Solving CCVRPTW using biased random key genetic algorithm (BRKGA) with multiple parent

H Prasetyo¹, M Qoyyiimah¹ and G Fauza²
¹ Dept. of Industrial Engineering, Universitas Muhammadiyah Surakarta, Jl. A Yani Tromol Pos I Pabelan Surakarta Indonesia
² Dept. of Food Science and Technology, Universitas Sebelas Maret, Jl. Ir. Sutami 36A Kentingan Surakarta Indonesia

hari.prasetyo@ums.ac.id

Abstract. This research addresses a Capacitated Vehicle Routing Problem with Time Windows (CCVRPTW) which is a Vehicle Routing Problem (VRP) with fleet capacity and delivery time constraints. In the research, a Biased Random Key Genetic Algorithm (BRKGA) is proposed to solve the problem. The standard BRKGA is improved by modifying the crossover process accommodating Multiple-Parent. The proposed BRKGA is coded using the Matlab programming language. A case of soft drink distribution is used to evaluate the performance of the algorithm. From the research, it can be concluded that (1) The proposed BRKGA is better than the heuristic method proposed by previous research for dealing with the same case; (2) the Multiple-Parent BRKGA can further improve the general BRKGA; (3) The Multiple-Parent BRKGA with third parent selected randomly from NON-ELITE group results in a better solution than that of selected randomly from the whole population.

1. Introduction

Vehicle Routing Problem (VRP) aims to identify routes using some vehicles for delivering products or services to consumers in different locations [1]. Generally, VRP consists of one depot where one vehicle functions to fulfill the demands or needs of consumers in particular geographical areas [2]. One important aspect is determining delivery routes so that all outlet or consumer demands can be fulfilled with minimal delivery distance or cost. VRP has been commonly implemented, such as for delivering products, waste collection or removal, and newspaper pickup and delivery.

In VRP, vehicles generally depart from a depot and return to the depot commonly known as Closed Vehicle Routing Problem [3]. In general, solutions for VRP case do not adequately consider the capacity of vehicles used [4]. The limited capacity of vehicles used to serve consumers is the main factor in VRP case, which is called Capacitated Vehicle Routing Problem (CVRP) [5]. Besides capacity limitation, there are other limitations which require all vehicles serving consumers to be in a particular time frame. This means all vehicles serving consumers should not exceed the time specified by consumers or the company. The problem of VRP due to service time limitation is called Vehicle Routing Problem with Time Windows (VRPTW) [6]. Reference [7] conducted a study on VRPTW using Nearest Neighbor method. However, the method needs much time if the scope of the problem is broad. Further, reference [2] examined CVRPTW in a soft drink company using Evolution Strategies.

In practices, limitations of both capacity and time are often simultaneously occurred in VRP also known as Capacitated Closed Vehicle Routing Problem with Time Windows (CCVRPTW). The
problems of CCVRPTW have been examined by [8] for the distribution of bottled water. This study compared two solution methods, Branch & Bound and Clarke & Wright Savings. The results of the comparison indicate that Branch and Bound method is better in solving the problem of CCVRPTW; however, solutions for the problem are difficult to find when the scope becomes bigger.

Generally, VRP is a problem of Non-Deterministic Polynomial-Time Hard (NP-Hard). When the number of nodes increases, both the solution space and the computation time will explode exponentially [3]. Research on VRP should consider the quality of the solutions in terms of optimal solution and computation time [9]. Analytic and exact approaches are often difficult to apply due to either impractical to find derivative formula or excessive computation time [10]. Therefore, some researchers use heuristic method as it can generate solutions more quickly, for example [11] who solved the distribution problem of soft drink and [12] who solved the problem of waste disposal. Yet, the solution generated by heuristic method is not optimal, although it requires less time. Thus, many researchers use metaheuristic method to generate optimal solutions in reasonable computation time, such as [13] who solved the VRP using Ant Colony. Furthermore, [14] used genetic algorithm to solve CVRP problems.

This study uses metaheuristic method by designing BRKGA through an efficient modification of multiple parents to solve CCVRPTW in the case of soft drink distribution investigated by [11]. The BRKGA with multiple-parent modification uses three parents to produce an offspring. The performance of the proposed BRKGA is then compared to the heuristic procedure which has been used to deal with CCVRPTW in [11]. In addition, a comparison with the standard BRKGA is also conducted to show the performance improvement by the proposed BRKGA.

