A New Efficient and Effective Golden-Ball-Based Technique for the Capacitated Vehicle Routing Problem

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***Abstract*— The Golden Ball (GB) algorithm is a relatively new meta-heuristic algorithm which can be used to solve the capacitated vehicle routing problem (CVRP). However, its application to solving that problem is still limited. This paper introduces a new technique based on the GB algorithm for solving the CVRP. Our proposed approach employs the solution representation in different way from the original one. More specifically, in this work, the team represents the CVRP solution and the players the routes in the team, while, in the previous work, the CVRP solution is modeled by a player. In the training process, the solution quality of players and teams is improved by using intra-route and inter-route improvement algorithms. The computational results have shown that our technique is better than both best known algorithms and previous GB-based algorithms in terms of efficiency and effectiveness.**

***Keywords*— Meta-heuristic algorithm; golden ball algorithm; vehicle routing problem.**

I. INTRODUCTION (*HEADING 1*)

The capacitated vehicle routing problem (CVRP) is to find a feasible set of vehicle routes that minimizes the total travelling distance when all vehicles depart from the warehouse (single pick-up point), deliver goods to customers (multiple drop-off points), and return to the same warehouse after complete the service [1]. The CVRP can be stated as follows: the number of customers (n); the number of available vehicles (k); the same loading capacity of all vehicles (Q). Each customer must be visited once by one vehicle. Each vehicle starts and ends at the same warehouse. The total demand of customers in each vehicle cannot exceed Q. The number of vehicles used in each problem cannot exceed k. The CVRP is known to be an NP-hard problem [2]. Nowadays, the development of new meta-heuristic algorithms for the CVRP is still active such as variable neighborhood simulated annealing algorithm [3], novel membrane algorithm [4], and cooperative parallel metaheuristic [5].

Golden ball (GB) algorithm is a relatively new meta-heuristic algorithm [6] which can be used to solve the CVRP. However, its application to solving the CVRP is still limited. In the literature, we have found that Osaba et al. [6] and Ruttanateerawichien et al. [7] are the only GB-related works. Therefore, this is our contribution to develop a new GB-based algorithm which can efficiently solve the CVRP in terms of solution quality.

This paper is organized as follows. Section 2 will review the related literature. Section 3 will describe our proposed approach. In section 4, the experimental result will be shown and discussed. Finally, we will conclude our work in section 5.

II. LITERATURE REVIEW

The GB algorithm began from the simulation of different concepts related to soccer for the search process [6]. It is a multiple population-based algorithm. The GB algorithm represents a solution of a problem as a soccer player, and a population is represented by the soccer teams. In each iteration, all players have the chance to improve their solution quality by training procedures. The players can switch from their team to another by transfer procedure.

Since the GB algorithm was firstly proposed in 2014, it has been applied to the travelling salesman problem [6], the capacitated vehicle routing problem [6-7], asymmetric travelling salesman problem [8], vehicle routing problem with backhauls [8], n-Queen problem [8], one-dimensional bin packing problem [8]. Two research works that are directly related to ours will be briefly reviewed as follows.

Osaba et al. [6] proposed an original version of GB algorithm to CVRP. In their work, all players are generated randomly. After that, these players are randomly divided among the different teams. In the training process, they used 2-opt and vertex insertion as intra-route improvement algorithm, and swapping routes and vertex insertion routes as inter-route improvement algorithm. Furthermore, they used golden help function in order to improve more solution quality of the players.

Ruttanateerawichien et al. [7] introduced an improved version of GB algorithm to CVRP. The solution representation in their work is similar to the original GB algorithm that one CVRP solution is represented by one soccer player. In their

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work, all players in each team are generated randomly, except one player who is generated by using an improved Clarke and Wright savings algorithm [9]. In the training process, they used intra-move and inter-move operators composed of shift and swap moves to improve solution quality of the players.

In term of computational result, Ruttanateerawichien's GB algorithm outperformed Osaba's GB algorithm and could provide high quality solution for some benchmark problems. However, their algorithm required significantly larger number of iterations. For example, when two GB parameters, which were used in their work [7] composed of four teams and six players per team, were concentrated. Totally, 24 different solutions were generated to be 24 players in initial teams for league competition. Therefore, numerous iterations were required for each player in their training process. In order to avoid these iterations, a new solution representation for GB algorithm is proposed in this paper.

