



# A New Heuristic Routing Algorithm for Fleet Size and Mix Vehicle Routing Problem

Kenan KARAGÜL<sup>1,\*</sup>

<sup>1</sup>*Pamukkale Üniversitesi, Honaz MYO, Lojistik Bölümü, Honaz, 20330, Denizli/TURKEY*

*Received: 24/01/2014 Accepted: 11/06/2014*

---

## ABSTRACT

Ochi's approach solves the heterogenous vehicle routing problem using the constraint having fixed costs as a multiplier of residuals. However, in this approach, there is not any information about which vehicle will be assigned to the route related to this constraint. In our study, Ochi's approach is interpreted again in terms of vehicle capacity and number of customers assigned to each route. The proposed routing approach is taking the higher capacity vehicle for improving the performance. Then the solution phases of a sample problem are shown by using the given algorithm. In order to highlight the performance of the routing approach, Golden's 12 test problems (Fleet Size and Mix Vehicle Routing Problem with Fixed Cost) are used. It is seen that the proposed method has better average time complexity and equal cost performances than Ochi's routing approach. Therefore, the solutions with higher capacity vehicle of the proposed method that uses vehicle type information are better than those of the methods that use residual cost based on the vehicle type information.

**Key Words:** *Fleet Size and Mix Vehicle Routing Problem, Constructive Routing Heuristics, Vehicle Routing Problem, Routing Algorithm, Ochi's routing approach*

---

## 1. INTRODUCTION

In fleet size and mix vehicle routing problem (HFVRP) each customer is visited by exactly one route. HFVRP consists of designing a number of feasible paths having minimum total cost / total distance. Aim of HFVRP is mainly to determine the best fleet composition as well as the set of paths that minimize the sum of fixed and travel costs in such a way that:

- (a) every route starts and ends at the depot and is associated to a vehicle type;
- (b) each customer belongs to exactly one route; and
- (c) the vehicle's capacity is not exceeded.

The HFVRP is an NP-hard problem and numerous methods have been proposed as it is a natural generalization of the travelling salesman problem (TSP) and as it includes the classical vehicle routing problem (VRP) [1-4].

Some researchers developed algorithms such as the savings algorithm of Clarke and Wright [5], the sweep algorithm of Gillett and Miller [6] and the generalized assignment of Fisher and Jaikumar [7]. Matching based saving algorithms were also proposed by Desrochers and Verhoog [8], Salhi and Rand [9] and Osman and Salhi [10]. Evolutionary algorithms have been attempted by Ochi et al. [1] and Lima et al. [2] on FSMF (Fleet Size and Mix Vehicle Routing Problem with Fixed Cost). However, the vehicle type information is always ignored in these methods [11]. In our study, a new constructive routing algorithm is proposed incorporating the vehicle type information.

---

\*Corresponding author, e-mail: [kkaragul@pau.edu.tr](mailto:kkaragul@pau.edu.tr)

**2. OCHI AND PROPOSED CONSTRUCTIVE ROUTING ALGORITHMS**

A undirected graph is defined by  $G = (V, A)$  where  $V = \{0, 1, 2, \dots, n\}$  is a set composed of  $n + 1$  vertices, and  $A = \{(i, j) : i, j \in V, i \neq j\}$  is the set of arcs.

The vertex 0 denotes the depot, where the vehicle fleet is initially located, while the set  $V' = V - \{0\}$  is composed of the remaining vertices that represent  $n$  customers.

It is assumed that each customer  $i \in V'$  has a positive demand  $q_i$  and depot's demand is always zero.

$C = [c_{ij}]$  is the distance matrix where the parameter

$c_{ij}$  represents a positive cost or distance between vertices  $i$  and  $j$ . A heterogenous fleet of vehicles must be used to supply the customers. The vehicle fleet is composed by a set  $\psi(k) \in \{1, 2, \dots, t\}$  of different vehicle types where  $t$  is the number of vehicle types associated with the route, and it is assumed that each vehicle type is available at unlimited numbers. For each vehicle type  $i \in \psi$ ,  $Q_i$  is the capacity,  $f_i$  is the fixed cost to be paid, and  $D_i$  is the amount of demand collected from or loaded to the vehicle. It is assumed that the fixed costs are increasing with the capacity i.e.  $Q_1 < Q_2 < \dots < Q_t$  and  $f_1 < f_2 < \dots < f_t$  [1-4].

