A New Metaheuristic Farmland Fertility Algorithm to Solve Asymmetric Travelling Salesman Problem

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Abstract

Asymmetric travelling salesman problem (ATSP) is an optimisation problem needed by a salesman to visit all cities. In the ATSP case, the range from city A to city B is not the same as city B to city A. Therefore, the salesman needs to find the shortest possible route. In this experiment, Farmland Fertility (FF) Algorithm is used to find the solution for the ATSP problem. As a metaheuristic, FF is inspired by farming activity. FF helps farming farmers to get a high-quality plant for selling at a high price. The farmers usually divide their farmland into sections by giving unique materials or treatments based on the soils. This study designs the farmland fertility algorithm to solve ATSP by finding parameters affecting the result. Three parameters are used in this experiment. The parameters are α which acts as a unique material for the worst section, β acts as a special material for other sections, and ω acts as combining soils. ANOVA is used for 27 combinations parameters to be implemented into five ATSP benchmarks. ANOVA results show that α has a significant impact on the algorithm performance. After setting the parameters, the algorithm is implemented to study the cases from BR17, FTV33, FTV44, FTV55, and FTV70. This algorithm can only find the best-known solution on BR17. It cannot find the best-known solution in other cases.

Keywords: Asymmetric Travelling Salesman Problem (ATSP), Farmland Fertility (FF), Algorithm, Parameters

INTRODUCTION

Asymmetric travelling salesman problem (ATSP) is a well-known combinatorial problem. Even though ATSP is an old problem but it is still relevant these days. The main reasons for its popularity are social interest and scientific interest [1]–[3]. Social interest means ATSP applies to real-world problems to improve their social life or business, such as logistics. The real world is distribution, sequencing, and vehicle routing problem [3]. Besides, ATSP is also an exciting problem to the scientific community because it is easy to describe but hard to find the optimal solution. Furthermore, from real-world applications, ATSP itself is used to develop artificial intelligence [4]. ATSP is considered an NP-hard problem [2], [5]–[7], where the problem is hard to solve within a reasonable time.

Many studies have been conducted to solve ATSP [1]–[3], [5]–[9]. Most of the studies use metaheuristic to solve the problem. A metaheuristic is popular because of its flexibility and efficiency. A metaheuristic is not a problem-dependent algorithm, which can be modified depends on the problem. For example, a genetic algorithm is a metaheuristic having many modifications to the algorithm [3], [8] to make it perform better.

The primary purpose of this experiment is to design the Farmland Fertility Algorithm to solve the asymmetric travelling salesman problem. Moreover, this experiment will find parameters affecting the solution. Three identified parameters significantly affect the algorithm solving the asymmetric travelling salesman problem.

The asymmetric travelling salesman problem led to a real-world problem. An algorithm is designed to solve real-world problems, with a bit of adjustment to each real-world problem [3]. Therefore, a case study is used to test whether the algorithm can solve ATSP or not. This test is effective because it saves many resources, such as time.

ASYMMETRIC TRAVELLING SALESMAN PROBLEM

ATSP is a travelling salesman problem where the difference ranges from city A to city B is not the same from city B to city A [10]. The main objective of ATSP is to find the shortest possible route for an n-set of cities, where the salesman cannot go through the same city twice. The model itself has no difference from the travelling salesman problem. The following is the mathematical models for ATSP as stated in Guten's Book.

$$Min\ z=\Sigma\Sigma cijxijnj=1ni=1 \quad (1)$$

Subject to:

$$\Sigma xij=1\ (j=1,\ldots,n)ni=1 \quad (2)$$

$$\Sigma xij=1\ (i=1,\ldots,n)nj=1 \quad (3)$$

$$ui-uj+nxij\leq n-1 \quad (4)$$

Equation number one is the main objective to find the minimum range within the n-set of cities. It has three constraints from equation number two through number four where the salesman cannot go through the same city twice. It means the salesman decision only to go or not to go.

Nagata[3] also describe ATSP as Given a complete directed graph G = (V, A), V being the vertex set and A being the arc set, with nonnegative costs associated with its arcs, find a minimum cost circuit in G passing through each vertex exactly once.

FARMLAND FERTILITY ALGORITHM

In this study, a new metaheuristic algorithm is chosen. The algorithm is Farmland Fertility Algorithm [11]. There are still few studies using this algorithm [12], [13], and this algorithm has not been created to solve a combinatorial problems such as TSP and ATSP. This algorithm is created for an ongoing problem, but we have proved that many metaheuristics algorithms can be modified based on the problem, even though not built for discrete problems.

