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Solving Capacitated Closed Vehicle Routing Problem with Time Windows (CCVRPTW) using BRKGA with local search

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Abstract. The main issue in vehicle routing problem (VRP) is finding the shortest route of product distribution from the depot to outlets to minimize total cost of distribution. Capacitated Closed Vehicle Routing Problem with Time Windows (CCVRPTW) is one of the variants of VRP that accommodates vehicle capacity and distribution period. Since the main problem of CCVRPTW is considered a non-polynomial hard (NP-hard) problem, it requires an efficient and effective algorithm to solve the problem. This study was aimed to develop Biased Random Key Genetic Algorithm (BRKGA) that is combined with local search to solve the problem of CCVRPTW. The algorithm design was then coded by MATLAB. Using numerical test, optimum algorithm parameters were set and compared with the heuristic method and Standard BRKGA to solve a case study on soft drink distribution. Results showed that BRKGA combined with local search resulted in lower total distribution cost compared with the heuristic method. Moreover, the developed algorithm was found to be successful in increasing the performance of Standard BRKGA.

1. Introduction

The main problem in Vehicle Routing Problem (VRP) is to find distribution routes between depot and outlets so that all outlets are covered with the most minimum distance, and delivery cost [1], with the vehicle, is limited to visit an outlet only once [2]. VRP is aimed to distribute products to outlets that are spread in many locations to optimize distribution distance [3] and distribution cost [4]. It is assumed that VRP is an open route, with the vehicle goes from and returns to the same depot [5]. Examples of VRP cases in the industrial world is the case of soft drink distribution [6], rice distribution [7], distribution of vegetables from places of higher altitudes [8], waste collection and disposal [9], etc.

Reference [6] has solved the problem of VRP for the case of soft drink distribution that used to have less optimum routes, resulting in high cost for companies to pay overtime for workers. A similar case in the distribution of computer spare parts by [4] and distribution of subsidized rice [7]. Some vehicle routing problems accommodate limited vehicle capacity and numbers or known as Capacitated

Vehicle Routing Problem (CVRP). Reference [10] dealt with CVRP for newspaper distribution, while [11] addressed CVRP for soft drink distribution. Another characteristic of VRP was time limitation (Time Windows), where product distribution was based on the time set by the companies. Vehicle Routing Problem with Time Windows (VRPTW) had successfully been applied in the study of [12] in the case of instant noodles delivery, where the decision on routes was highly important to ensure optimum delivery time so that the products sent to customers on time. Another example is the distribution of blood sample, where time is crucial considering the nature of blood that rapidly degrades. Thus time frame had to be decided carefully in distribution [3]. The route where vehicles leaving from and returning to the depot is called a closed route, while if the vehicles start from a specific place to distribute products to several outlets before ending up in the depot, it is called an open VRP route (with the assumption that vehicles are not owned by the company). In practices, both capacity and time constraints may simultaneously exist. Therefore, this research is concerned with Capacitated Closed Vehicle Routing Problem with Time Windows (CCVRPTW). There have been some studies dealing with CCVRPTW, such as [13], [14] and [15]. This research contributes in proposing a biased random-key genetic algorithm approach for solving CCVRPTW efficiently.

In general, VRP is difficult to solve with analytical methods, since functions cannot be integrated. Thus solutions are difficult to find or even cannot be found [16]. Even though the solution suggested could yield optimum results, but it took a long time to compute. Reference [6] solved the case of soft drink distribution using the heuristic method, which is called Nearest Neighbor. Several researchers have used heuristic methods for instance [17], [11] and [18]. However, the heuristic method does not consider whether the solution could bring optimum results. Therefore, a computing model was designed to suit the research, which is a metaheuristic method. Metaheuristic could provide a more optimum solution with shorter computing time compared to an analytical/numerical method and heuristic method. Thus, this method has been used more frequently in solving complicated problems like in this study. Several famous metaheuristic methods are Simulated Annealing, Ant Colony Optimization, and Genetic Algorithm [19]. Simulated Annealing has been used by [13], while Ant Colony Optimization was utilized by [20] to solve scheduling problem and Genetic Algorithm was applied by [8]. Reference [21] used the Tabu Search method to develop optimum distribution route for bread industry. In this study, the metaheuristic method that was used was Biased Random Key Genetic Algorithm (BRKGA) that takes the concept of human evolution. Introduced in 2002, BKRGA has successfully solved many optimization problems due to its flexibility and good performance. Reference [22] presented a review of the application of this algorithm. In this study, to improve the performance of BKRGA, the algorithm was modified and combined with local search. Therefore, several experiments were performed to proof that BRKGA combined with local search was better than both Standard BKRGA and heuristic method.

