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Football Game Algorithm Implementation on the Capacitated Vehicle Routing Problems

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Abstract- Capacitated Vehicle Routing Problem is a problem about finding the shortest route travelled by the vehicles in serving the customers. Each vehicle starts from a depot and the vehicle that has completed the assigned route will return to the depot. Each customer can only be served by one vehicle. The vehicle capacity and demand of each customer are considered. In this research, Capacitated Vehicle Routing Problem was solved by using Football Game Algorithm. Football Game Algorithm is a metaheuristic algorithm that is inspired by the behavior of football players in finding the best position to score. The total distance travelled by all the vehicles was used to measure the performance of Football Game Algorithm in solving the Capacitated Vehicle Routing Problem. Football Game Algorithm was implemented in six benchmark cases. The performances of the implementation were compared to those of Artificial Bee Colony and Genetic Algorithm. In four cases, Football Game Algorithm performed as good as Artificial Bee Colony and Genetic Algorithm in achieving best solutions. In the other two cases, Football Game Algorithm performed slightly worse than Genetic Algorithm. Several parameters that used in Football Game Algorithm were tested. The objective of testing the parameters was to see the effect of parameter values in the performance of Football Game Algorithm. The results of the test indicated that the values of some parameters affect the performance of Football Game Algorithm.

Keywords—Capacitated Vehicle Routing Problem (CVRP); Combinatorial Problem; Distribution; Football Game Algorithm; Metaheuristics

I. INTRODUCTION

Vehicle Routing Problem (VRP) is a problem that related to the distribution management [8], [18], [22], [29] which was first introduced by Dantzig and Ramser in 1959 [20]. VRP is classified as a combinatorial problem[27], [28]. The objective of VRP is to find the shortest route that can be travelled by the vehicles in serving the customers. There are many variants of VRP. One of them is the Capacitated VRP (CVRP) [5], [14], [21]. CVRP is an operational problem that must be solved in the operation of physical distribution. Therefore, it is important to learn about this problem and the method for finding the solution of the problem [2]. In CVRP, there is capacity constraint of each vehicle that needs to be considered in finding the shortest route. CVRP is an NP-hard problem [4], [12], [16], [30] which needs more time in finding the optimal solution if it is solved by using exact method. The time required depends on the complexity of the problem. Therefore, an appropriate method is needed to solve CVRP. During the past decades, some metaheuristic algorithms have shown satisfactory capabilities to solve high dimension optimization problems [6]. Metaheuristic is a development of heuristic method [15]. Metaheuristic uses an iterative process to explore and exploit the search space with a certain strategy [6], [15]. This method does not guarantee to get the optimal solution. The objective by using metaheuristic is to find a good solution in a reasonable time [15], [26].

Football Game Algorithm (FGA) is a relatively new metaheuristic. FGA can be used to solve continuous global optimization problem. It is inspired by the behavior of football player in finding the best position to score [10]. In this research, FGA was used to solve CVRP. The results were compared with the results obtained by other algorithms, those are Artificial Bee Colony (ABC) [7] and Genetic Algorithm (GA) [19]. The parameters of FGA can affect the algorithm's performance [10].

Therefore, this research was also intended to find out the effect of the parameters of FGA on the algorithm's performance statistically. This paper consists of seven sections. Section II is about the explanations of CVRP and the related works. Section III is about the explanations of the FGA. Section IV is about the explanations of the proposed FGA in solving CVRP. Section V is about the explanations of the encoding and decoding method used in the proposed algorithm. Section VI is about the explanations of the benchmark functions and the test results. Section VII is about the conclusion of this research and the possible plans for the future work.