III. PROPOSED GOLDEN-BALL-BASED ALGORITHM

As described in Section 2, existing applications of GB algorithm to CVRP use the same solution representation by generating the player as CVRP solution. This section describes our application of GB algorithm which uses different solution representation from the original one. The population of the proposed GB algorithm is represented by the soccer teams that each team represents one CVRP solution. Each team has the number of players that each player represents one CVRP route. The flowchart of the proposed GB algorithm is given in Fig. 1 and is described in the following subsection.

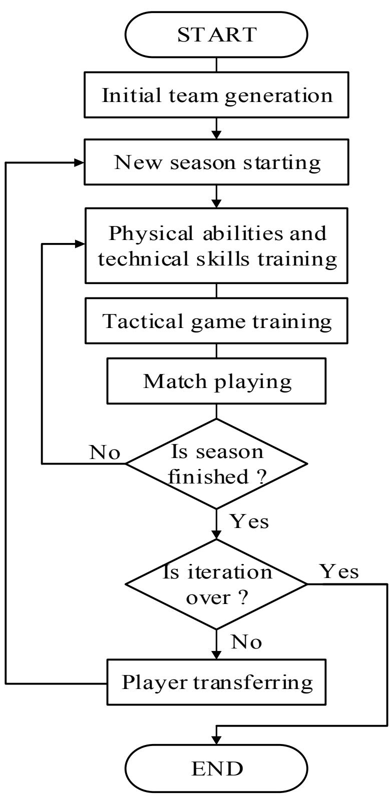

Fig. 1. Flowchart of the proposed GB algorithm

A. Initial Team Generation

In this procedure, teams (t) are generated that an example of an initial team composed of two soccer players (p) is shown in Fig. 2. The member in team t_1 represents two CVRP routes of customer node which is randomly generated. For the player p_1, the vehicle departs from the warehouse 0, delivers goods to customers 1, 2 and 3, and return to the same warehouse. For player p_2, the vehicle departs from the warehouse, delivers goods to customers 4, 5 and 6, and return to the same warehouse. Moreover, in this research, one stronger team is more generated by using an improved Clarke and Wright savings algorithm introduced by Pichpibul and Kawtummachai [9]. After that, the solution quality of each team is calculated by the summation of the total travelling distance of all routes. According to Fig. 2 the total travelling distance of the first route (player p_1) is equal to 10+15+5+15=45 and the second one (player p_2) is equal to 15+5+10+5=35. Therefore, the solution quality of team t_1 is equal to 45+35=80.

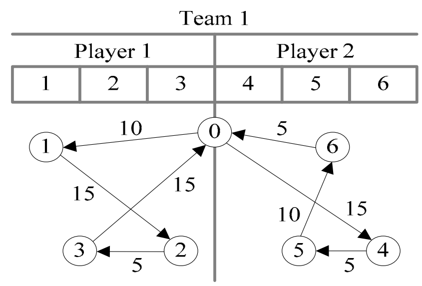

Fig.2. Example of soccer team

B. Physical Abilities and Technical Skills Training

As in real life, the physical abilities and technical skills training is an individual player development plan to improve the quality of each player in each team. This plan will target to provide every player with the opportunity to develop themselves into the best player they can possibly be. The example components of physical abilities are: jogging, running and sprinting, and technical skills are: dribbling, passing, heading and shooting.

In the proposed GB algorithm, these components are represented by intra-route moves [10] composed of shift and swap moves that an example is shown in Fig. 3. The shift move removes customer 3 from the first route (player *p1*) and insert them in the second place of the same route. The swap move select customers 4 and 5 from the second route (player *p2*) and exchange them. This procedure obtains new route which is accepted only if the quality of new route is better than the quality of existing route.

C. Tactical Game Training

After complete the physical abilities and technical skills training, all players have to learn, on a more individual base, the roles and tasks in order to perform their skills under guidance and then applying their skills in a suitable situation. The example components of tactical game are: defending and attacking exercises with 1-1, 2-2, and 3-3 players involving attackers and defenders.

