# SRBFOs for Solving the Heterogeneous Fixed Fleet Vehicle Routing Problem

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**Abstract.** The purpose of this paper is to present a new method to solve the heterogeneous fixed fleet vehicle routing problem (HFFVRP) based on structure-redesign-based bacterial foraging optimization (SRBFO). The HFFVRP is a special case of the heterogeneous vehicle routing problem (HVRP), in which the number of each type of vehicles is fixed. To deal with this combinatorial optimization problem, two improved SRBFOs (SRBFOLDC and SRBFONDC) are presented by integrating the same time decreasing chemotaxis step size mechanism of BFOLDC and BFONDC into the optimization process of SRBFO. SRBFOLDC and SRBFONDC are successfully applied though encoding the position of bacteria by 2N dimensions. The first N dimensional vectors indicate the corresponding vehicle, and the next N dimensional vectors present the execution order of the corresponding vehicle routing. In the simulation experiments, it is demonstrated that SRBFONDC and SRBFOLDC are efficient to solve the heterogeneous fixed fleet vehicle routing problem with lower transportation cost and get better vehicle routing. Besides, SRBFONDC performs best compared with other five bacterial foraging optimization algorithms.

**Keywords:** Bacterial foraging optimization · Chemotaxis step · The heterogeneous fixed fleet vehicle routing problem

## 1 Introduction

The vehicle routing problem (VRP) is first proposed in 1959 by Dantzig and Ramser [1], which is an important problem in transportation, distribution and logistics areas. VRP is a combinatorial optimization and integer programming problem that calls for the determination of the optimal set of routes to be taken up by a fleet of vehicles serving customers subject to side constraints.

In the previous literature, a quite number of variants vehicle routing problem have been studied on either classical variants or the different versions, considering these factors: pickup and delivery, soft or hard time window, multi-depot, etc. such as the


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capacitated VRP (CVRP) [2], which takes the factor of vehicles having limited capacity into consideration. VRP with pick-up and delivery (VRPPD) [3], which considers the pick-up and delivery of goods. The multi-depot VRP (MDVRP) [4], which more than one depot is considered. VRP with time windows (VRPTW) [5], which adds the hard or soft service time windows of customers to research. The site-dependent VRP (SDVRP) [6] and the heterogeneous fleet vehicle routing problem (HVRP) [7] etc. The heterogeneous fixed fleet vehicle routing problem (HFFVRP) is one of the vehicle routing problems, which is much harder to solve. Taillard is the first researcher who has proposed an efficient and robust heuristic method to solve the HFFVRP in the past twenty years [8].

In reality, the phenomenon of various delivery types and different properties, or customer requirements is very common. Using the same type of vehicle involved in the distribution is likely to lead to significantly increased costs. And the use of heterogeneous fixed fleet vehicles may improve vehicle load factor, reduce logistics costs and improve economic efficiency of enterprises. Therefore, it has important theoretical and practical significance for research in the heterogeneous fixed fleet vehicle routing problem.

Bacterial foraging optimization (BFO) is a stochastic optimization technique that simulates the bacteria swarms' social foraging behavior, which was first proposed by Passino in 2002 [9]. It inspired by the foraging behavior of E. coli bacteria and it has attracted increasing attention as its strong optimization capabilities in solving optimization problems. In previous research, there are many improved BFO applied to VRP. In recent years, some research made great effort to settle the variants of VRP using BFO algorithms. Such as Niu et al. developed a novel bacterial foraging optimization with adaptive chemotaxis step in 2012 to solve Vehicle Routing Problem with Time Windows (VRPTW) [10]. Besides, a variant of the bacterial foraging optimization algorithm with time-varying chemotaxis step length and comprehensive learning strategy (ALCBFO) is proposed by Tan et al. to apply in vehicle routing problem with time windows in 2014 [11]. What's more, Seda et al. also presented BFO algorithm to solve the vehicle routing problem with simultaneous delivery and pick-up (VRPSDP) efficiently [12].

SRBFO is first proposed by Niu et al. [13], which is taking advantage of single-loop structure, and developed a new execution structure to improve the convergence rate as well as lower computational complexity. In pervious study, SRBFO is proved to solve portfolio selection such continuous problem efficiently. However, till now, SRBFO hasn't been applied to any other discrete optimization problems, such as VRP. In this paper, SRBFOs is presented to solve an improved kind of VRP model (HFFVRP). Furthermore, two improved SRBFOs with varying chemotaxis step (SRBFOLDC and SRBFONDC) are proposed, which imitate the same mechanism of BFOLDC and BFONDC by moderate the chemotaxis step length in the process of SRBFO.