2. Methods

2.1 Problems and assumptions

The problem addressed in this study is the same problem addressed by [23] who discussed VRP problems in the soft drink industry. The distributor is aimed to find optimum route so that products are distributed from a depot to 45 outlets. Moreover, the vehicle has a limited capacity that affects the order limit from every outlet. The company has set the maximum distribution time for each delivery.

In this study, data were collected to support the main results. Those data were for example location of outlets, distance and travel time between each outlet and depot, order from each outlet, vehicle capacity, distribution time, vehicle setup time, service time at every outlet, as well as loading and unloading time at every outlet. Several assumptions were also needed in the study such as an order from each outlet had been known based on order record and outlet's order was assumed constant in every distribution batch. The vehicle that was used for the distribution was a truck with the capacity of 130 crates. The delivery time limit was assumed to be equal and constant in every sub route, which was 480 min, including 15 min for vehicle setup at every sub-route and 19 min service, loading and unloading time at every outlet. Distribution time allowance of 20% was used for unforeseen circumstances that might happen during distribution, for example, if the vehicle broke down or if there was a traffic jam.

2.2 Solution approach
Biased Random Key Genetic Algorithm (BRKGA) is a variant of Random Key Genetic Algorithm (RKGA) that was introduced by [24] to perform optimization, and it was first proposed in [25] and [26]. BRKGA consisted of a population (*p*) that is represented in a vector of random real numbers within the interval of 0 to 1 and it has been used from generation to generation. Numbers form a chromosome that represents an outlet to be decoded. Decoding a population is done by translating every gene at every chromosome into outlets. Therefore, the order of distribution route can be formed based on the limitations in capacity and time, so that distribution cost can be calculated. In figure 1, chromosomes with the genes 0.27, 0.65, 0.74, 0.53, and 0.81 represent every outlet to be decoded. The order of a route is developed by sorting genes from the smallest to the largest, so that the sorted genes become 0.27, 0.53, 0.65, 0.74, and 0.81 resulting in the ordered route of 1-4-2-3-5. At the next iteration, new genes are developed by encoding them from the outlet with minimum fitness and next translated into the best chromosomes.

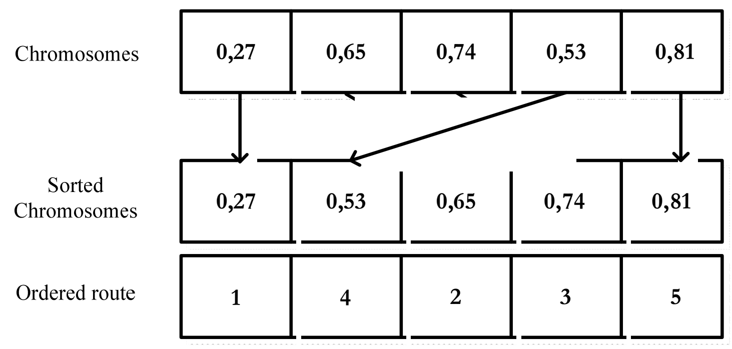

Figure 1. Decoding chromosomes

For *g* generation, it consists of the elite category (*pe*) and non-elite category (*p-pe*) in the initial population (*p*). One part of the generation (*g*+1) is formed from the copy of the elite category (*pe*) in the generation *g* to ensure that the best solution stays within the population. Next, the mutant (*pm*) is added to the population. The mutant comes from the random numbers similar to the initial population. The final part of the generation (*g*+1) is the result of a crossover (*p-pe-pm*) between the elite category (*pe*) with the non-elite category (*p-pe*) with probability values shown in table 1 [16]. RKGA selects two parents from all individuals in the population to be paired [3] (Grasas et al., 2014), while BRKGA selects two parents from each chromosome of the elite category and the non-elite category in the population to be paired [27]. As an illustration, parent 1 (*pe*) has the genes 0.27, 0.65, 0.74, 0.82, 0.39 and parent 2 (*p-pe*) has the genes 0.78, 0.71, 0.18, 0.53, 0.81. Random numbers with the interval of 0 to 1 along the parents' chromosomes are generated into 0.32, 0.69, 0.42, 0.87, and 0.76. If random numbers are lower than 0.7, the next generations will inherit the genes of the elite parents; if the numbers are higher than 0.7, the next generations will inherit the genes of the non-elite parents. Based on the crossover, the new generations will have chromosomes with the genes 0.27, 0.65, 0.74, 0.53, and 0.81. The similar process is applied to crossover generation (*g*+2+3+…).