A route for vehicle type  $k$  is defined by the pair  $(R, \psi(k))$  where  $R = (i_1, i_2, \dots, i_{|R|})$ , with  $i_1 = i_{|R|} = 0$  and  $\{i_2, i_3, \dots, i_{|R|-1}\} \subseteq V$ , is a simple circuit in  $G$  containing the depot. Here,  $R$  will be used to refer both to visiting sequence and to the set of customers (including depot) of the route. A route  $(R, \psi(k))$  is feasible if the total demand of the customers visited by the route does not exceed the vehicle capacity  $Q_k$ , that is,  $\sum_{h=2}^{|R|-1} q_{i_h} \leq Q_k$ . The cost of a route corresponds to the sum of the costs of the edges forming the route, plus the fixed cost of the associated vehicle, that is,  $\sum_{h=1}^{|R|-1} c_{i_h i_{h+1}}^k + f_k$  [3].

The route configuration proposed by Ochi et al is achieved by selecting the minimum from the alternatives obtained by the constraint  $(Q_k - D_k) * f_k$ . However, our study is based on  $(Q_k - D_k)$  constraint for route configuration and then selecting the minimum from the alternatives obtained. The constraints of the related routing strategies are given in Table 1. Ochi's approach solves the HVRP with Petal algorithm using the constraint  $(Q_k - D_k) * f_k$ . However, in [1], there is not any information about which vehicle will be assigned to the route related to this constraint.

Table 1. Proposed Approach and Ochi Approach routing constraint for HFVRP

	Ochi (1998)	Karagul
Route Construction / Route Selection Strategy	$\min_k (Q_k - D_k) * f_k$	$\min_k (Q_k - D_k)$

In our study, Ochi's approach is interpreted in terms of vehicle capacity and number of customers assigned to each route and with this interpretation Ochi's approach is denoted as **Ochi Minimum Distance Maximum Vertex Algorithm (Ochi MinDis-MaxVer Algorithm)**. The proposed routing approach is denoted as **Karagul Minimum Distance Maximum Vertex Algorithm**

**(Karagul MinDis-MaxVer Algorithm)**. In Figure 1, the Ochi MinDis-MaxVer algorithm is demonstrated where the constraint  $(Q_k - D_k) * f_k$  is defined as (Residuals\*FixedCost). If any two paths has equal values of minimum(Residuals\*FixedCost), the one with the maximum vertex is used.

```

start with the Initial Solution Space (TSP_order)
for each TSP_order
  while {end of the TSP_order}
    while {end of the number of vehicle_type}
      Construct temporary routings for each vehicle_type
    end {of while}
    Find the minimum(Residuals*FixedCost) that is the temporary Path
    If
      there is only one min temporary routes
      Assign the vertex and vehicle type to Route
    else
      there are equal residuals for temporary routes more than one
      Find temporary route with max vertex
      Assign the vertex and vehicle type to Route
    end
    Assign the vertex and vehicle type to the Path
    Calculate Routing_Cost, TSP_order, vehicle_type
  end {of while}
  TSP order solution: [Total_Cost Routings Type_of_Vehicles
TSP_order]
end {of for}

Solution Space:[TSP_order solution [Total_Cost Routings Type_of_Vehicles
TSP_order] ]

```

Figure 1. Ochi Minimum Distance Maximum Vertex Algorithm ( Ochi MinDis-MaxVer Algorithm )

In Figure 2, Karagul MinDis-MaxVer algorithm is given. For this algorithm, the constraint  $(Q_k - D_k)$  is defined with (Residuals) instead of (Residuals\*FixedCost). Similar to Ochi MinDis-MaxVer Algorithm, If any two paths has equal values of minimum(Residuals), the one with the maximum vertex is used.

```

start with the Initial Solution Space (TSP orders)
for each TSP order
  while {end of the TSP order}
    while {end of the number of vehicle type}
      Construct temporary routings for each type of vehicle
    end {of while}
    Find the minimum(Residuals) that is the temporary paths
    If
      there is only one min temporary routes
      Assign the vertex and vehicle type to Route
    else
      there are equal residuals for temporary routes more than one
      Find temporary route with max vertex
      Assign the vertex and vehicle type to Route
    end
    Assign the vertex and vehicle type to Path
    Calculate Routing Cost, path part of TSP order, TSP order part,
vehicle type
  end {of while}
  TSP order solution: [Total Cost Routings Type of Vehicles TSP
order]
end {of for}

Solution Space:[TSP order solution [Total Cost Routings Type of Vehicles
TSP order] ]