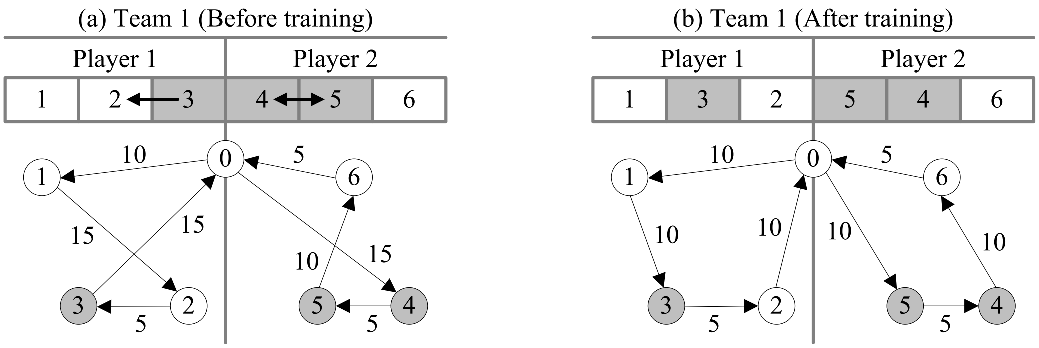

Fig. 3. Example of physical abilities and technical skills training

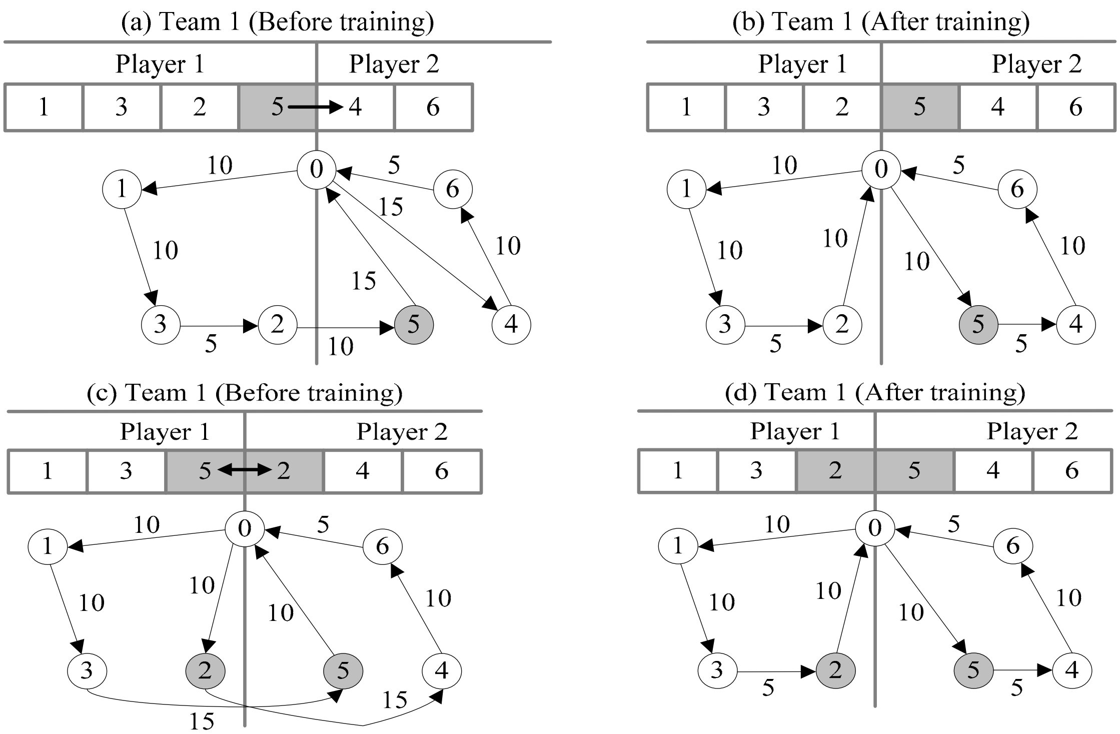

Fig. 4. Example of tactical game training

In the proposed GB algorithm, these components are represented by inter-route moves [10] composed of shift and swap moves that an example is shown in Fig. 4 In Fig. 4(a)-4(b), the shift moves remove customer 5 from the first route (player *p1*) and insert them in the first place of the second route (player *p2*). In Fig. 4(c)-4(d), the swap moves select customer 5 from the first route (player *p1*) and customer 2 from the second route (player *p2*), and exchange them. This procedure obtains new solution which is accepted only if quality of new solution is better than the existing one.