This paper is structured as follows: Sect. 2 describes the heterogeneous fixed fleet vehicle routing problem (HFFVRP). Structure-redesign-based bacterial foraging optimizations for HFFVRP are presented in Sect. 3. Section 4 provides the experiment studies. Finally, the conclusion of this study and future research is presented in Sect. 5.

## 2 Description of HFFVRP

In real distribution management areas, the heterogeneous fixed fleet vehicle routing problem (HFFVRP) is more realistic compared with other standard VRP proposed by Taillard [8]. The HFFVRP is a design to seek a set of minimum cost routes, which is originated and terminated at a depot, and in which each types of vehicle have different fixed number and variable capacities and different unit running costs of servicing customers with known demands in the process of distribution. HFFVRP is a special case of the heterogeneous fleet vehicle routing problem (HVRP), for the number of each type of vehicles is fixed while in HVRP is unlimited [7, 14].

In HFFVRP, we assume that vehicles are start and end in the same depot. All the customers demand must be satisfied and only using one service time. Besides, all the goods can be mixed in vehicles and vehicles can't be overloaded. HFFVRP is described as follows: suppose that there are $K$ vehicles in depot, including two types of vehicle. One with $K1$ vehicles, and another with $K2$ vehicles, and the speed are $\mathrm{v}_1$, $\mathrm{v}_2$ respectively. There are $l$ customers to be serviced. For $i_{th}$ customer, the demand is $q_i$, service time is $S_i$, and time window is $[ET_i, LT_i]$. In this model, there will generates a waiting cost $pe$ if the vehicle reach customer $i$ before $ET_i$ and a late cost if the vehicle arrival at customer $i$ over $LT_i$. The distance between customer i and customer $j$ is $d_{ij}$. Assuming that $n_k$ is the number of customers been serviced by the $\mathrm{k_{th}}$ vehicle, if $n_k = 0$, the $\mathrm{k_{th}}$ car is not involved in the delivery. $R_k$ represents the $\mathrm{k_{th}}$ vehicle's routing path, where $r_{ki}$ represent customer $i$ in the path(not including the depot). $r_{k0}$ represents the depot. $d_{r_{k(i-1)}r_{ki}}$ is the distance between $r_{k(i-1)}$ and $r_{ki}$. $d_{r_{kn_k}r_{k0}}$ is the distance between the customer of vehicle $k$ last service and the depot. The structured Model is adopted in Ref. [15].

The objective function is:

$$\begin{aligned}\min z = & \sum_{k=1}^{K1} sign(n_k) * c_1 * \left[\sum_{i=1}^{n_k} d_{r_{k(i-1)}r_{ki}} + d_{r_{kn_k}r_{k0}}\right] \\ & + \sum_{k=1}^{K2} sign(n_k) * c_2 * \left[\sum_{i=1}^{n_k} d_{r_{k(i-1)}r_{ki}} + d_{r_{kn_k}r_{k0}}\right] \\ & + pe * \sum_{i=1}^{l} \max(ET_i - T_i, 0) + pl * \sum_{i=1}^{l} \max(T_i - LT_i, 0)\end{aligned} \tag{1}$$

where Eq. (1) represents the objective function for the sake of the total cost is minimized. Which consists of three parts, the first part is a first type of vehicles involved in the transport charges generated during transportation; the second part is the second type of vehicle transportation costs involved in the transport process produces; the third part is the total cost of late fees and waiting fees result from these does not meet the time window during transport procedure.

The constraints of the model are described as follows:

$$t_{r_{ki}} = t_{r_{k(i-1)}} + d_{r_{ki}r_{k(i-1)}}/v_k + s_{r_{k(i-1)}} \tag{2}$$

$$\sum_{i=1}^{n_k} q_{r_{ki}} < Q_{K1} \qquad \text{k} = 1\ldots\ldots\ldots\text{K1} \tag{3}$$

$$\sum_{i=1}^{n_k} q_{r_{ki}} < Q_{K2} \qquad \text{k} = 1\ldots\ldots\ldots\text{K2} \tag{4}$$

$$0 \le n_k \le l \tag{5}$$

$$\sum_{k=1}^{K} n_k = l \tag{6}$$

$$sign(n_k) = \begin{cases} 1 & n_k \ge 1 \\ 0 & n_k = 0 \end{cases} \tag{7}$$

$$\text{R}_{\text{k1}} \cap R_{k2} = \varphi \qquad \forall \text{k}_1 \ne k_2 \tag{8}$$

where Eq. (2) is used to calculate the time of the vehicle reaches each customer. Equations (3) and (4) are used to ensure that transport cargo capacity on each route of the vehicle does not exceed the vehicle load; Eq. (5) ensures that the number of customer each vehicle serviced is less than the total number of customers. Equation (6) is used to assure that each customer is serviced. Equation (7) defines an variable, if vehicle $k$ is not participate in the distribution, $sign(n_k) = 0$ else, $sign(n_k) = 1$. Finally, Eq. (8) indicates that each customer can only have a vehicle to make delivery.

