Solving Capacitated Vehicle Routing Problem Using Meerkat Clan Algorithm

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Abstract: *Capacitated Vehicle Routing Problem (CVRP) can be defined as one of the optimization problems where customers are allocated to vehicles to minimize the combined travel distances regarding all vehicles while serving customers. From the many CVRP approaches, clustering or grouping customers into possible individual vehicles' routes and identifying their optimal routes effectively. Sweep is considered a well-studied clustering algorithm to group customers, while various Traveling Salesman Problem (TSP) solving approaches are mainly applied to generate optimal individual vehicle routes. The Meerkat Clan Algorithm (MCA) can be defined as a swarm intelligence algorithm derived from careful observations regarding Meerkat (Suricata suricatta) in southern Africa's the Kalahari Desert. The animal demonstrates tactical organizational skills, excellent intelligence, and significant directional cleverness when searching for food in the desert. In comparison to the other swarm intelligence, MCA was suggested for solving optimization problems via reaching the optimal solution effects. MCA demonstrates its ability to resolve CVRP. It divides the solutions into subgroups based on meerkat behavior, providing a wide range of options for finding the best solution. Compared to present swarm intelligence algorithms for resolving CVRP, it was demonstrated that the size of the solved issues can be increased by using the algorithm suggested in this work.*

Keywords: *Capacitated vehicle routing problem, ant colony optimization, genetic algorithm, meerkat clan algorithm, sweep clustering.*

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1. Introduction

The aim of the Vehicle Routing Problem (VRP) is to find the best routes for multiple vehicles to serve many customers. In addition, customers with identified needs are typically visited via a homogeneous fleet of vehicles with limited capacity. The vehicle's capacity constraint limits the number of customers it can serve on its route. Because of the significance regarding the capacity constraint, the problem is also known as Capacitated Vehicle Routing Problem (CVRP) [22].

CVRP considers many vehicles and one depot of equal capacity in general. All vehicles leave the depot and return to it at the end. Each customer has established demands and delivery locations. A customer's delivery cannot be split and completed in a single visit via a vehicle. CVRP is a complex optimization task with the primary goal of reducing the total travel distance for all vehicles for serving all customers.

CVRP was considered a real-world constraint satisfaction problem where customers are allocated to individual vehicles (based on their capacity) to keep CVRP costs to a minimum. In the last few decades, many approaches to solving CVRP have been investigated; some strategies allocate customer nodes to vehicles and generate vehicle routes together [4]. The primary method to solve CVRP, on the other hand, is to divide the task into 2 phases: assigning customers to various vehicles and, after that determining the best route for each one of the vehicles [12].

Because of its simplicity, the sweep clustering algorithm is one of the most popular methods for customer assignment. The algorithm estimates all the nodes' polar angles and then groups them into clusters based on their angles. Lastly, regarding each one of the cluster nodes, a vehicle is allocated, and its route is optimized using Traveling Salesman Problem (TSP).

Meerkats, also referred to as circuits, are small (less than 1 kg) carnivores in the mongoose family, with 37 species divided into 18 genera and 2 subfamilies. Meerkats are cooperative breeders who live in groups of up to 50. Meerkats have been defined as the major outgoing species in the mongoose family, with the dwarf mongoose and banded mongoose being other well-known social mongooses. Meerkats are desert-adapted, and their range has been restricted to semi-arid regions regarding southwest of Africa (which comprises Namibia, southern Angola, South Africa, and Botswana). They aren't endangered, and the International Union for Conservation of Nature classifies their conservation status as “least concern” [3].

Lastly, the following is the outline for the paper: section 2 revises a few interrelated studies. Section 3 provides a brief overview of Meerkat's behaviors. The proposed algorithm has been presented in section 4. The application regarding the case study and the experimental results is covered in section5. Finally, in section 6, there are closing remarks.

2. Related Works

Nurcahyo *et al*. [12] studied public transport in Semarang, Indonesia, using the Sweep-based VRP. For route generation, the researchers took into account the nearest neighbor algorithm of TSP. A study conducted by Suthikarnnarunai [17] solved the routing issue of a University of Bangkok using Sweep clustering algorithms and TSP routes created via integer programming. Abd-Elaziz *et al*. [2] studied a hybrid Sweep and nearest neighbor algorithms for solving the CVRP. The researchers have tested the approach on Augerat's Euclidean benchmark dataset and solve dairy product delivery problems for Tiba Trade and Distribution Company in Egypt.