```

Figure 2. Karagul Minimum Distance Maximum Vertex Algorithm ( Karagul MinDis-MaxVer Algorithm )

### 3. SAMPLE PROBLEMS AND SOLUTION PHASES

In Figure 3, an HFVRP problem defined by Liu-Huang-Ma [13] is used in order to show the effectiveness of the proposed method. The problem is composed of a depot, two types of vehicles ( $t_1, t_2$ ), and 6 customers. In Figure 4, the parameters defining the problem are given.

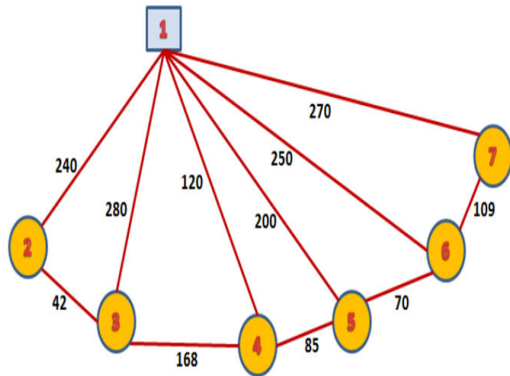


Figure 3. Representation of sample problem 1 and sample problem 2 with vertices and some connections

Sample Problem 1							
<b>Distance Matrix (C) (<math>c_{ij} = c_{ji}</math>)</b>							
	1	2	3	4	5	6	7
1	0	240	280	120	200	250	270
2		0	42	210	295	365	474
3			0	168	253	323	432
4				0	85	155	264
5					0	70	179
6						0	109
7							0
<b>Vehicle Capacity</b>							
$Q_1 = 60$							
$Q_2 = 90$							
<b>Fixed Costs</b>							
$f_1 = 40$							
$f_2 = 50$							
<b>Variable Costs</b>							
$v_1 = 1$							
$v_2 = 1$							
<b>Sum of Demand for Vehicle k</b>							
$D_k$							
<b>Depot/Vertex</b>							
Demand Quantity							
	1	2	3	4	5	6	7
	0	60	32	30	15	50	50
							$q_i$

Figure 4. Sample problem 1's distance matrix, customer demands, vehicle types fixed costs and vehicle type's capacity.

In Figure 5, the solution routes of Ochi MinDis-MaxVer algorithm for a random TSP order {7, 3, 2, 4, 6, 5} is shown step by step.

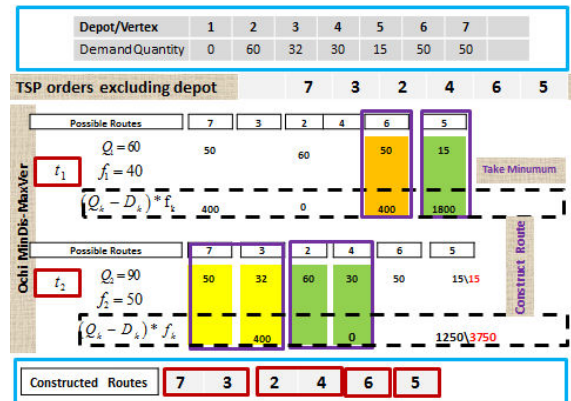


Figure 5. Ochi Minimum Distance Maximum Vertex Algorithm solution phases for routing TSP order {7, 3, 2, 4, 6, 5}

The vehicle routes are constructed with respect to  $(Q_k - D_k) * f_k$  constraint and vehicles with higher capacities are considered first. As shown in Figure 5, when customer 7 is considered for  $t_1$ , the demand is 50 units. As the vehicle capacity will exceed 32, customer 3 cannot be added. Therefore, for vehicle  $t_1$  the temporary route is {7}, the total load quantity is 50 units and residual is  $60-50=10$  units, and the residual cost is  $10*40=400$  unit cost.