# 3 SRBFOs for HFFVRP

## 3.1 SRBFONDC and SRBFOLDC

Original bacterial foraging algorithm (BFO) offers a constant chemotaxis step length C [9]. However, from the previous study, the proposed BFO-LDC [16] and BFO-NDC [17] has been demonstrated that chemotaxis C step length is one of the most important parameters to get a good balance between local and global search abilities. It proved that a small chemotaxis step length accelerate local search ability while a big one accelerates global search. SRBFO is making use of single-loop structure, and developed a new execution structure to improve the convergence rate as well as lower computational complexity [13]. According to those former studies, SRBFOLDC and SRBFONDC imitate the same mechanism through moderate the chemotaxis step length of SRBFO. Chemotaxis C step length is decided based on the following equation:

$$C_j = C_{min} + (1 - \frac{iter}{itermax}) \times (C_{max} - C_{min}) \tag{9}$$

$$C_j = C_{min} + \exp(-a \times \left(\frac{iter}{itermax}\right)^n) \times (C_{max} - C_{min}) \tag{10}$$

where Eqs. (9) and (10) respectively represent the SRBFOLDC and SRBFONDC chemotaxis step length change over the run process. $C_{max}$ and $C_{min}$ are the start value and end value of chemotaxis step. Different value of modulation index $n$ will lead to different variants.

### 3.2 Design for HFFVRP

In previous VRP study, researchers often use $N + K - 1$ dimensional coding way to solve the problem with N customer and K vehicles, which is simple and efficient. However, in the research of HFFVRP, the number of vehicles involved in the distribution is uncertain. So we adopt 2N dimensional coding scheme for encoding, which corresponds to the vehicle routing problem with N customers. Each customer correspond two-dimension s. One dimension is the vehicle number k which service the customer, another is the $k_{th}$ vehicle routing order r. That is to say, to express and to facilitate the calculation, each particle corresponding 2N dimensional vector X is divided into two N dimensional vectors: $x_v$ indicate each task corresponding vehicle and $x_r$ expressed execution order of the tasks in the corresponding path of the vehicle.

## 4 Experiments and Results

In this part, heterogeneous fixed fleet vehicle routing problem (HFFVRP) with 12 customers and 7 vehicles is developed. The depot coordination is set as (50, 60). And location of the customers is defined by coordinates and with each arc ($x_i$, $y_i$). The distance between customer $i_{th}$ and customer $j_{th}$ is associated with a Euclidean distance $d_{ij}$, which is approximately calculated: $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$. The customer location coordinate parameters are shown in Table 1. There are two types of delivery vehicles, including 3 class A vehicles with 550 units capacity, 4 class B vehicles with 650 units capacity; the average speed was 75; the cost of the vehicle to wait for 25 yuan per hour, the delay cost 85 yuan per hour. In the experimental studies, six algorithms are used: SRBFOLDC, SRBFONDC, BFO [9], BFOLDC [16], BFONDC [17] and SRBFO [13]. The parameters of these algorithms are included in Table 2. Table 3 lists the customer demands and lay time and time windows. Table 4 gives the runs results including max value, min value, average value and variances of 20 runs. The best routes of vehicle to customers based on SRBFONDC are presented in Table 5. Finally, Fig. 1 shows the average values of all algorithms run 20 times.

From Table 4, SRBFONDC and SRBFOLDC get a better result regarding minimum, mean and maximum while BFO get the worst results. Besides, from the results, SRBFONDC performs superior than SRBFOLDC. Meanwhile, SRBFONDC observed gain the fastest convergence to optimum and obviously performs better than other algorithms in Fig. 1.

**Table 1.** Customer location coordinate

| Customer $i$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *X*coordinate | 20 | 50 | 78 | 100 | 35 | 68 | 90 | 125 | 150 | 110 | 84 | 70 |
| *Y*coordinate | 45 | 37 | 30 | 59 | 60 | 85 | 105 | 92 | 65 | 70 | 42 | 50 |

**Table 2.** Parameters of BFO algorithms

| Algorithms | Nc | Nre | Ned | Cmax | Cmin | Ns | Popsize |
|---|---|---|---|---|---|---|---|
| BFO | 400 | 5 | 2 | 0.1 | 0.1 | 5 | 100 |
| BFO-LDC | 400 | 5 | 2 | 0.2 | 0.01 | 5 | 100 |
| BFO-NDC | 400 | 5 | 2 | 0.5 | 0.01 | 5 | 100 |
| SRBFO | 4000 | – | – | 0.1 | 0.1 | 5 | 100 |
| SRBFO-LDC | 4000 | – | – | 0.2 | 0.01 | 5 | 100 |
| SRBFO-NDC | 4000 | – | – | 0.5 | 0.01 | 5 | 100 |