Nazif and Lee [10] studied optimized crossover GA to solve CVRP. A study conducted by Yousefikhoshbakht and Khorram [23] suggested a hybrid algorithm that combines the Ant Colony Optimazation (ACO), sweep algorithm, and 3opt local search to solve CVRP. Darani *et al*. [5] showed the collection of re-using waste from family units through ACO. Tan *et al*. [19] have utilized many heuristics in combination with the ACO to solve CVRP and reported that it's a possible alternative for solving CVRP. In addition, a study conducted by Kao *et al*. [7] suggested a novel hybrid algorithm on the basis of ACO and Practical Swarm Optimization (PSO) to solve CVRP.

Kanthavel and Prasad [6] studied Nested PSO (NPSO) for route generation. Tavakoli and Sami [20], also Venkaetsan *et al*. [21], studied CVRP. Porting [14] suggested 2 new PSO-based algorithms for solving CVRP, referred to as Survival Sub-swarms Adaptive PSO (SSS-APSO) as well as Survival Sub-swarms Adaptive PSO with velocity-line bouncing (SSS-APSO-vb).

Al-Obaid *et al*. [3] presented Meerkat Clan Algorithm *(*MCA) and showed its ability to solve the TSP. Also, MCA is obtained by dividing the solution set into 2 sets (carefully and foraging). Most operations are done on the foraging, and optimal care solutions substitute the least reasonable solutions. In the care set, the least good solution is dropped, and another one is added, which is created in a random manner. Results showed excellent performance regarding the capacity of the algorithm for obtaining near-optimal and optimal solutions rapidly.

In the present study, Niazy *et al*. [11], the problem of the capacitated vehicle routing is solved via chicken swarm optimization, Tabu Search, and a new hybrid approach. The principal concept of the suggested algorithm is using a hierarchical order of tabu search and chicken swarm method to find the best neighborhood for finding the shortest path with the least costs, then utilizing the moving equations regarding 2 algorithms on each chicken for constructing the tracks, after that, choosing the shortest path with least costs. In addition, the results of computational experimentation, ten datasets showing that hybrid algorithm might be specified as effective method and overcoming the best-known results in nine datasets indicating that it has been 90% better compared to the known results.

Mutar *et al*. [9], this study enhances ACS for solving such a problem. The problem handles several vehicles which were used to transport products to certain places. Each one of the vehicles starts from a significant location at various times daily. CVRP is specified for serving a set of delivering customers with the specified requirements. The work attempts to recognize CVRP's best solution via utilizing improved ACS with accompanying targets:

1. Decreasing distance, since the long distances badly affect the process course, since it is consuming a lot of time for visiting all customers.
2. Implementing the Ant Colony System (ACS) algorithm improvement on new data from CVRP database. By implementing the suggested algorithm, good results have been acquired from the results of other approaches; a comparison of the results has been conducted.

Shalaby *et al*. [16], this work examines a variant related to the Sweep algorithm for the clustering of the nodes and various Swarm Intelligence (SI)-based approaches for generating the routes and getting optimum solution the CVRP. About the traditional Sweep algorithm, the formation of the cluster begins with the smallest angle, and after that, it advances for considering all nodes. In the variant Sweep of the research, a cluster formation is viewed from various starting angles. At the same time, 4 TSP enhancement approaches, including the recent ones, have been taken into account for optimizing the route. In addition, experimental results on many benchmarks CVRPs indicated that the clustering with suggested variant Sweep and route optimization with Velocity Tentative PSO could produce a better solution. Lastly, the suggested method is for achieving better solutions for many CVRP cases in the case of being put in comparison with prominent existing approaches.

3. Sweep Clustering

As a heuristic algorithm, Miller and Gillett coined the term “sweep algorithm.” Based on their polar angle, Sweeping nodes form the initial routes or clusters (decreasing or increasing order). When a constraint of vehicle capacity is violated, sweeping comes to a halt, completes one vehicle route, and then resumes a different vehicle [1, 13].

The sweep algorithm can be defined as an approach for grouping the customers in groups to be served via the exact vehicle and are geographically close together. The sweep algorithm employs the steps listed below [21].

1. Locating depot as center regarding the 2D plane.
2. Computing polar coordinates for every one of the customers in terms of the depot.
3. Begin sweeps every customer through the increase in the polar angle.
4. Assign every one of the customers encompassed via the current cluster's Sweep.
5. Terminate the Sweep in the case of adding the next customer could violate the maximal capacity of the vehicle.
6. Creating a new cluster through resuming Sweep in which the final one has been left off.
7. Repeating the steps from 4 to 6 till all customers were included in the cluster.

