenth step is to compare the total time gained with the hours worked. In this case, the working hours used are 465 minutes. 465 is obtained from 8 hours of work made into minutes, i.e. 480 minutes and then reduced by 15 minutes for apples.

DOI: 10.25077/josi.v21.n2.p75-86.2022