**Table 3.** The demands, lay-time and time window of customers

| Customer $i$ | Demands $q_i$ | Lay-time (minutes) | Time window [$ET_i$, $LT_i$] |
|---|---|---|---|
| 1 | 300 | 80 | [9:00 12:00] |
| 2 | 250 | 60 | [9:00 17:00] |
| 3 | 170 | 45 | [12:00 17:00] |
| 4 | 90 | 60 | [8:00 16:30] |
| 5 | 200 | 50 | [8:00 12:00] |
| 6 | 250 | 60 | [9:00 17:00] |
| 7 | 350 | 90 | [9:00 17:30] |
| 8 | 230 | 55 | [9:00 18:00] |
| 9 | 180 | 45 | [9:00 16:00] |
| 10 | 150 | 40 | [9:00 17:00] |
| 11 | 230 | 40 | [9:00 18:00] |
| 12 | 290 | 75 | [9:00 17:00] |

**Table 4.** The maximum, minimum, mean and variance results of all algorithms

| Algorithms | Maximum | Minimum | Mean | Variance |
|---|---|---|---|---|
| BFO | 3136 | 2691 | 2964 | 127.7 |
| BFO-LDC | 3212 | 2603 | 2883 | 154.3 |
| BFO-NDC | 3199 | 2637 | 2931 | 156.1 |
| SRBFO | 3035 | 2622 | 2820 | 91.9 |
| SRBFO-LDC | 2889 | 2626 | 2790 | 99.8 |
| SRBFO-NDC | 2964 | 2587 | 2786 | 87.6 |

**Table 5.** The best routes of the vehicle to each customer using SRBFONDC

| Vehicle | | Route of vehicle | Cost |
|---|---|---|---|
| Type A | 1 | 0 → 11 → 0 | 2587 |
| | 2 | 0 → 5 → 1 → 0 | |
| | 3 | 0 | |
| Type B | 4 | 0 → 10 → 6 → 2 → 0 | |
| | 5 | 0 → 9 → 8 → 12 → 0 | |
| | 6 | 0 → 4 → 7 → 3 → 0 | |
| | 7 | 0 | |

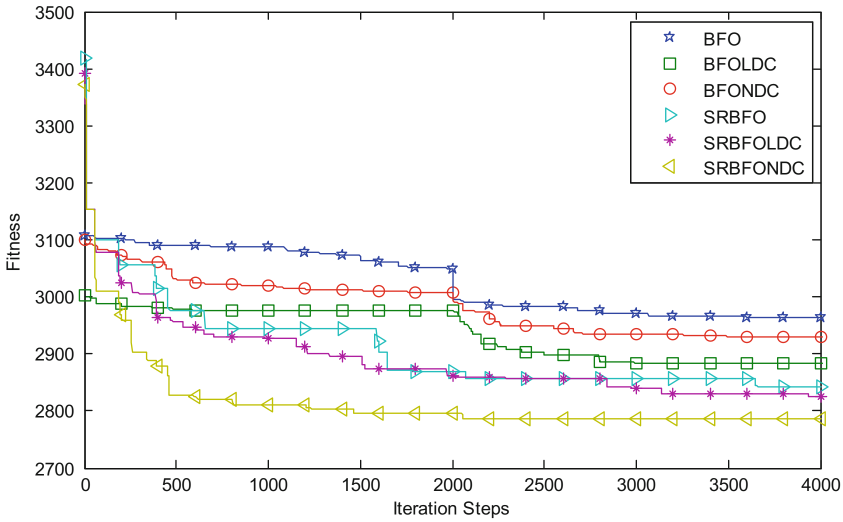


**Fig. 1.** The average values of all algorithms run 20 times.

## 5 Conclusions and Future Research

In this paper, a new way to solve HFFVRP based on BFO has been proposed. SRBFONDC and SRBFOLDC are improved SRBFO [13] with vary chemotaxis step change over the process of algorithm. From the results, we can conclude that SRBFONDC preforms best compared with other BFO algorithms, and get the best vehicle routing. SRBFONDC has the potential to applicate in other VRP variants. In further research, other vehicle routing problems, such as the multi-depot vehicle routing problem (MDVRP) [4] and the site-dependent vehicle routing problem (SDVRP) [6], will have a good capacity to solve by variant BFO algorithms.

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