4. The Capacitated Vehicle Routing Problem

CVRP (traditional VRP) can be specified on a full undirected graph G=(V, E), in which V={0,1,…, n} represents the vertex set, while E={(I, j): I, j∈V, I < j} represents edge set. In addition, vertices 1,.., and represent customers; every one of the customers I is related to non-negative demand audio and a non-negative service time. Also, vertex 0 represents depot where a fleet m homogeneous vehicles of Q capacity have been based. Furthermore, the fleet size is handled as one of the decision variables. All edges (I, j) are related to a non-negative traveling cost or traveling time cij. CVRP determines m vehicle routes such that [18]:

a) All routes start and end at the depot.
b) Each one of the customers is visited only one time.
c) The total demand regarding any one of the vehicle routes doesn't exceed Q.
d) The total costs of all of the vehicle routes are reduced. In a few cases, CVRP imposes constraints of duration, in which duration regarding any one of the vehicle routes mustn't be exceeding a certain bound L.

5. Meerkat Clan Algorithm (MCA)

Meerkats have been defined as social animals which live in groups of 5 to 30. They are sharing both latrines as well as parental care duties because they are amiable animals. There is an overwhelming alpha female and command alpha male in each crowd. Each horde has its domain, which it moves from time to time if food is rare or when a more grounded horde pushes it out. The leader divides the clan into two groups; the first is responsible for searching for food (foraging), while the second is responsible for taking care of the young (care). He also chooses the best individual in the clan to be the group's watchdog (sentry) and inform them of any danger nearby. Clan size n, care group size c, foraging group size m, number of neighbors K, worst foraging and care ratio Fr and Cr, are significant parameters derived from Meerkat behavior and used in MCA [15].

As demonstrated in Algotithm (1), the algorithm first initializes the parameters used in the algorithm, with n representing the number of clan solutions. The size of the foraging and care groups are represented by m and c, respectively. In addition, the algorithm determines the worst foraging and care ratio. Last but not least, set the number of neighbors to K [15].

The algorithm begins by randomly generating a group of solutions, referred to as a clan of size n. The fitness function is used to assess the clan that has been generated. The optimal solution from the clan has been selected and given the name Sentry. The clan's remaining members are divided into 2 groups: a care group of size c (n-m-1) and a foraging group of size m (where m < n) [15].

Algorithm (1): Meerkat Clan Algorithm [15].

```
Meerkat Clan Algorithm
Parameter
    n       size of the clan between 30 and 50
    c       size of the care      n-m-1
    m       foraging size         m < n
    Fr      worst foraging rate
    Cr      worst care rate
    k       neighbour solution
Start
 Generating random solution clan clan (n)
Computing the value of the fittest for the solutions of the clan
 Sentry = optimal clan solution
 Dividing clan into 2 groups (care and foraging)
 While not termination condition
 For I=1 to me
        Call neighbor_generat (k, Sentry, foraging (I), best_one)
        foraging (I) = best one from k neighbor
 Endeavor
 Swapping worst for the Fr solution in the foraging group with optimal ones' solution in the core group;
 Dropping the worst solution of the Cr from the core group and randomly generating ones' solution;
 Selecting the optimal one of foraging, best_forg
 If best_forg <= Sentry then
        Sentry best_forg
 Endif
Endwhile
End
```

Every foraging group solution has been sent to the neighborgenerate sub-algorithm, illustrated in Algorithm (2), and the optimal solution from the generated neighbor is returned. In the neighborgenerate receives Sentry K and foraging. Neighborgenerate performs the generation of K neighbors from foraging and calculating its function of fitness. In the case where all generated neighbors have been worse than the foraging, in this case, K neighbor is generated from the sentry. The optimal solution is chosen from K neighbors, and it is being returned to the main algorithm. If the foregoing, which has been sent to neighborgenerate is worse than the best neighbor, it should be replaced [15].

Algorithm (2): neighbour generated subroutine [15].

neighbour_generated
Inputs: K, Sentry, foraging
Outputs: best_one
Begin
Generate k neighbor from foraging;
Computing the value of the fitness of k
In the case where there is no one better than the foregoing then
Generating the k neighbor from the sentry
Endif

end

According to the worst foraging ratio, the algorithm separates the least good solution in the foraging group and substitutes it with the best ones of the core group. Replace the least good solution in the care group with a new random solution generated based on the worst care ratio [15]. The optimal solution from the foraging group has been selected and compared to sentry; if it is superior, sentry is replaced with optimal solution from the foraging group. Those steps will be repeated to the point where the condition of termination is reached. Sentry is the best solution in the end [15].

6. General Experimental Method

In the present work, 27 Instances CVRPs from 2 separate sets of Augerat Instances problems [8]. Of A-VRP were taken under consideration. In an A-VRP, the number of customers ranges between 32 and 80. total demand ranged between 407 and 942, the number of vehicles ranges between 5 and 10, and capacities of the individual vehicle is 100 for all issues.