Table 1. brkga recommended parameters (Goncalves & Resende, 2011)

Parameter	Description	Recommended value
p	size of population	p = ax, where $1 \leq a \in \mathbb{R}$ is a constant and x is the length of the chromosome
pe	size of elite population	$0.10p \leq p_e \leq 0.25p$
pm	size of mutant population	$0.10p \leq p_m \leq 0.30p$
ρ_e	elite allele inheritance probability	$0.5 \leq \rho_e \leq 0.8$

Local Search Procedure (LSP) by two methods i.e. swapping two genes randomly and incrementing a gene, can further improve BRKGA. To illustrate for swapping method, the chromosome with the genes 0.27, 0.65, 0.74, 0.53, and 0.81 results in the route order 1-4-2-3-5. The random search of neighboring genes results in the genes 0.27 and 0.53 as shown in figure 2. The local search found new chromosomes by swapping these genes resulting in new chromosome 0.53, 0.65, 0.74, 0.27, and 0.81 and distribution route 4-1-2-3-5. For incrementing method, suppose gene 0.65 is chosen randomly. The local search procedure is performed by searching 45 values near 0.65.

In their report, [22] stated that BRKGA combined with local search had been applied by [28] and [29] with different methods, but similar local search concept. BKRGA was reported to give more optimum results compared to other methods. Therefore, in this study, several methods were compared, namely heuristic method, Standard BKRGA, and BKRGA combined with local search to identify if BKRGA could provide more optimum results.

3. Results and Discussion

3.1 Setting of parameters for BKRGA combined with local search

BKRGA program has been implemented in MATLAB version 7.11.0.584 (R2010b), 64 bit (win64) and runs on a notebook Intel® Core™ i5-2450M @ 250 GHz with the capacity of 4 GB RAM. The setting of BKRGA parameters was done through extensive experiment. With population size of 45, a number of set parameters are studies, i.e. *pe* (0.1, 0.15, 0.2, and 0.25), *pm* (0.1, 0.2, and 0.3) and ρ_e (0.5, 0.6, 0.7, and 0.8). Parameter setting configuration resulted in 48 parameters, every parameter was computed with 50 samples of fitness values with the iteration of 700 repetitions, and average fitness value was obtained in every parameter. The selected parameter was the parameter with the lowest average fitness values among all parameters. The lowest fitness value was obtained from the first parameter configuration with the setting as follows: the elite probability of 0.1, the elite generation probability of 0.5, and the mutant probability of 0.1, as shown in table 3, with the value of Rp 4,054.02. Figure 2 shows the convergent point of the computation of BKRGA with the local search using the best setting parameters.

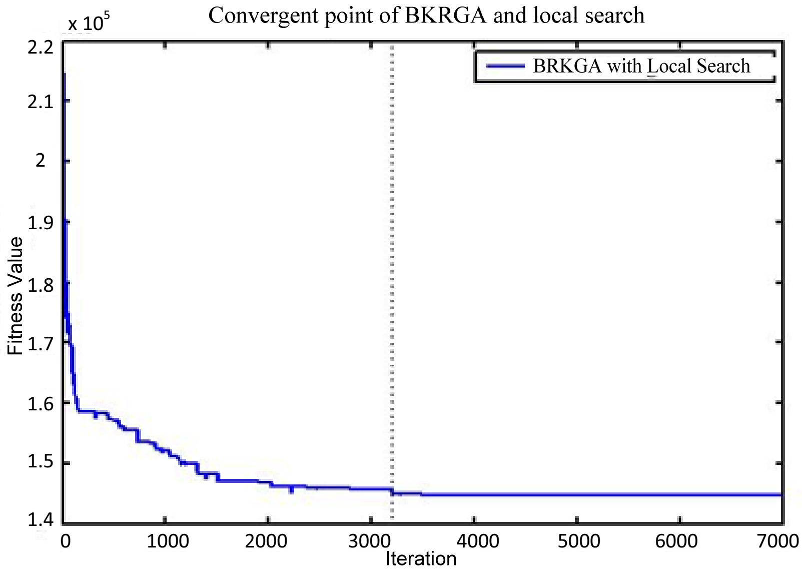

Figure 2. Convergent point of BKRGA with local search

After finding the best setting parameters, the algorithm was run to get final minimum cost. The computation was performed with the best setting parameters and repeated with 7000 iterations, resulting in the minimum cost of IDR 144,760.00.