D. Match Playing

When the season starts, each match is played between two teams. All teams have to play matches against each other in order to create a league competition. In each match team t_i face team t_j, and the team with better solution quality is the winner of the match. The team winner of the match obtains three points, and the loser obtains zero point. In case of a tie match, both teams get one point. These points are used to rank teams in the league.

E. Player Transferring

The transfer is a procedure that the players are moved between the teams in every season. In general, all teams are ranked depending on their point in the league. Teams which are in the top half of the league have opportunities to sign better players. In the proposed GB algorithm, team t_i and team t_j are chosen to move their players that an example is shown in Fig. 5. The player p_2 from team t_1 is replaced by the player p_1

from team t_2. This procedure obtains new solution which is accepted only if quality of new solution (new team t') is better than the existing solutions (team t_1 and team t_2). The proposed GB algorithm is stopped when the maximum number of iterations is reached.

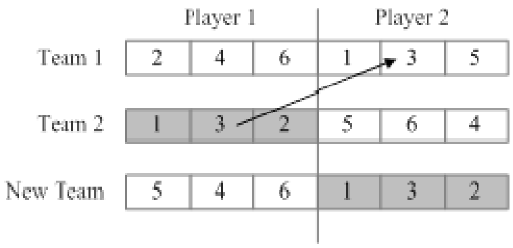

Fig. 5. Example of player transferring

IV. Computational Results

The performance of the proposed GB algorithm was investigated by using the benchmark data sets[6]. The algorithm was implemented in VISUAL BASIC language using Microsoft Visual Basic 6.0 on an Intel Core i7, 2.8 GHz with 1.99 GB of RAM under Windows XP platform. The main purpose of the experiment was to compare the proposed GB algorithm to the best known algorithms and previous GB algorithms.

The GB parameters were set as follows: the number of teams is equal to four; the number of players per team depends on the number of available vehicles (k) for each problem; the number of stronger teams is equal to one; the number of iterations per stronger team is equal to 1000; the number of iterations per physical abilities and technical skills training is equal to ten; the number of iterations per tactical game training is equal to ten; the number of seasons is equal to ten; the number of iterations of the proposed GB algorithm is equal to 1000 the GB parameters in the same values[7].

Table 1 shows the results on the Osaba's benchmark problem set [6]. *BKS* in the table represents the best known solution obtained from [11-13]. *GB* represents the results of Osaba et al. [6]. *IGB* is from Ruttanateerawichien et al. [7]. *NGB*, which is the acronym for new GB algorithm, represents the results of the proposed GB algorithm. The best solutions are indicated by bold number. *GB*, *IGB*, and *NGB* generated best solutions for 0, 6, and 8 problems, respectively. The proposed GB algorithm outperformed both of *GB* and *IGB*. Fig. 6 shows the percentage deviation between obtained solution (*obs*) and the best known solution (*bks*) which is calculated as follows:

$$\text{Percentage deviation} = \left(\frac{obs - bks}{bks}\right) \times 100 \qquad (1)$$

TABLE I. Computational Results of Osaba's Benchmark Data Sets

Problem	No. customers	Total travelling distance			
		BKS	*GB*	*IGB*	*NIGB*
E-n22-k4	21	**375.28**	376.00	**375.28**	**375.28**
E-n23-k3	22	**568.56**	589.70	**568.56**	**568.56**
E-n33-k4	32	**837.67**	857.80	**837.67**	**837.67**
E-n51-k5	50	**524.61**	578.10	**524.61**	**524.61**
E-n76-k7	75	**687.60**	755.80	**687.60**	**687.60**
E-n76-k10	75	**835.26**	913.60	837.36	**835.26**
E-n76-k14	75	**1024.40**	1124.60	1026.71	**1024.40**
E-n101-k8	100	**826.14**	906.40	**826.14**	**826.14**

Fig. 7 shows an example of the experiment of results by *IGB* and *NGB* in every 100-iteration. *NGB* rapidly drops in the early iterations but *IGB* slowly drops continuously until the best solution is found or the maximum number of iterations is reached. Similar behaviors were observed in seven problems that an example is shown in Fig. 8.