Farmland Fertility Algorithm is inspired by nature phenomenon where farmers will try to increase the quality of their soils to produce better-quality products. The better the product, the higher price will be. In the process, the farmer divides their land into several sections, and every section contains several results or products. Each section has different soil quality [11]. Below are six steps in Farmland Fertility Algorithm with a formula for each step proposed by Shayanfar [11].

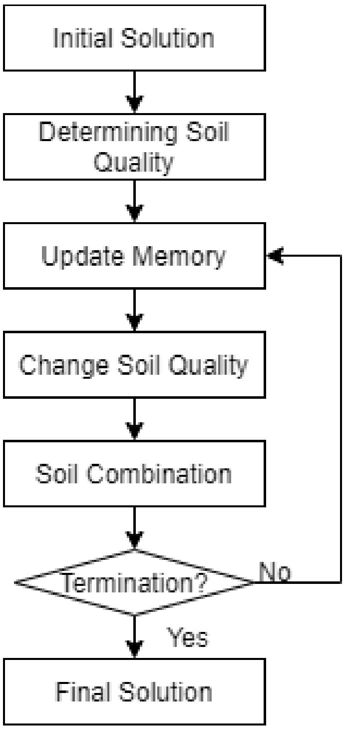

Figure 1. Farmland Fertility Algorithm

1. Create initial value. Like another metaheuristic algorithm, the first step is to create an initial value or solution for the problem. In this experiment, random key [14]–[16] encoding is used to create an initial solution and also translate the problem ATSP so the algorithm can solve it. Besides from initial solution, this step also determines the population and parameters to use. Here is the formula to determine the population.
   $N = k * n$ (5)
   N = Number of populations
   k = Number of sections
2. Determine soil quality. Remember that all sections contain many solutions, so determining soil quality means finding the means of every section. In this case, the solution will be the distance to cover all cities, then find the mean in each section.
3. Update memory. In each iteration, if the algorithm finds a better solution, it will update the memory.
4. Change soil quality. At this point, the algorithm has determined which section is the worst. The worst section will treat with the same treatment as the best section of the farmland. For the worst section will follow this formula.
   $h = \alpha * rand(-1,1)$ (6)
   $Xnew = h * \left(X_{ij} - X_{MGlobal}\right) + X_{ij}$ (7)
   Other sections follow this formula.
   $h = \beta * rand(0,1)$ (8)
   $Xnew = h * \left(X_{ij} - X_{uj}\right) + X_{ij}$ (9)
   α and β are parameters where the value is between 0 and 1.
5. Soil combination. To improve the soil quality, farmers try to combine all the soil available. There are two formulas here, but they will be chosen based on the random number for every iteration. If the random number is less than Q, then it will be using the formula below.
   $X_{new} = X_{ij} + \omega_1 * (X_{ij} - Best_{Global}(b))$ (10)
   Nevertheless, if a random number is more significant than Q, it will be using the formula below.
   $X_{new} = X_{ij} + rand(0, 1) * (X_{ij} - Best_{Global}(b))$, (11)
   ω is the third parameter, and the value is the same as before between 1 and 100 and is an integer number. In this step, a 2-opt algorithm[9], [17] is used to increase the soil quality further or improve the solution.
6. Final conditions. The last step is to pick the best result as the final solution to the problem.

This algorithm also has termination criteria. The criteria itself depends on the problem. It may be the number of iterations, the solution itself, or maybe if it does not change for t period.

RANDOM KEY

This experiment, it modified by a random-key schemed. With the random key, it can pass a continuous space to combinatorial space [16]. This method is a well-known encoding schemed and has been used to translate the discrete problem into a continuous metaheuristic [14]–[16]. A random key will random a number for each city. After randomising all city numbers, the city will be sorted based on the random number, obtaining the route.

Random key:	0.42	0.06	0.38	0.48	0.81
Decodes as:	3	1	2	4	5

Figure 2. Random Key Illustration

2-OPT ALGORITHM

A metaheuristic can be combined with another heuristic or other methods to improve the solution. For example, Karagul [7] uses Harmony Search Algorithm and combines it with a 2-Opt algorithm to improve the result.

2-Opt algorithm works to improve the solution and iteratively looks for improvement opportunities [18]. For an example of ATSP, the initial solution is 5-4-3-1-2 for a 5 set of cities. The 2-Opt algorithm tries to change 4 and 3 and see if it is a better solution or not, and so on.