II. CAPACITATED VEHICLE ROUTING PROBLEM AND RELATED WORK

Capacitated Vehicle Routing Problem (CVRP) is a problem of finding the shortest route that can be travelled by the vehicles in serving the customers. Each route travelled by each vehicle starts from the depot and finishes at the depot. Each customer is visited only once by a vehicle. The total demand of each route should not be more than the vehicle's capacity [2]. In CVRP, the customer's demand is known, the vehicle is identical and based at a depot, and the vehicle's capacity becomes the restriction of the problem. The objective is to find the smallest total distance required to fulfill the customer's demand [17], [28]. The mathematical formulation for CVRP is defined as follows [24]:

$$\min \sum_{(i,j)\epsilon A} c_{ij} \sum_{k=1}^{k} x_{ijk} \quad (1)$$

subject to

$$\sum_{k=1}^{K} y_{ik}=1 \quad \forall i \in V\backslash\{0\} \quad (2)$$

$$\sum_{k=1}^{K} y_{0k}=K \quad (3)$$

$$\sum_{j \in V\backslash\{i\}} x_{ijk}=y_{ik} \quad \forall i \in V,\ k=1,\ldots,K \quad (4)$$

$$\sum_{j \in V\backslash\{i\}} x_{jik}=y_{ik} \quad \forall i \in V,\ k=1,\ldots,K \quad (5)$$

$$\sum_{i \in V\backslash\{0\}} d_i y_{ik} \leq U_k \quad \forall k=1,\ldots,K \quad (6)$$

$$\sum_{i \in S} \sum_{j \in S\backslash\{i\}} x_{ijk} \leq |S|-1 \quad \forall S \subseteq V\backslash\{0\}, |S| \geq 2, k=1,\ldots,K \quad (7)$$

$$y_{ik} \in \{0,1\} \quad \forall i \in V,\ k=1,\ldots,K \quad (8)$$

$$x_{ijk} \in \{0,1\} \quad \forall (i,j) \in A,\ k=1,\ldots,K \quad (9)$$

Notation:

x_{ijk} = Decision variable (take a value of 1 if vehicle k move to customer j from customer i).
y_{ik} = Binary variable (take a value of 1 if vehicle k visited customer i).
c_{ij} = Distance between customer i and customer j.
k = Index of vehicle
K = Number of Vehicles that can be used
U_k = Maximum capacity of vehicle k that can be used
d_i = Demand of customer i.
V = Set of customers (0, 1, 2, …, n), where 0 is depot.
S = Subset of the stops that does not contain depot.
A = Set of arcs between two customers.

Equation (1) shows the objective function of CVRP. Equation (2), equation (3), equation (4), equation (5) ensure that each customer is visited only once and there are K vehicles that can be used to serve customers starting from depot. Equation (6) is the capacity constraint for each vehicle. Equation (7) is sub-tour elimination constraint for each vehicle [24].

CVRP is an NP-hard problem [4], [12], [16], [30]. In the recent years, researchers have have been using approximation methods to solve the NP-hard problem [3]. The approximate methods consist of heuristic method and metaheuristic method [9]. There were some metaheuristics that have ever been used to solve CVRP, such as Artificial Bee Colony [7], Genetic Algorithm [19], Particle Swarm Optimization [1], [2], Ant Colony Optimization [27], Simulated Annealing [11], Bat Algorithm [25], Grey Wolf Algorithm [13], Improved Golden Ball Algorithm [23], and Cuckoo Search [4]. The results showed that these metaheuristics can find a fairly good solution.

In addition, there was also research that combined the metaheuristic method with some local improvements. In [2], the authors combined the local improvement with the Particle Swarm Optimization to solve CVRP. The local improvement they used were 2-opt, 1-1 exchange, and 1-0 exchange. The 2-opt works on improving single route by exchanging the route directions between two pairs of consecutive customers in the route. The 1-1 exchange and 1-0 exchange work on improving two adjacent routes by exchanging customers between routes. The 1-1 exchange was done by exchanging one customer from the first route with another customer from the second route. The 1-0 exchange was done by moving one customer from the first route to the second route [2]. The authors implemented the combined method in some CVRP benchmark cases. They found that the addition of the local improvement has significant effect on the quality of the solution. We proposed to use a relatively new metaheuristic algorithm, known as Football Game Algorithm, for solving CVRP. Football Game Algorithm was proposed by Fadakar and Ebrahimi in 2016. Football Game Algorithm was only ever used to solve some benchmark functions. We also proposed to add the local improvement based on the modification of the local improvement proposed by Ai and Kachitvichyanukul (2009).