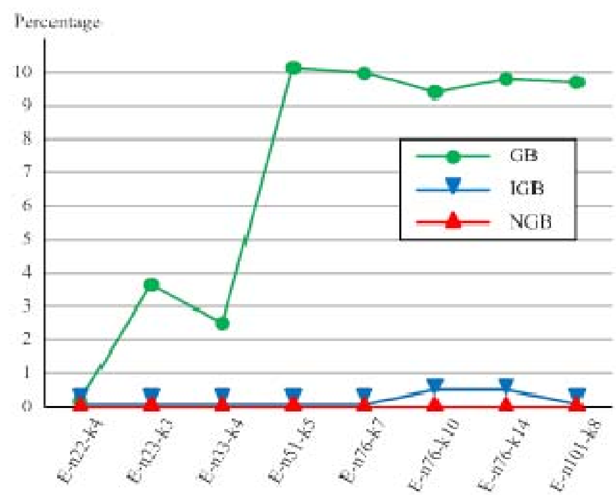

Fig. 6. Percentage deviation from BKS

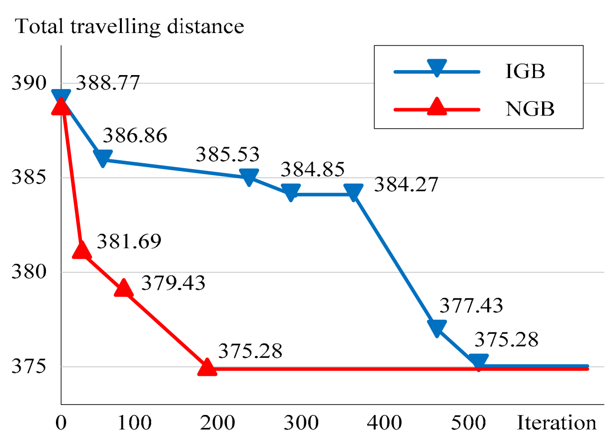

Fig. 7. The numbers of iterations of E-n22-k4 problem

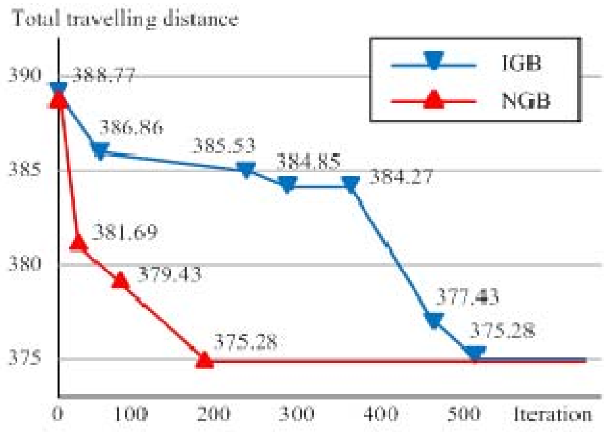

Fig. 8. The total numbers of iterations to reach the best solutions of problems

V. CONCLUSION

This paper has proposed a new technique based on the GB algorithm for solving the CVRP. The proposed algorithm uses different solution representation from the original one. In the training procedure, the intra-route and inter-route improvement algorithms composed of shift and swap moves are used to improve the solution quality of the players and the teams. Computational experiments on benchmark data sets have demonstrated the efficiency and effectiveness of the proposed GB algorithm compared to the best known algorithms and the existing GB algorithms. That is to say, our approach results in shorter total travelling distances in some problems and much less iterations in finding the best known solutions in all problems.

In our future work, we will extend the proposed GB-based algorithm to deal with other variants such as backhauls, and simultaneous delivery and pickup.

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