2. Problem and solution approach

2.1. Problem definition

The problem of soft drink distribution investigated by [11] is addressed in this research. The distribution company serves the demand of 45 outlets geographically dispersed consisting of supermarkets, minimarkets, canteens, cooperatives, business entities, and restaurants. A truck with limited capacity is used to serve all outlets for 7 days in a week. The demand per week of all outlets is known and constant. The truck must depart from the depot and return to the depot within the working hours prescribed by the company. Thus the problem is to find the best set of sub-routes passed by the truck for one week. The data required for the problem includes truck capacity, demand of each outlet, service time of each outlet, setup time of the vehicles, company’s working hours, and transportation time and cost matrices among depot and outlets.

2.2. Solution approach

The proposed solution for dealing with CCVRPTW is Biased Random Key Genetic Algorithm (BRKGA) which has been extensively used for other combinatorial optimization problems [15] due to its flexibility in representing various problems [16]. This algorithm consists of initial $p$ individual population each of which is represented by $x$-vector length randomly generated from 0 to 1 [3]. Each chromosome/individual comprises a set of genes representing outlets (as seen in figure 1).

![Figure 1. Coding process.](image-url)
Figure 1 illustrates the encoding process of a chromosome comprising 5 genes. Genes 1-2-3-4-5 have their corresponding gene values which are 0.99-0.78-0.01-0.32-0.35. By sorting the gene values in ascending order, one has a sub-route of 3-4-5-2-1. Note that for this study this sub-route must meet the truck capacity and distribution time constraints.

In BRKGA, as explained by [17], and [3], the \( p \) initial population is divided into two groups; small group called ELITE (\( pe \)) individuals approximately 10-20% of most fit solutions, and NON-ELITE individuals with the rest of individual from \( p-pe \). This population evolves to obtain the next generation (figure 2) until stopping criteria is met. The ELITE individual will be copied to the next generation, called TOP chromosomes, while \( pm \) individuals are randomly generated and placed in the next generation, also called BOT chromosomes. The number of population in the next generation is kept to be \( p \) chromosomes. Thus, the remaining members of the next generation (\( p-(pe+pm) \)) are filled by offspring obtained from mating between ELITE individual and NON-ELITE individual. This crossover process is conducted by selecting multiple parents, one ELITE chromosome and two NON-ELITE chromosomes and combining them to produce one offspring. The crossover process is illustrated in figure 3. Chromosome 1 refers to ELITE and chromosomes 2 & 3 to NON-ELITE. In this example the probability of allele inheritance is 0.5 for chromosome 1, 0.25 for chromosome 2 and 0.25 for chromosome 3 to produce offspring chromosome.
The modification of crossover process using more than two parents or called multiple-parent has previously been done by [18], [19], and [20]. In BRKGA, there are some parameters which need to be set in order to obtain the best solutions. Based on research conducted by [16], and a survey done by [15] on the implementation of BRKGA in various fields, the recommended parameter setting of BRKGA is presented in Table 1.

### Table 1. BRKGA parameters [15].

| Parameter (a) | Description (b) | Recommended value (c) |
|---------------|-----------------|-----------------------|
| \( p \)       | size of population | \( p = ax \), where \( 1 \leq a \in \mathbb{R} \) is a constant and \( x \) is the length of the chromosome |
| \( p_e \)     | size of elite population | \( 0.10p \leq p_e \leq 0.25p \) |
| \( p_m \)     | size of mutant population | \( 0.10p \leq p_m \leq 0.30p \) |
| \( \rho_e \)  | elite allele inheritance probability | \( 0.5 \leq \rho_e \leq 0.8^* \) |

*for two-parent crossover

3. Results and discussion

3.1. BRKGA parameter setting

BRKGA algorithm is coded in Matlab version 7.11.0.584 (R2010b) 64-bit (win64) and run using a notebook with the following specifications: processor Intel® Core™ i5-2450M, processor speed 2.50 GHz and RAM 4GB. The program is run to obtain a parameter with solutions which generate the lowest average cost. The best parameter was obtained through 12 parameter combinations, consisting of number of population, ELITE percentage, and mutation percentage. The parameter setting is evaluated based on the survey conducted by [15]. The number of population is 45, the elite percentages are 0.1, 0.15, and 0.25, and the percentages of mutation are 0.1, 0.2, and 0.3. From each combination, 50 samples are collected; to identify the best parameters, each sample is iterated 700 times. Based on the experiment, the best parameter combination is population size 45, elite percentage 0.25, and mutation percentage 0.1.

Figure 4 shows how the BRKGA with the selected parameter is able to converge to the optimal solution faster and better in comparison with another set of parameter. It reaches the convergence point at iteration 2000. This result demonstrates that the selection or setting of appropriate parameters plays an important role in implementing the proposed BRKGA.