III. FOOTBALL GAME ALGORITHM

Football Game Algorithm (FGA) is a relatively new metaheuristic algorithm proposed by Fadakar and Ebrahimi in 2016. It is inspired by the behavior of football players in finding the best position to score. Two things in a football game that become the basis of the FGA are the general movement of the players and the coaching from the coach. There are two strategies that can be applied by the coach, those are the attacking strategy and the substitution strategy [10].The first step of FGA is to define the population. The population defined shows the initial formation of players in the field. Every player will move around their last

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position (random walk) and tend to move towards the ball. The ball will be passed between players. Every player has a fitness value which shows the quality of the player's position. The player in the better position (having a smaller fitness value in a minimization problem) have a greater chance to receive the ball. The coach will remember some best positions of the players and uses them to guide the other players [10]. Hyper sphere (HS) with hyper radius (HR) is defined. The best player's position is set as its center. Hyper radius limitation value (HRLV) is also be defined. HRLV decreases gradually as the iteration proceed. Every player has a hyper distance (HD) from the best position. Players with higher hyper distance in comparison with HRLV are pushed toward the nearest best position. The coach can also change some weaker players. Fitness limitation value (FLV) is defined. FLV decreases gradually as the iteration proceed. Players with greater fitness values in comparison with FLV are replaced with the other players. The position of the new player is around the nearest best position. The steps of FGA can be summarized as the pseudo code shown below [10]:

```
Define the fitness function
Initialize the team formation (Players position)
Define the parameters of the algorithm
while (t < maximum number of iterations)
    Compute the fitness values of each player
    Rank the players and save the best solutions in the CM
    Identify the player who possess the ball (X^t_ball)
   if (fitness value > FLV^t OR HD_i > HRLV^t)
        Generate a local solution around nearest best solution
   else
        Generate new positions by general movement
   end
        Update α_i, HRLV, FLV
end while
```

IV. THE PROPOSED FOOTBALL GAME ALGORITHM FOR CAPACITATED VEHICLE ROUTING PROBLEM

The proposed method to solve Capacitated Vehicle Routing Problem (CVRP) was the combination between the Football Game Algorithm (FGA) and the local improvement based on the modification of the local improvement proposed by Ai and Kachitvichyanukul (2009). FGA is an algorithm that is designed to solve continuous problem. CVRP is a discrete problem. Therefore, encoding and decoding is needed to adapt FGA for solving CVRP. Encoding and decoding that we used are a modification from the SR-2 representation that was proposed by Ai and Kachitvichyanukul (2009). The local improvement was added in the decoding step. The proposed Football Game Algorithm developed to solve CVRP was given in Fig. 1.

V. ENCODING AND DECODING

Encoding and decoding are an important steps in this algorithm. A solution of CVRP was encoded as player's position in Football Game Algorithm. Position of the player was denoted by a position vector. Each position vector consisted of 3K dimensions where K was the number of vehicles in CVRP. The first dimension showed the x coordinate point of the vehicle. The second dimension showed the y coordinate point of the vehicle. The third dimension showed the vehicle coverage radius. The initial player's position was defined by generating a real number with a minimum value of the minimum point in customer coordinate and with a maximum value of the maximum point in customer coordinate. Fig. 2 shows an example of the player's position. The player's position represented the solution of CVRP. The solution of CVRP can be obtained by decoding the player's position. The steps of decoding were as follow:

1. Route construction
   1a. Determine the vehicle reference points.
   1b. Assign the customer based on the vehicle coverage radius.
   1c. Assign the customer to the nearest vehicle.
2. Calculate the total distance for each route.
3. Do the local improvement for each route.
4. Calculate the total distance by using the route obtained by doing the local improvement.

The first step of the decoding was to construct the route of each vehicle. Suppose the player's position during the decoding process is shown in Fig. 2. Vehicle reference points are the x coordinate point, y coordinate point, and the coverage radius of each vehicle. The next step is to assign the customer based on the vehicle coverage radius. Therefore, we must calculate the euclidean distance between each vehicle and each customer. Table I shows an example of the euclidean distance between each vehicle and customer.