Similar to  $t_1$ , when the demands of 50 units from customer 2, 32 units from customer 3 are loaded to the vehicle  $t_2$  not to exceed 90 units capacity, 82 units loading is made in total. The temporary path {7, 3} is obtained. The residual for  $t_2$  is  $90-82=8$  units and the residual cost is  $8*50=400$  unit cost.

When the residual costs of two vehicles are considered, it is seen that there is 400 units cost for  $t_1$  and 400 units cost for  $t_2$ . In this case, there are two equal residual costs for temporary routes and the one with the maximum vertex is chosen. Therefore, the first constructed path  $R1=(\{1-7-3-1\}, t_2)$  is taken as it has minimum residual cost. Then, customer {7, 3} is discarded from TSP order.

The unrouted customers {2, 4, 6, 5} are reconstructed for temporary routes. As can be seen from the second phase in Figure 5, firstly for vehicle  $t_1$ , 60 units from {2} is loaded. The residual is 0 units and the residual cost is 0 unit cost. Similarly, for vehicle  $t_2$ , 60 units from {2}, 30 units from {4} are loaded which in total compose 90 unit load. The residual is 0 units and the residual cost is 0 unit cost. In this case, there are two equal residual costs for temporary routes and therefore the one with the maximum vertex is chosen. Therefore, the second constructed path  $R2=(\{1-2-4-1\}, t_2)$  is taken as it has the maximum vertex.

Then, customer {2, 4} are discarded from TSP order. The unrouted customers {6, 5} are reconstructed for temporary routes. As can be seen from the second phase in Figure 5, firstly for vehicle  $t_1$ , 50 units from {6} is loaded. The residual is 10 units and the residual cost is 400 units cost. Similarly, for vehicle  $t_2$ , 50 and 15 units

from {6, 5} are loaded which in total compose 65 unit load. The residual is 25 units and the residual cost is 1250 unit cost. When the residual costs of two vehicles are considered for the second phase, it is seen that there is 400 units cost for  $t_1$  and 1250 unit cost for  $t_2$ . Therefore, the third constructed path  $R3=\{1-6-1\}$ ,  $t_1$  is taken as it has minimum residual cost. Then, customer {6} is discarded from TSP order and the unrouted customers {5} are reconstructed for temporary routes.

When the same process is executed for remaining customer {6}, the route and assigned vehicle is  $R4=\{1-6-1\}$ ,  $t_1$ . Thus, for Ochi MinDis-MaxVer algorithm the routing process for the TSP orders is completed. The summary table for the routings and costs are given in Figure 6 and graph solution is given in Figure 7. Figure 8 gives us Sample Problem 2. And the solution routes of Karagul MinDis-MaxVer algorithm for different TSP orders are shown step by step in Figure 9.

TSP orders excluding depot		7	3	2	4	6	5
Routes	T	Fixed Cost	Route Distances	Total Distance	Route Cost		
R1=[1-7-3-1]	t2	50	(270+432+280)	982	1032		
R2=[1-2-4-1]	t2	50	(240+210+120)	570	620		
R3=[1-6-1]	t1	40	(250+250)	500	540		
R4=[1-5-1]	t1	40	(200+200)	400	440		
Total Cost					2632		
Best Known Solution (Estimated Value)					2228		

Figure 6. Ochi Minimum Distance Maximum Vertex Algorithm routes solutions for TSP order {7, 3, 2, 4, 6, 5}

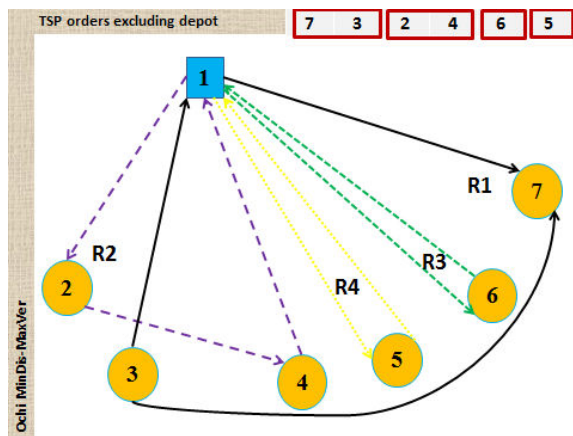


Figure 7. Ochi Minimum Distance Maximum Vertex Algorithm graph solution for routing TSP order {7, 3, 2, 4, 6, 5}