![Figure 4. Convergence point of BRKGA.](image-url)
3.2. Performance of multiple-parent BRKGA and standard BRKGA

The performance of multiple-parent BRKGA designed in this research is evaluated by comparing this algorithm with the standard BRKGA. The aim of the comparison is to indicate that the modification of multiple-parent BRKGA is able to improve the results of standard BRKGA in terms of quality of generated solution. Based on the application of BRKGA algorithm conducted by [15], the average allele percentage or crossover probability often used in previous research is 0.7. Therefore, standard BRKGA in this study uses crossover probability of 0.7, meaning that descendant opportunity of ELITE chromosome is 70%.

In this study, the modification of multiple-parent BRKGA algorithm is done not only by selecting the third parent from NON-ELITE group, but also from the whole population (both from ELITE and NON-ELITE groups). The total costs generated by multiple-parent BRKGA and standard BRKGA are presented in table 2. As table 2 column b indicates, the cost generated by multiple-parent BRKGA using the third parent from NON-ELITE group is the best solution cost, that is IDR 144,948. This BRKGA is better than the standard BRKGA with a lower cost, which is IDR 11,672. The BRKGA using the third parent from the whole population is not better than the NON-ELITE; however, it can improve the standard BRKGA with a cost difference of IDR 5,710 as shown in table 3 column c. Therefore, with insignificant time difference, the use of multiple-parent in the crossover process is able to improve the standard BRKGA. However, in the research, the selection of third parent from NON-ELITE group results in a lower cost than that of from the whole population.

Table 2. Cost of BRKGA results.

| Methods                      | Cost (IDR/week) | Gap with standard BRKGA (IDR/week) |
|------------------------------|-----------------|-----------------------------------|
| General BRKGA                | 156620          | -                                 |
| Mutiple-Parent BRKGA with all population | 150910          | 5710                              |
| Mutiple-Parent BRKGA with NON-ELITE | 144948          | 11672                             |

The performance comparison of standard BRKGA and BRKGA with multiple-parent (MP BRKGA) is presented in figure 5.

Figure 5. Convergence points of BRKGA and Multiple-Parent BRKGA.

Figure 5 indicates the number of iterations for obtaining solutions toward convergence. Multiple-parent BRKGA with the selection of the third parent from NON-ELITE group is faster in generating
solutions toward convergence, that is at iteration 2000, followed by standard BRKGA at point 3500 and multiple-parent BRKGA with the selection of third parent from the whole population at point 4400. After many iterations, the three algorithms still experience the decrease of solution cost. However, the cost decrease is not significant compared to the number of iterations needed. Although standard BRKGA reaches convergence faster than the multiple-parent BRKGA using parent from the whole population, multiple-parent BRKGA is better in generating low-cost solutions.

3.3. Performance of the proposed BRKGA and Heuristic
Vehicle routing problem in a soft drink company in Medan has previously been solved by [11] using heuristic method comprising two phases: divide and conqueror. The problems of CCVRPTW in the soft drink company should be solved so that consumer demands can be fulfilled effectively with low distribution cost. Heuristic method used by [11] can decrease the distribution cost of the company.

In this study, multiple-parent BRKGA algorithm for solving CCVRPTW problems is designed and evaluated using CCVRPTW case which has been investigated by [11]. The results indicate that multiple-parent BRKGA is able to generate low-cost solutions. The costs generated by the heuristic method and multiple-parent BRKGA can be seen in Table 3. As table 3 indicates, the solution obtained using multiple-parent BRKGA is able to decrease the distribution cost, that is IDR 91,552 or 38.7%. The main advantage of the implementation of multiple-parent BRKGA in this case is that it can improve service quality, which is the fulfillment of consumer demand without exceeding working hours with minimal cost.

| Method             | Cost (IDR/week) | Gap (IDR/week) |
|--------------------|-----------------|----------------|
| Heuristic          | 236500          |                |
| Multiple-Parent BRKGA | 144498         | 91552          |

4. Conclusions and recommendations
This research has produced the design of an efficient multiple-parent BRKGA algorithm program for solving optimization problems in the distribution of soft drink in Medan. The proposed BRKGA has identified subroutes set reducing distribution cost for fulfilling the demand of outlets. The set of subroutes was determined by taking into account the working hours and capacity of vehicles used, which become constraints in the CCVRPTW of the soft drink company. Not only does multiple-parent BRKGA provide better solutions than those generated by heuristic method (18.7% saving), it also improves the results of standard BRKGA. Multiple-parent BRKGA generates solution result of 7.4% better than the standard BRKGA. The designed multiple-parent BRKGA program is easy to apply to various CCVRPTW problems with similar characteristics. It can also be adapted for solving other distribution problems by modifying its obstacles and objective function. This study has some limitations. The demand is deterministic; thus, probabilistic cases should be investigated. Also, further research using more than one type of vehicles should be conducted.