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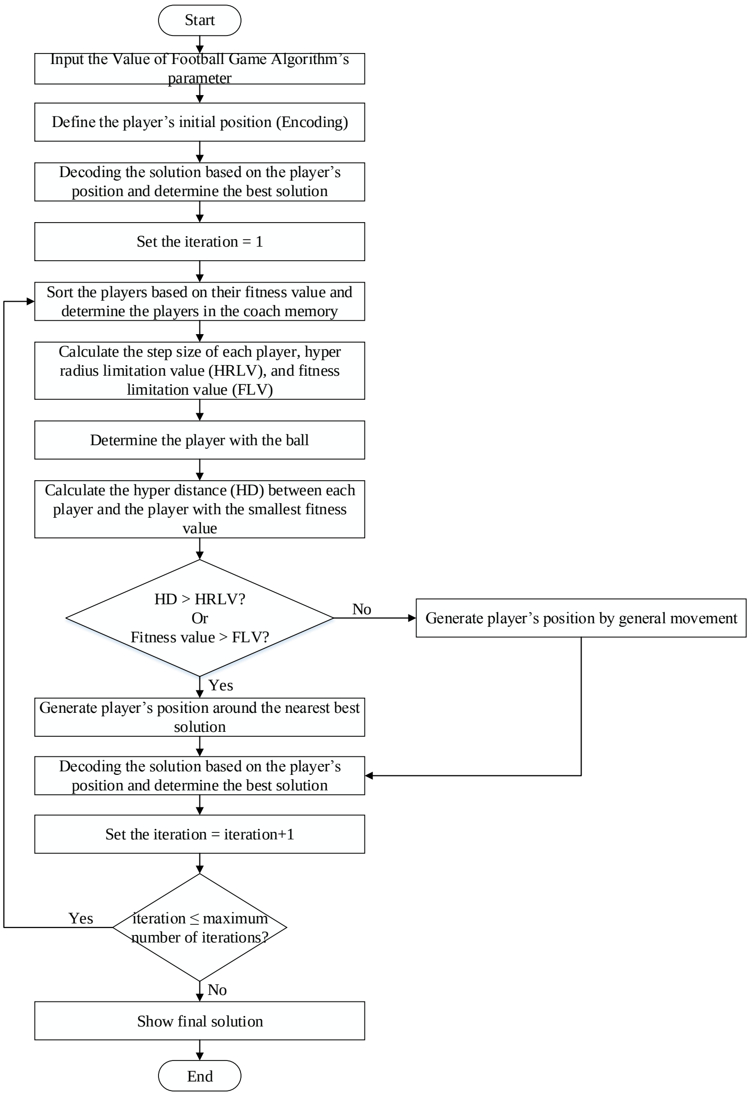

Fig. 1. Flow Diagram of the Proposed Algorithm

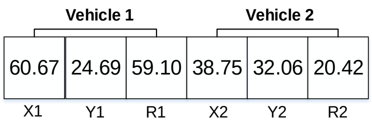

Fig. 2. Example of A Player's Position

Table 1 : Euclidean distance between vehicle and customer

	Customer				
	1	**2**	**3**	**4**	**5**
Vehicle 1	56.33	58.92	32.68	59.26	59.57
Vehicle 2	49.24	43.82	17.98	36.15	36.87

Suppose the vehicle coverage radius of vehicle 1 and vehicle 2 were 59.10 and 20.42 respectively. Based on Table 1, the customers that could be assigned to vehicle 1 are customer 1, customer 2, and customer 3. Whereas, the customer that can be assigned to vehicle 2 is customer 3. The customer that can be assigned to both of the vehicles is prioritized to be assigned to the nearest vehicle. Therefore, customer 3 is assigned to vehicle 2 and customer 1 and customer 2 are assigned to vehicle 1. The priority of customer that will be served is determined by the distance to the vehicle. The vehicle's capacity was considered in the route constuction. The route construction based on the vehicle coverage radius is shown below:

1. Vehicle 1: Depot – 1 – 2
2. Vehicle 2: Depot – 3

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A Customer who have a farther distance from depot is assigned first. The customer is assigned to the nearest vehicle. If the customer's demand is more than the remaining capacity of the nearest vehicle, then the customer is assigned to the other vehicle. In this example, customers that haven't be assigned are customer 4 and customer 5. Based on Table I, customer who has a farther distance from depot is customer 4. Therefore, customer 4 will be assigned first. The nearest vehicle from customer 4 is vehicle 2. Then, customer 4 is assigned to vehicle 2. The nearest vehicle from customer 5 is vehicle 2. Assume that the demand of customer 5 is more than the remaining capacity of vehicle 2. Therefore, customer 5 is assigned to vehicle The result of the route construction is shown below:

1. Vehicle 1: Depot – 1 – 2 – 5 – Depot
2. Vehicle 2: Depot – 3 – 4 – Depot

The second step of the decoding was to calculate the total distance for each route. The total distance is calculated by using the euclidean distance matrix between depot and customer. The third step of the decoding is to do the local improvement for each route based on the route construction. Local improvement used in this research was the modification of the 2-opt proposed by Ai and Kachitvichyanukul (2009). In our proposed method, local improvement was done by changing the order of customers served on each route. If the total distance of modified route was less than the initial route, then keep the modified route. Otherwise, keep the initial route. The local improvement was done repeatedly until the changing process could not generate a modified route with a smaller total distance. The ilustration of the local improvement process was given in Fig. 3.

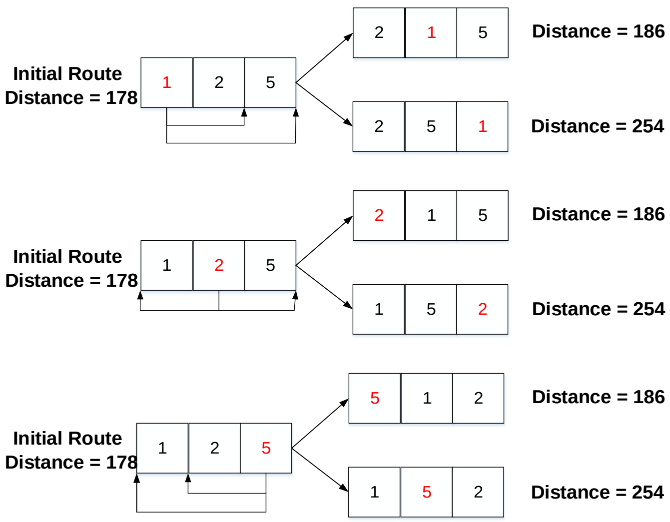

Fig. 3. The Illustration of The Local Improvement

The fourth step of the decoding was to calculate the total distance based on the route obtained in the local improvement. The total distance obtained by this step is the fitness value of the player's position.

VI. RESULTS AND DISCUSSIONS

In this research, Football Game Algorithm was implemented to six Capacitated Vehicle Routing Problem (CVRP) benchmark cases. Table II shows the list of benchmark cases and the characteristics of each cases [31].

Table II: List of benchmark cases

No	Problem	Number of Customers	Number of Vehicles	Capacity	Best Known Solution
1	P-N16-K8	15	8	35	450
2	P-N19-K2	18	2	160	212
3	B-N31-K5	30	5	100	672
4	A-N32-K5	31	5	100	784
5	A-N54-K7	53	7	100	1,167
6	B-N57-K7	56	7	100	1,153

The number of the players used in the implementation of Football Game Algorithm for all the benchmark cases is 300. The number of the iterations used in the implementation is different for each case. Table III shows the number of the iterations used in each benchmark case.