Sample Problem 2							
Distance Matrix (C) ( $c_{ij} = c_{ji}$ )							
	1	2	3	4	5	6	7
1	0	240	280	120	200	250	270
2		0	42	210	295	365	474
3			0	168	253	323	432
4				0	85	155	264
5					0	70	179
6						0	109
7							0
Vehicle Capacity							
$Q_1 = 600$				$t_1$			
$Q_2 = 900$				$t_2$			
Fixed Costs							
$f_1 = 400$				$v_1 = 1$			
$f_2 = 500$				$v_2 = 1$			
Sum of Demand for Vehicle k							
$D_k$							
Depot/Vertex							
Demand Quantity	1	2	3	4	5	6	7
	0	600	320	300	150	500	500
							$q_i$

Figure 8. Sample problem 2's distance matrix, customer demands, vehicle types fixed costs and vehicle types capacity

TSP orders excluding depot		7	4	2	3	6	5
Possible Routes		7	4	2	3	6	5
$t_1$	$Q_1=600$	500	600	320	150	500	150
	$f_1=400$						
	$(Q_k - D_k)$	100	0	280	450		
Possible Routes		7	4	2	3	6	5
$t_2$	$Q_2=900$	500	300	600	320	500	150
	$f_2=500$						
	$(Q_k - D_k)$	400	100	300	80	250	
Constructed Routes							
		7	4	2	3	6	5

Figure 9. Karagul Minimum Distance Maximum Vertex Algorithm solution phases for routing TSP order {7, 4, 2, 3, 6, 5}

The vehicle routes are constructed with respect to  $(Q_k - D_k)$  constraint and vehicles with higher capacities are considered first. As shown in Figure 9, when customer {7} is considered for  $t_1$ , the demand is 500 units. As the vehicle capacity will exceed 300, customer {4} cannot be added. Therefore, for vehicle  $t_1$  the temporary route is {7}, the total load quantity is 500 units and residual is  $600-500=100$  units.

Similar to  $t_1$ , when the demands of 500 units from customer {7}, 300 units from customer {4} are loaded to the vehicle  $t_2$  not to exceed 900 units capacity, 800 units loading is made in total. The temporary path {7, 4} is obtained. The residual for  $t_2$  is  $900-800=100$  units.

When the residuals of two vehicles are considered, it is seen that there is 100 units for  $t_1$  and 100 units for  $t_2$ . There are two equal residuals, this means to take path with maximum vertex. Therefore, the first constructed path  $R1=\{1-7-4-1\}$ ,  $t_2$  is taken as it has minimum residual with maximum vertex. Then, customer {7, 4} is discarded from TSP order.

The unrouted customers {2, 3, 6, 5} are reconstructed for temporary routes. As can be seen from the second phase in Figure 9, firstly for vehicle  $t_1$ , 600 units from {2} is

loaded which in total compose 600 unit load. The residual is 0 units. Similarly, for vehicle  $t_2$ , 600 units from {2}, 300 units from {4} are loaded which in total compose 900 units load. The residual is 0 units. When the residual of two vehicles are considered for the second phase, it is seen that there is 0 units for  $t_1$  and 0 units for  $t_2$ . Therefore, the second constructed path  $R2 = (\{1-2-4-1\}, t_2)$  is taken as it has minimum residual and maximum vertex. Then, customer {2,4} are discarded from TSP order. The unrouted customers {6, 5} are reconstructed for temporary routes. As can be seen from the second phase in Figure 9, firstly for vehicle  $t_1$ , 500 units from {6} is loaded. The residual is 100 units. Similarly, for vehicle  $t_2$ , 650 units from {6, 5} are loaded. The residual is 250 units. Therefore, the third constructed path  $R3 = (\{1-6-1\}, t_1)$  is taken as it has minimum residual. Then, customer {6} is discarded from TSP order and the unrouted customer {5} is reconstructed for temporary routes.

When the same process is executed for remaining customer {5}, the route and assigned vehicle are  $R4 = (\{1-5-1\}, t_1)$ . Thus, for Karagul MinDis-MaxVer algorithm the routing process for the TSP orders is completed. The summary table for the routings and costs are given in Figure 10. Karagul MinDis-MaxVer algorithm graph solution is given in Figure 11.