3.2 Performance of the proposed BRKGA over standard BRKGA

The performance of the proposed BKRGA was measured by comparing standard BKRGA, and BKRGA combined with local search. Every computation resulted in the lowest fitness value with a specific distribution route. Figure 3 showed the graph of the convergent point of minimum fitness values of Standard BKRGA and BKRGA combined with the local search using the best setting parameters. It was shown that standard BKRGA reached its convergent point at the 2375th iteration, as shown by the vertical line on Figure 3, with the total cost of IDR 152,057.60. Meanwhile, BKRGA with local search could find the minimum cost of IDR 144,760.50. Therefore, there was the budget saving of IDR 7,297.10 that was gained, which was approximately 4.8% of the total distribution cost.

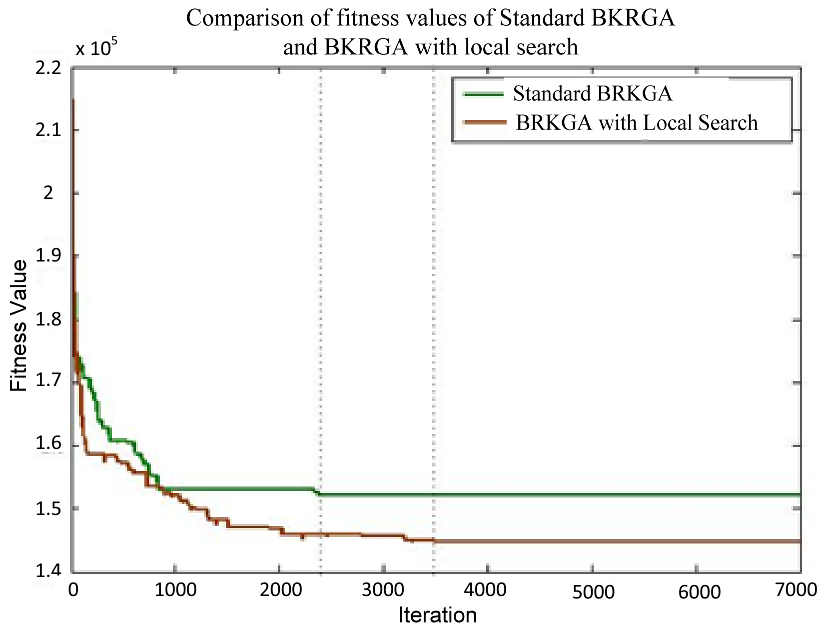

Figure 3. Comparison of BKRGA with local search and Standard BKRGA

3.3 Comparison between BKRGA with heuristic method

Other than comparing BKRGA with local search and Standard BKRGA, the main objective of this study was to compare BKRGA with local search with the heuristic method. This study compared the two methods using similar data used by Sembiring (2008). After the analysis was performed on the BKRGA algorithm, results show that BKRGA won over the heuristic method regarding the obtained distribution cost. Total distribution cost used by the heuristic method was IDR 236,500.00, while total distribution cost for BKRGA with local search was IDR 144,760.50. Thus, there was a saving of cost of IDR 91,739.50, which represented 38.8% of the total cost. Regarding the computation time the heuristic method performed faster than the proposed BRKGA. However, the computation time of fewer than one minutes for the proposed BRKGA is worthy when noting that the obtained result was a significant saving.

4. Conclusions

This article offers the solution for CCVRPTW case using BKRGA with local search approach. BKRGA configuration was very efficient in solving the problems of CCVRPTW: limitation in vehicle capacity and time allocation. In industry, one of the applications of this method was in soft drink distribution. Cutting of order of distribution route was based on the limitations in capacity and time. Thus the order of distribution route obtained was feasible. The algorithm of BKRGA with local search was able to improve the performance of Standard BKRGA by 4.8% regarding the distribution cost. The proposed algorithms could save the cost, as compared to the heuristic method. The saved amount was IDR 91,740.00, which represented 38.8% of the total distribution cost.

The results of this study cannot always be applied on all probabilistic situation since consumer demand can change anytime. Thus it needs further study for different cases of probabilistic. Moreover, several assumptions used in this study limit it from being used for all other cases of CCVRPTW.

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