TABLE III: Number of iterations

No.	Problem	Number of Iterations
1	P-N16-K8	100
2	P-N19-K2	100
3	B-N31-K5	100
4	A-N32-K5	10,000
5	A-N54-K7	10,000
6	B-N57-K7	10,000

In this research, there were four Football Game Algorithm's parameters that were tested in order to see the effect of each parameter on the performance of Football Game Algorithm. The four parameters were teta (θ), gamma (γ), lamda (λ), and CMS (coach memory size). Teta is the reduction constant of the player's step size. Gamma is the reduction constant of the hyper radius limitation value (HRLV). Lamda is the reduction constant of the fitness limitation value (FLV). CMS is the size of the coach memory. The parameter values that were tested were as follows:

1. teta: 0.1 and 1.
2. gamma: 0.1 and 0.95.
3. lamda: 0.1 and 0.95.
4. CMS: 25% and 75% of the number of players (75 and 225).

Football Game Algorithm was replicated five times for each combinations of the parameter values. Table IV shows the best total distance obtained by the Football Game Algorithm for each benchmark cases [31].

Table IV: Best total distance obtained by football game algorithm

Problem	Best Total Distance
P-N16-K8	450
P-N19-K2	212
B-N31-K5	672
A-N32-K5	784
A-N54-K7	1,176
B-N57-K7	1,172

Analysis of Variance (ANOVA) was conducted to see the effect of each parameter value on the performance of the Football Game Algorithm. The results show that all the parameters and the interaction between parameters do not affect the performance of the Football Game Algorithm in problem P-N16-K8 and B-N31-K5. The parameter that affected the performance of the Football Game Algorithm in problem P-N19-K2 and A-N32-K5 was teta. The parameter that affected the performance of the Football Game Algorithm in problem A-N54-K7 was the interaction between teta and lamda. The parameters that affected the performance of the Football Game Algorithm in problem B-N57-K7 were teta and CMS.The parameters and interaction between parameters that affected the performance of the Football Game Algorithm for each benchmark case was analyzed by using main effect plot or interaction plot. Fig. 4 shows the main effect plot of teta for problem P-N19-K2.

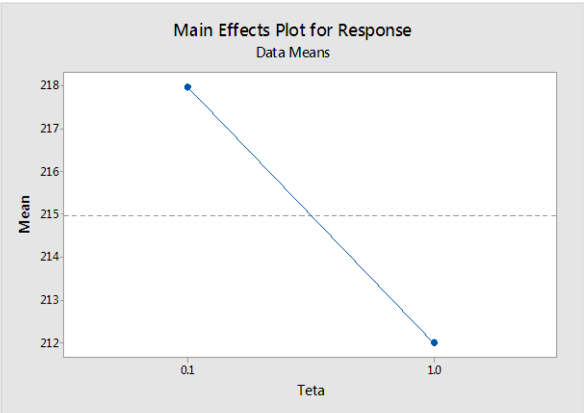

Fig. 4. Main Effect Plot of Teta for Problem P-N19-K2

Based on the main effect plot in Fig. 4, it can be inferred that higher teta (1) was better than lower one (0.1). Fig. 5 shows the main effect plot of teta for problem A-N32-K5.

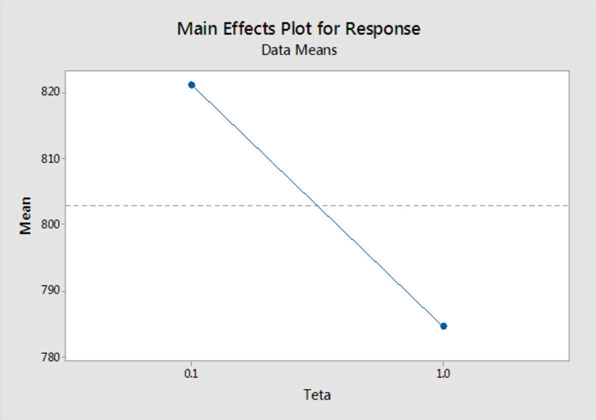

Fig. 5. Main Effect Plot of Teta for Problem P-N19-K2

Based on the main effect plot in Fig. 5, it can be inferred that higher teta (1) was better than lower one (0.1). Fig. 6 shows the main effect plot of teta and CMS for problem B-N57-K7.