TSP orders excluding depot		7	4	2	3	6	5
Karagul MinDis-MaxVer	Routes	T	Fixed Cost	Route Distances	Total Distance	Route Cost	
	R1=[1-7-4-1]	t2	500	(270+264+120)	654	1154	
	R2=[1-2-1]	t1	400	(240+240)	480	880	
	R3=[1-3-6-1]	t2	500	(280+323+250)	853	1353	
	R4=[1-5-1]	t1	400	(200+200)	400	800	
Total Cost						4187	
Best Known Solution						3908	

Figure 10. Karagul Minimum Distance Maximum Vertex Algorithm routes solutions for TSP order {7, 4, 2, 3, 6, 5}

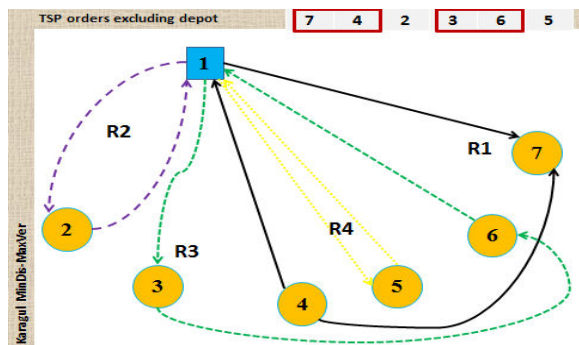


Figure 11. Karagul Minimum Distance Minimum Vertex Algorithm graph solution for TSP order {2, 3, 4, 5, 6, 7}

TSP orders excluding depot		7	4	2	3	6	5
Ochi MinDis-MaxVer	R Name	Route	T	Fixed Costs	Route Distance	Route Cost	
	R1	1-7-3-1	t2	50	982	1032	
	R2	1-2-4-1	t2	50	570	620	
	R3	1-6-1	t1	40	500	540	
	R4	1-5-1	t1	40	400	440	
Total						2452 2632	
TSP orders excluding depot		7	3	2	4	6	5
Karagul MinDis-MaxVer	R Name	Route	T	Fixed Costs	Route Distance	Route Cost	
	R1	1-7-4-1	t2	500	654	1154	
	R2	1-2-1	t1	400	480	880	
	R3	1-3-6-1	t2	500	853	1353	
	R4	1-5-1	t1	400	400	800	
Total						2387 4187	

Figure 12. Ochi and Karagul Routings Algorithms solutions results for TSP orders that are {7, 4, 2, 3, 6, 5} and {7, 3, 2, 4, 6, 5}

As can be seen from Figure 12, different routes are obtained by using the given algorithms. The graph of routes for both Ochi and Karagul routing algorithms are given in Figure 12.

From the sample routing problems, In the next section, to see the performance of the proposed method and to analyses the difference of the proposed method from Ochi's approach, some known test problems from the literature, especially Golden's test instances, are used.

#### 4. COMPUTATIONAL RESULT

The proposed method is tested by using 12 sample problems obtained by Golden et al. [12] and extensively used in the literature for FSMF.

The calculations are constructed from two phases: the first step is obtaining the initial solution space, and the second step is the route configuration and the selection of the appropriate constraint. The initial solution space is generated based on the method presented by Liu et al. [13] where the initial solution space is composed of 3 parts: first part from the Savings Algorithm, second part from the Sweep Algorithms and the rest of the individuals are generated randomly. In our study, on the other hand, the randomly generated individuals are not used. The solutions of the Savings and Sweep algorithms are obtained by using "Matlog: Matlab Logistic Engineering Toolbox" [14].

The problems are tested on a computer with Pentium Core Duo i7 processor and 4 GB RAM. The results obtained on the basis of the initial solutions from Sweep and Savings algorithms are listed in Table 2 where **P.No** is the problem number as given by Golden et al. [12], **BKS** is the best known solution in the literature, **Solution** is the Karagul and Ochi solutions obtained for the given problems with this study, **Deviation** is the percent deviation from the best known solution, Time is the solution time in seconds and **S.S.** is the dimension of the initial solution space. The initial solutions are obtained excluding the depot in the form of **TSP order**. Then the routes are configured with respect to the related methods. From the alternative route solutions, the type of vehicle that provides the minimum condition is selected as the optimal route. For the solution times in Table 2, the period for obtaining the initial solutions are not considered. Therefore, the solution times are solely giving the execution times (seconds) of the algorithms.