RESEARCH METHOD

In this study, there are several tools used, namely:

1. Laptop with Intel i7 8750H computer processor unit, NVIDIA GTX1050Ti graphic card unit, and 16 GB of random access memory (RAM)
2. MATLAB R2018a is used to code the algorithm and run the code to find the optimal solution for five study cases which consist of BR17, FTV33, FTV44. FTV55 and FTV70.
3. MINITAB 17 is used to do statistical tests such as ANOVA.

A study is conducted to understand what the asymmetric travelling salesman problem is. After understanding the problem, an algorithm for farmland fertility is chosen to find the solution to the problem. This study is essential to identify the characteristic of both the problem and algorithm. ATSP is a discrete problem, but the algorithm is created for an ongoing problem. An encoding that is a random key is needed to fix this problem.

After conducting the study, the algorithm for the asymmetric travelling salesman problem is the next step. In the designing step, all properties asymmetric travelling salesman problems will be translated to the metaheuristic.

After the designing process is done, the algorithm needs to be validated. The algorithm will try to solve a simple asymmetric travelling salesman problem. If the algorithm cannot find the solution, then the algorithm needs to modify.

When the algorithm is validated, the next step is to find the best parameters for each case. There are three parameters, and each parameter has a range between 0 and 1. The algorithm will try different parameter combinations for each case to find the best combination to be used. Besides finding the best combination, the ANOVA test is also used to find which parameters or interaction between parameters affects the result.

After the best combination of parameters is found, the algorithm is ready to find the best possible solution. The algorithm runs ten times for each case, and the best result will be the algorithm solution for each case.

RESULTS AND DISCUSSION

As stated above, the first step is designing the farmland fertility algorithm with random key and 2-opt for asymmetric travelling salesman problem. A random key is to see the problem, and the 2-opt algorithm is needed to improve the performance of this algorithm. Table 1 below is the algorithm that used in this experiment.

Table 1. Farmland Fertility Algorithm

Farmland Fertility Algorithm	
1	Initialise Parameters: k, n, alpha, beta, Q, and omega
2	Input range matrix and number of cities
3	Set number of iterations
4	While (i < number of iteration)
5	Determining solution
6	Determining quality in each section: Average in each section
7	Update memory
8	Worst sections: Change with equations (6) and (7)
9	Other sections: Change with equations (8) and (9)
10	Evaluation of all solutions. If better, change the solution
11	For all solution
12	if (Q>rand)
13	Change according to equation (10)
14	else

Table 1. Farmland Fertility Algorithm (cont.)

15	Change according to equation (11)
16	2-opt algorithm
17	Evaluation of all new solutions, if better, change the solution
18	Print best solution

There are seven parameters in this algorithm, but only three parameters will focus on this experiment. The three parameters are α, β, and ω.

1. Parameter α: 0,1; 0,5; 0,9
2. Parameter β: 0,1; 0,5; 0,9
3. Parameter ω: 1, 50, 100

The value 0,1; 0,5, and 0,9 for α and β was chosen because it covers the lowest number possible, the highest, and the middle. Whilst on ω is also choose like that.

The other parameters are n, K, Q and number of iterations. Those parameters will not be the focus in this experiment but have the exact number on each run because if the higher the number automatically, the algorithm will have a broader search space and a better chance to find a better solution. Based on the creator of the farmland fertility algorithm, the best value for this number is already obtained. So, in this experiment, those values will be followed. The value of n or population is 100, k or number of spaces is 8, Q as the decision-maker for is 0.5, and the number of iterations is 1000.

There are three parameters with a different value for each parameter. The possible combination for the three parameters is shown in table 2 below.

Table 2. Possible Combinations

Combination	α	β	ω
1	0,1	0,1	1
2	0,1	0,1	50
3	0,1	0,1	100
4	0,1	0,5	1
5	0,1	0,5	50
6	0,1	0,5	100
7	0,1	0,9	1

Table 2. Possible Combinations (Cont.)

Combination	α	β	ω
8	0,1	0,9	50
9	0,1	0,9	100
10	0,5	0,1	1
11	0,5	0,1	50
12	0,5	0,1	100
13	0,5	0,5	1
14	0,5	0,5	50
15	0,5	0,5	100
16	0,5	0,9	1
17	0,5	0,9	50
18	0,5	0,9	100
19	0,9	0,1	1
20	0,9	0,1	50
21	0,9	0,1	100
22	0,9	0,5	1
23	0,9	0,5	50
24	0,9	0,5	100
25	0,9	0,9	1
26	0,9	0,9	50
27	0,9	0,9	100

From table 2, each combination will try to solve all the cases available, which is BR17, FTV33, FTV44, FTV55 and FTV70. The solutions from each case are then put on the ANOVA test to know which parameters or interactions between parameters give effect. Table 3 below is the result of the ANOVA test.