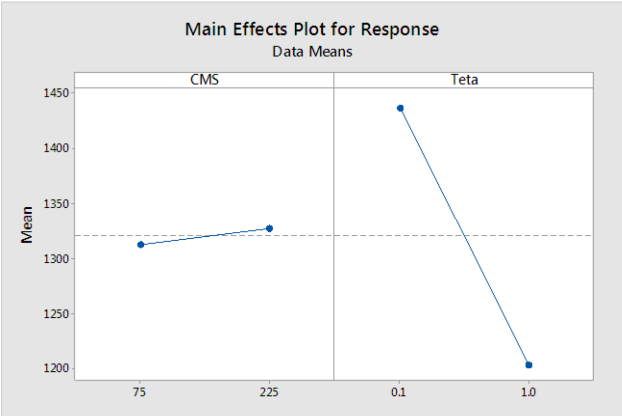

Fig. 6. Main Effect Plot of Teta and CMS for Problem B-N57-K7

Based on the main effect plot in Fig. 6, it can be inferred that higher teta (1) was better than lower one (0.1). It can also be inferred that smaller CMS (75) was better than higher one (225). Fig. 7 shows the interaction plot of teta and lamda for problem A-N54-K7.

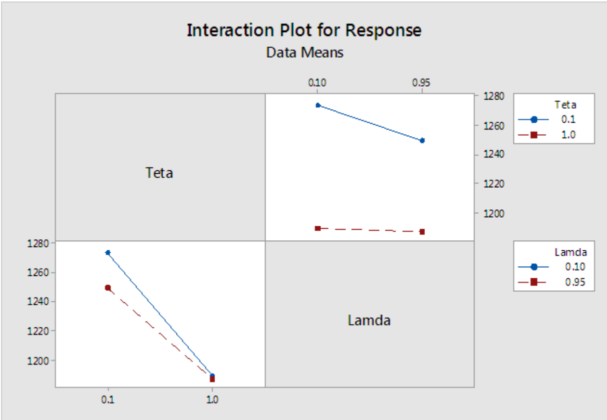

Fig. 7. Interaction Plot of Teta and Lamda for Problem A-N54-K7

Based on the interaction plot in Fig. 7, it can be inferred that the combination between higher teta (1) and higher lamda (0.95) was better than the other combination of teta and lamda. The performance of the Football Game Algorithm was also compared with Artificial Bee Colony [7] and Genetic Algorithm [19] in term of the best total distance obtained by each algorithm. Table V shows the comparison among those algorithms.

Table V: the comparison between football game algorithm, genetic algorithm, and artificial bee colony

Problem	Best Total Distance			
	Football Game Algorithm	**Genetic Algorithm**	**Artificial Bee Colony**	**Best Known Solution**
P-N16-K8	450	-	450	450
P-N19-K2	212	-	212	212
B-N31-K5	672	-	672	672
A-N32-K5	784	784	-	784
A-N54-K7	1,176	1,167	-	1,167
B-N57-K7	1,172	1,140	-	1,153

Based on Table V, it can be known that Football Game Algorithm can get the best known solution for four benchmark cases. Football Game Algorithm generally shows performance that is as good as Genetic Algorithm and Artificial Bee Colony.

VII. CONCLUSION

In this research, Football Game Algorithm has been developed to solve Capacitated Vehicle Routing Problem. The implementation for six benchmark cases shows a promising result. Football Game Algorithm can get the best known solution for four benchmark cases. In the comparison with Genetic Algorithm and Artificial Bee Colony, Football Game Algorithm perform as good as those algorithms. Analysis of Variance (ANOVA) has been conducted to know the parameter of Football Game Algorithm that affect the algorithm's performance statistically. The result shows that the parameters that affect the algorithm's performance is different for each benchmark cases. The parameter that affect the algorithm's performance in most cases is teta. Football Game Algorithm is a relatively new metaheuristic. It shows a promising result to solve Capacitated Vehicle Routing Problem. Therefore, Implementation of Football Game Algorithm to solve another optimization problem can be an interesting topic for the future research.

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