Table 2. Ochi MinDis-MaxVer Algorithm and Karagul MinDis-MaxVer Algorithm computational results for FSMVRP with fixed cost (FSMF) on 12 test problems

P.No	BKS	Ochi MinDis-MaxVer Algorithm			Karagul MinDis-MaxVer Algorithm			S. S.
		Solution	Deviation	Time	Solution	Deviation	Time	
3	961,03	1.088,70	-13,28	0,1085	999,20	<b>-3,97</b>	0,0890	4
4	6.437,30	7.324,70	-13,78	0,0898	7324,7	-13,78	0,0840	6
5	1.007,10	1.153,00	-14,49	0,0711	1097,4	<b>-8,97</b>	0,0629	4
6	6.516,50	7.031,40	-7,90	0,0582	7.031,40	-7,90	0,0565	6
13	2.406,40	2.670,70	<b>-10,98</b>	0,2457	2.680,20	-11,38	0,1692	8
14	9.119,00	9.214,40	-1,05	0,0681	9.214,40	-1,05	0,0721	6
15	2.586,40	2.800,10	<b>-8,26</b>	0,0869	2.861,20	-10,63	0,0780	6
16	2.720,40	3.063,80	-12,62	0,0730	2.899,00	<b>-6,56</b>	0,0668	4
17	1.734,50	2.088,90	-20,43	0,1572	1.954,10	<b>-12,66</b>	0,1133	8
18	2.369,70	2.992,40	-26,28	0,3156	2.986,50	-26,03	0,1776	10
19	8.661,80	9.599,20	<b>-10,82</b>	0,0889	9.824,80	-13,43	0,0992	6
20	4.039,50	4.459,10	<b>-10,39</b>	0,1197	4.498,90	-11,37	0,1119	6
Average	4.046,64	4.457,20	-12,52	0,1235	<b>4.447,65</b>	<b>-10,65</b>	<b>0,0984</b>	

When Table 2 is reviewed, for 4 of 12 test problems **Karagul MinDis-MaxVer Algorithm** has better total cost values. Also, for 4 problems it has same total costs with Ochi MinDis-MaxVer Algorithm. For 4 of 12 test problems, Ochi MinDis-MaxVer Algorithm have best total cost values. When the average performances are compared, the proposed method has better characteristics from time complexity and total cost point of view. Based on the given tests, Karagul MinDis-MaxVer Algorithm can be proposed as a new constructive heuristic routing algorithm for HFVRP.

### 5. CONCLUSION AND DISCUSSION

In this study, a new constructive route configuration different from the method recommended by Ochi et al and an approach certainly competitive with their method is proposed. The problems in the literature are solved using a seeding with Sweep and Savings algorithms proposed by Liu-Huang-Ma [13]. When the proposed method is logically compared for different situations, it gives better results than the approach of Ochi et al [1]. Thus, the new method can be suggested both for route configuration and route selection in heterogeneous VRPs. The solution given in this study can be enriched using different initial solution generation methods and new hybrid solution methods can be obtained by combining with heuristic search methods.

### ACKNOWLEDGEMENTS

I gratefully acknowledge that research for this paper is financially supported by the Pamukkale University Scientific Research Projects Unit, grant no. 2013-BSP026.

### CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

### REFERENCES

- [1] L. Ochi, D. Vianna, L. M. Drummond and A. Victor, "A Parallel Evolutionary Algorithm for the Vehicle Routing Problem with Heterogeneous Fleet," *Parallel And Distributed Processing*, pp. 216-224, 1998.
- [2] C. Lima, M. Goldberg and E. Goldberg, "A Memetic Algorithm for Heterogeneous Fleet Vehicle Routing Problem," *Electronic Notes in Discrete Mathematics*, vol. 18, pp. 171-176, 2004.
- [3] R. Baldacci, M. Battarra and D. Vigo, "Routing a Heterogeneous Fleet of Vehicles," *Operations Research/Computer Science Interfaces*, vol. 43, pp. 3-27, 2008.
- [4] A. Subramanian, P. H. V. Penna, E. Uchoa and L. S. Ochi, "A Hybrid Algorithm for the Heterogeneous