Table 3. ANOVA Result

Cases	Parameters						
	α	**β**	**ω**	**α * β**	**α * ω**	**β * ω**	**α * β * ω**
BR17	Yes	-	-	-	-	-	-
FTV33	Yes	-	-	-	-	-	-
FTV44	Yes	-	-	-	-	-	-
FTV55	Yes	-	-	Yes	-	-	-
FTV70	Yes	-	-	-	-	-	-

Based on table 3, parameters α is affecting in every case and interaction between α and β only affecting case FTV55. Then, because the ANOVA result shows that only α and interaction between α and β affect the result, those two parameters will be checked from 0,1 until 0,9 to see the best value for the parameters. In this stage, the best value for α can be determined because the result is already obtained. The result will show in an interval plot like figure 1 below. This interval plot shows the average of every value between 0,1 and 0,9. Because the problem is ATSP, the lowest solution shows the best value for each parameter.

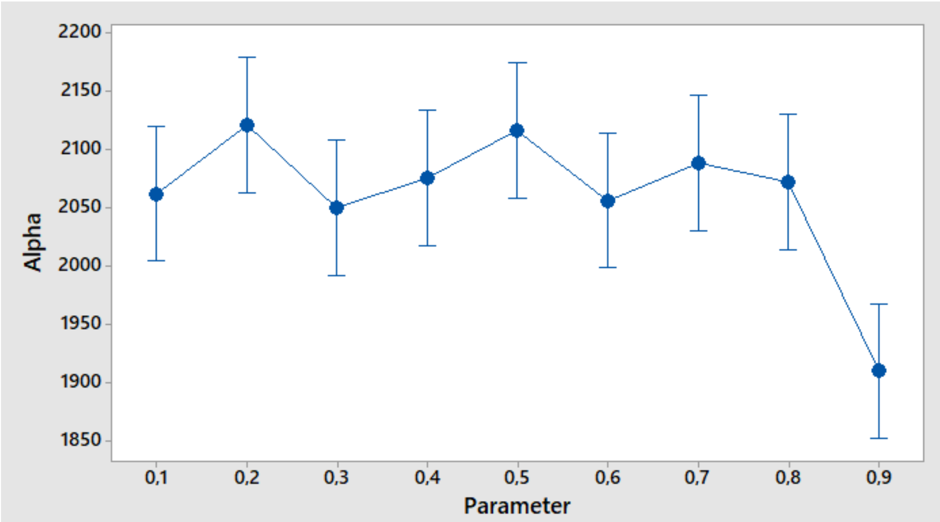

Figure 3. Interval Plot α

From figure 3, it is found that the best value for α is 0.9 because the main objective for the asymmetric travelling salesman problem is to find the minimum range. So, the lower, the best. Based on table 3, there is the interaction between α and β, so an interval plot is also made for β. The interval plot can be seen in figure 4 below.