A customer node has been represented as a coordinate in a problem. Thus, the costs are identified after estimating distance with the use of coordinates. The variant Sweep algorithm was utilized for each of the problems for various starting angles (ϴs), and those were 0^o, 45^o, 90^o, 135^o, 180^o, 225^o, and 270^o. It is indicated that traditional Sweep considers ϴs = 0^o for clustering. The clan size of MCA is 100, where the foraging group is 60, and the care group is 40. The fitness function is the same as that used in a problem TSP where the vehicle's distance traveled on each lane is calculated. Each node represents the position of a city, whereas each edge corresponds to a joining path between two cities. The distance *dij* which is associated with edge (*i*, *j*), represents the Euclidean distance from city *i* to city *j*, and is calculated according to Equation (1).

$$dij = \sqrt{(xi - xj)^2 + (yi - yj)^2} \quad (1)$$

The number of iterations is set at 120 for the algorithm.The results of the MCA were compared with those of the algorithms GA, ACO, PSM, and Velocity Tentative PSO (VTPSO) presented in [21]. Table 1 compares CVRP cost values for clustering with variant Sweep on A-VRP benchmark tasks. The bottom of the table shows the average and best/worst summary overall of 27 problems. The results presented for the variant Sweep with an optimal result from 7 different starting angles clustering. For an MCA method, if the cost was found better than the cost of other methods, it was placed in bold font.

Table1. CVRP cost comparison on A-VRP benchmark problems.

Sl.	Problems	MCA	GA	ACO	PSM	VTPSO
1	A-n32-k 5	882	882	897	882	882
2	A-n33-k 5	**690**	698	719	698	698
3	A-n33-k 6	751	751	758	751	751
4	A-n34-k5	**770**	785	804	785	785
5	A-n36-k5	**879**	884	917	881	881
6	A-n37-k5	739	739	766	746	739
7	A-n37-k6	**998**	1097	1116	1097	1097
8	A-n38-k5	813	813	844	813	813
9	A-n39-k5	**860**	878	912	877	877
10	A-n39-k6	969	969	981	975	969
11	A-n44-k6	**1012**	1056	1116	1056	1056
12	A-n45-k6	**1050**	1073	1081	1075	1073
13	A-n45-k7	1043	1343	1380	1343	1343
14	A-n46-k7	**987**	990	1033	990	990
15	A-n48-k7	**1110**	1152	1165	1152	1152
16	A-n53-k7	1091	1091	1132	1090	1090
17	A-n54-k7	1278	1361	1374	1361	1361
18	A-n55-k9	**1900**	1201	1215	1201	1201
19	A-n60-k9	1510	1503	1528	1503	1503
20	A-n61-k9	1219	1219	1238	1219	1219
21	A-n62-k8	**1498**	1501	1532	1501	1501
22	A-n63-k9	**1799**	1823	1852	1823	1823
23	A-n63-k10	1461	1461	1478	1446	1446
24	A-n64-k9	**1577**	1598	1622	1598	1598
25	A-n65-k9	1317	1317	1339	1317	1317
26	A-n69-k9	1254	1254	1280	1252	1252
27	A-n80-k10	**2120**	2137	2195	2136	2136

Through what was presented in Table 1, we can see that the Meerkat algorithm is better in most problems, especially when the complexities of the problem increase, as is evident in Problems No. 18, 21, 22, 24, and 27.

7. Conclusions

CVRP can be defined as a common combinatorial optimization problem, and interest in finding the best solution has grown in recent years. Sweep algorithm is commonly used for clustering nodes based on vehicles, and after that, TSP is used for generating routes for each vehicle. Sweep cluster construction typically begins with the node with the lowest polar angle. The outcomes of MCA received via divide the solution group into two sets (foraging and care). Maximum the operations are done on foraging set, and the worst solutions changed with the quality ones in care solutions. The worst solution in the care set is dropped, and from the care, the set is dropped, an evolution is selected randomly. These outcomes display the excellent overall performance of the algorithm's capability to acquire optimum or near-optimum solutions at a highly rapid rate. To generate optimum routes for individuals. Clusters, the various optimization approaches, including Genetic Algorithm (GA), MCA, PSM, ACO, and VTPSO, are used. Many starting angles positively impact Sweep clustering, and MCA is more sufficient than other optimization approaches to solving CVRP, according to the experimental results of benchmark problems. Lastly, when compared with related current approaches, MCA with variant Sweep is recognized as a prominent CVRP solving technique.

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