- Fleet Vehicle Routing Problem," *European Journal of Operational Research*, vol. 221, pp. 285-295, 2012.
- [5] G. Clarke and J. W. Wright, "Scheduling of Vehicles from a Central Depot to a Number of Delivery Points," *Operations Research*, vol. 12, no. 4, pp. 568-581, 1964.
- [6] A. E. Gillett and L. R. Miller, "A Heuristic Algorithm for the Vehicle-Dispatch Problem," *Operations Research*, vol. 22, no. 2, pp. 340-349, 1974.
- [7] M. L. Fisher and R. Jaikumar, "A Generalized Assignment Heuristic for Vehicle Routing," *Networks*, vol. 11, no. 2, p. 109-124, 1981.
- [8] M. Desrochers and T. W. Verhoog, "A New Heuristic for the Fleet Size and Mix Vehicle Routing Problem," *Computers and Operations Research*, vol. 18, no. 3, pp. 263-274, 1991.
- [9] S. Salhi and G. K. Rand, "Incorporating Vehicle Routing Into the Vehicle Fleet Composition Problem," *European Journal of Operational Research*, vol. 66, no. 3, pp. 313-330, 1993.
- [10] I. H. Osman and S. Salhi, "Local Search Strategies for the Vehicle Fleet Mix Problem," in *Modern Heuristic Search Methods*, Chichester, *Wiley*, 1996, pp. 131-154.
- [11] S.-C. Liu and H.-J. Lu, "A hybrid heuristic method for the fleet size and mix vehicle routing problem," *Journal of Industrial and Production Engineering*, vol. 30, no. 3, p. 181-189, 2013.
- [12] A. L. Golden, A. A. Assad, L. Levy and F. Gheysens, "The Fleet Size and Mix Vehicle Routing Problem," *Computers and Operations Research*, pp. 49-66, 1984.
- [13] S. Liu, W. Huang and H. Ma, "An Effective Genetic Algorithm for the Fleet Size and Mix Vehicle Routing Problems," *Transportation Research Part E*, vol. 45, pp. 434-445, 2009.
- [14] M. G. Kay, "Matlog: Logistics Engineering Matlab Toolbox," 1 1 2013. [Online]. Available: <http://www.ise.ncsu.edu/kay/matlog/>. [Accessed 16 2 2013].
- [15] H. Yaman, "Formulations and Valid Inequalities for the Heterogeneous Vehicle Routing Problem," *Mathematical Programming*, vol. 106, pp. 365-390, 2006.
- [16] A. D. Taillard, "A Heuristic Column Generation Method for the Heterogeneous Fleet Vehicle Routing Problem," *RAIRO Rech. Oper.*, vol. 33, pp. 1-14, 1999.
- [17] M. Gendreau, G. Laporte, C. Musaraganyi and E. D. Taillard, "A Tabu Search Heuristic for the Heterogeneous Fleet Vehicle Routing Problem," *Computers and Operations Research*, vol. 26, pp. 1153-1173, 1999.
- [18] N. Wassan and I. Osman, "Tabu Search Variants for the Mix Fleet Vehicle Routing Problem," *Journal of the Operational Research Society*, vol. 53, pp. 768-782, 2002.
- [19] A. Choi and D.-W. Tcha, "A Column Generation Approach to the," *Computers and Operations Research*, vol. 34, p. 2080-2095, 2007.
- [20] J. Brandao, "A Deterministic Tabu Search Algorithm for the Fleet Size and Mix Vehicle Routing Problem," *European Journal of Operational Research*, vol. 195, no. 3, pp. 716-728, 2009.
- [21] A. H. Liu and S. Y. Shen, "The Fleet Size and Mix Vehicle Routing Problem with Time Windows," *The Journal of the Operational Research Society*, vol. 50, no. 7, pp. 721-732, 1999.
- [22] J. Renaud and F. F. Boctor, "A Sweep-Based Algorithm for the Fleet Size and Mix Vehicle Routing Problem," *European Journal of Operational Research*, vol. 140, no. 3, pp. 618-628, 2002.