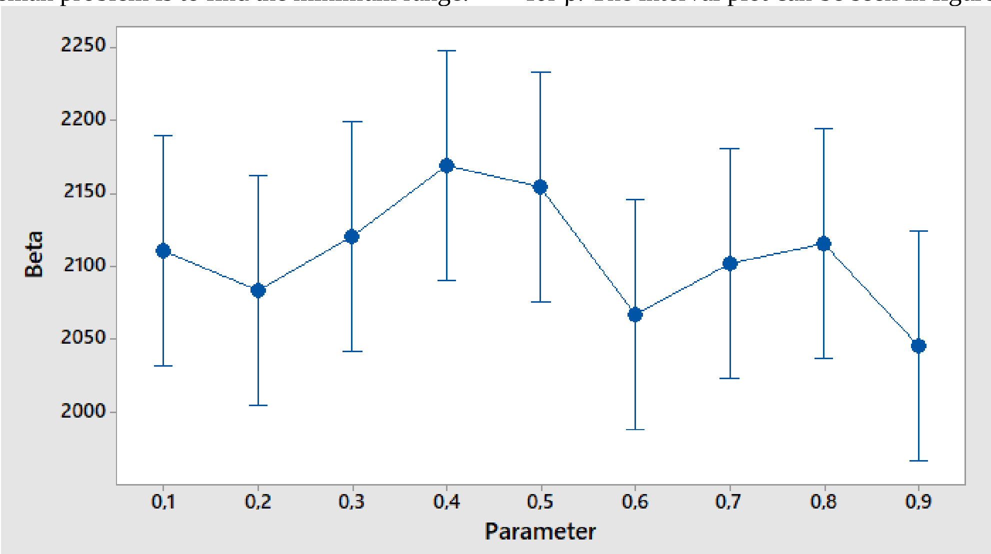

Figure 4. Interval Plot β

As shown in figure 4, it can be determined that the best value of β is the same as α; it is 0.9. It can happen because α and β are used for similar steps that are change soil quality. The difference is that α use for the worst section while β is used for other sections.

For ω itself, because the ANOVA result does not affect the solution, the interval plot is not made. ω value chosen for this experiment is 50 because if the number is too low, like 1, the solution change will be small. If the number is too high, like 100, the change will be too big. So, based on all that, table 4 below shows all the parameters used for each case.

Table 4. Parameters used for each case

Cases	Parameters						
	α	**β**	**ω**	**n**	**k**	**Q**	**Number of Iterations**
BR17	0.9	0.9	50	100	8	0.5	1000
FTV33	0.9	0.9	50	100	8	0.5	1000
FTV44	0.9	0.9	50	100	8	0.5	1000
FTV55	0.9	0.9	50	100	8	0.5	1000
FTV70	0.9	0.9	50	100	8	0.5	1000

After the parameters are decided, the last step in this experiment is to run the algorithm with those parameters. Each case runs ten times, and from 10 solutions will take one best solution for each case. Table 5 below is the result for ten runs, and the best know solution for each case will be shown.

Table 5. Result

Run	Cases				
	BR17	**FTV33**	**FTV44**	**FTV55**	**FTV70**
1	39	1746	2510	3484	4434
2	39	1668	2573	3365	4777
3	39	1698	2243	3218	4692
4	39	1965	2763	3665	4549
5	39	1737	2623	3444	5091
6	39	1756	2479	3590	5137
7	39	1690	2415	3171	5101
8	39	1530	2700	3297	4585
9	39	1904	2567	3511	4990
10	39	1775	2881	3535	4616
Best Known Solution	39	1286	1613	1608	1950

From table 5, it is shown that this algorithm can solve asymmetric travelling salesman problems and get the best result for each run. However, the farmland fertility algorithm designed for this experiment cannot find the rest of the cases.

For cases BR17, this algorithm can perform flawlessly. BR17 contains 17 cities. While a more extensive set of cities like FTV33 contains 34 cities and until FTV70 contains 71 cities, the farmland fertility algorithm designed for this experiment cannot find the best-known solution even with another algorithm such as a 2-opt algorithm to improve its performance.

Another weakness that was found beside the result is that it takes a long time to run. Especially for the FTV70, it takes 20 minutes to finished. Considering the hardware in this experiment used is i7-8750H, it takes a while to finish. The cause of this was because the 2-opt algorithm takes a long time to find a better solution, even though it cannot reach the best-known solution.

There are some recommendations for following research regarding farmland fertility algorithms for the discrete problem. First, another encoding method may give a better initial solution. Second, besides the 2-opt algorithm to improve the solution, the k-opt algorithm or another local search method could improve the algorithm's performance.

CONCLUSION

Farmland fertility at first was created for the persistent problem, and the asymmetric travelling salesman problem is discrete. It needs encoding and decoding to translate the problem into the algorithm. A random key is used to solve this. There is also a 2-opt algorithm that has proven to improve the solution just like another study did.

There are three parameters, α, β and ω. The Only α parameter affects each case's result, while on FTV55, the interaction between α and β is also affecting the result. The best value for α, β and ω, respectively, are 0.9, 0.9, and 50.

Farmland fertility algorithm for asymmetric travelling salesman problem is considered successful even though it cannot find the best possible solution for every case. It can solve the asymmetric travelling salesman problem for BR17. Nevertheless, it cannot solve the problem with many cities in it.

As stated above, a study about the combinatorial problem could lead to a real-world problem. Solver for combinatorial problems can directly solve a real-world problem. With modifications in the algorithm itself, it can solve many real-world problems.

The following research about farmland fertility algorithm on a discrete problem can try another encoding method and combine it with another heuristic to perform better.

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