References
[1] Gunawan G, Maryati I and Wibowo H K 2012 Optimasi penentuan rute kendaraan pada sistem distribusi barang dengan ant colony optimization Semantik vol 2 no 1
[2] Harun I A, Mahmudy W F and Yudistira N 2014 Implementasi evolution strategies untuk penyelesaian vehicle routing problem with time windows pada distribusi minuman soda doro J. PTIIK Universitas Brawijaya vol 4 no 1
[3] Grasas A, Ramalhinho H, Pessoa L S, Resende, M G C, Caballé I and Barba N 2014 On the improvement of blood sample collection at clinical laboratories BMC Health Services Research vol 14 no 1
[4] Arvianto A, Setiawan A H and Saptadi S 2014 Model vehicle routing problem with parameter values, multiple time windows, multiple products and heterogeneous fleet for depot problem. J. Teknik Industri vol 16 pp 83–94.

[5] Awansari S A and Abusini S 2013 Implementasi model capacitated vehicle routing problem pada pengiriman pupuk urea bersubsidi J. Mahasiswa Matematika vol 5 p 372.

[6] Nugraha D C A and Mahmudy W F 2015 Optimasi vehicle routing problem with time windows pada distribusi katering menggunakan algoritma genetika SESINDO.

[7] Amri M, Rahman A and Yuniarti R 2014 Penyelesaian vehicle routing problem dengan menggunakan metode nearest neighbor; studi kasus di MTP Nganjuk Distributor PT. Coca cola J. Rekayasa Dan Manajemen Sistem Industri vol 2 pp 36–45.

[8] Nurhayati S 2013 Perbandingan metode branch and bound dengan metode clarke and wright savings untuk penyelesaian masalah distribusi aqua galon di PT. Tirta Investama Yogyakarta UNY.

[9] Gonçalves J F and Resende M G C 2011 A biased random-key genetic algorithm for job-shop scheduling AT&T Labs Res. Tech. Report vol 46 pp 253–71.

[10] Gonçalves J F and Resende M G C 2011 A parallel multi-population genetic algorithm for a constrained two-dimensional orthogonal packing problem J. of Comb. Opt. vol 22 pp 180-201.

[11] Sembiring C A 2008 Penentuan rute distribusi produk yang optimal dengan menggunakan algoritma heuristik pada pt. coca cola bottling indonesia medan Medan.

[12] Al’Aziz M R, Utomo B and Nurhadi K 2013 Analisis sistem pengangkutan sampah kota surakarta dengan metode penyelesaian vehicle routing problem (VRP) J. Matriks Teknik Sipil vol 1.

[13] Sari I N and Widodo A 2014 Penentuan rute yang optimal pada distribusi kacang menggunakan ant colony system: studi kasus di PT Qlauworks Indonesia J. Mahasiswa Matematika vol 2 pp 271.

[14] Shahab M L and Irawan M I 2016 Algoritma genetika ganda untuk capacitated vehicle routing problem J. Sains dan Seni ITS vol 4 no 2.

[15] Prasetyo H, Fauza G, Amer Y and Lee S H 2015 Survey on applications of biased-random key genetic algorithms for solving optimization problems IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) pp 863–70.

[16] Gonçalves J F and Resende M G C 2011 Biased random-key genetic algorithms for combinatorial optimization J. of Heuristics vol 17 pp 487–525.

[17] Gonçalves J F and Resende M G C 2015 A biased random-key genetic algorithm for the unequal area facility layout problem Euro. J. of Op. Res. vol 246 pp 86–107.

[18] Gonçalves J F and Resende M G C 2015 A parallel multi-population biased random-key genetic algorithm for a container loading problem Comp. & Op. Res. vol 39 pp 179–90.

[19] Fontes D B M M and Gonçalves J F 2013 A multi-population hybrid biased random key genetic algorithm for hop-constrained trees in nonlinear cost flow networks Opt. Letters vol 7 pp 1303–24.

[20] Lucena M L, Andrade C E, Resende M G C and Miyazawa F K Some extensions of biased random-key genetic algorithms 2014 In Simposio Brasileiro de Pesquisa Operacional XLVI