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A Comparative Study on Heuristic and Meta Heuristic Approach in Solving a Capacitated Vehicle Routing Problem

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Abstract:- In the present day scenario most of the requirements of our day to day life are made by service providers to our footsteps. These services are door delivery off Pizza (Domino's Pizza) within a stipulated time limit, transportation service like office picking of employees or School Children, Milk man delivering milk door-to door, postal and logistic services like Ekart logistics, Blue Dart etc. In such services, service delivery and timely service are very important. These issues mainly require scheduling and routing of service vehicles. The Vehicle Routing problem (VRP) is a combinatorial optimization and integer programming problem seeking to service a number of customers with a fleet of vehicles. Objective of this problem is to minimize the time and distance travelled. Among the various types of VRP'S, Capacitated Vehicle Routing Problem is the most important operational decision related to transport in Supply Chain Management. C-VRP is a Vehicle Routing problem which has an additional constraints like capacity constraint for a vehicle and variable demand at different nodes. Service Providers must plan in such a way that service is delivered to customers at right location to a right person at right time to draw the attention of Customer's satisfaction. In this present work a real time data from a logistic company is collected and evaluated using Heuristic Algorithms like Clarke and Wright Savings Algorithm, Sweep Algorithm and Holmes and Parker Algorithm and results are compared with state-of-art techniques, which shows that performance of Ant Colony Optimization (ACO) is feasible for solving this Capacitated Vehicle Routing Problem.

***Keywords**:- Ant Colony Optimization, Capacitated Vehicle Routing Problem, Heuristic Algorithm, Routing and Scheduling.*

I. INTRODUCTION

Physical distribution is one of the key functions in Logistic industries. Distribution companies face great challenges to organize their fleet efficiently and effectively. It is a very costly function in Logistic & in Supply Chain Management. Dantzig and Ramser proposed Vehicle routing Problem in the year 1959 as a generalized problem of travelling salesman problem and from then many hundreds of research works have been published on several variants of VRP.VRP's found to be useful in many of the real world applications like newspaper distribution, goods distribution, mail delivery, school bus routing, garbage collection, private travels operation, courier service applications and many more. Even though VRP is classified into many variants the most important and basic variants of VRP are Capacitated Vehicle Routing Problem (CVRP), VRP with time windows (VRPTW), Open VRP (OVRP), Multi Depot Vehicle Routing Problem (MDVRP) and VRP with pickup and delivery (VRPPD).The present variant on which the work is focused is Capacitated Vehicle Routing Problem (CVRP). In this problem, a complete study was done on a Private Courier service provider, who has a warehouse at particular location, homogeneous vehicles for delivery with a capacity constraints and customers at different places with a particular demand are organized to form nodes. Based on the data collected we will formulate the Forecasted demand at every node point. The distance matrix is formulated from the warehouse to all the nodes available. After this the main objective of our work is to minimize the distance travelled by providing the courier service , the optimal routes by using Heuristic algorithms like Clarke and Wright Savings method, Holmes and Parker and Sweep algorithm and the results obtained from these algorithms are Analyzed and compared with a Meta-Heuristic algorithm i.e. Ant Colony Optimization (ACO). The next phase of the paper is structured as follows; Literature review in section 2, methodology and methods in section 3, data collection in section 4, result analysis in section 5, discussion and conclusion in section 6and finally references at the end of the paper.

II. LITERATURE REVIEW

Amberg et al (2000) in his paper mainly focused on Capacitated arc routing problem which has Multiple number of centres the main aim is to find out the optimum route starting from the initial depot or centre by satisfying various constraints involved and thereby reducing the travelling cost. Here he used a heuristic algorithm called Capacitated Minimum Spanning tree. Additionally in this paper he also mentioned the possibilities to introduce additional and side constraints into the objective function. After evaluating the results with the real world problems he compared them with Tabu Search, Simulated Annealing and various other Meta Heuristic algorithms.

Caricl et al (2007) in his paper basically proposed and proposed a framework model for solving large and complex vehicle routing problems. He used a Script based modelling language. The performance measures and algorithm is very clearly explained and also a detailed description of how this framework helps in solving vehicle routing problems with time windows. This is a programming language which is very much similar to other languages which consists of syntax, data types, Boolean and various characteristics like loops. Here the list of customers to be served at different nodes and list of vehicles available and their capacity are stored in the database and attributes are assigned to them. But in this paper he was not able to solve the VRP with time windows because in practical and real time view it would become much complex in calculations and due to his time and other constraints he applied on capacitated vehicle routing problem and evaluated the results. The major objective of the paper is finding the best routes by limiting the usage of vehicles and allocating the nodes to the vehicle very effectively there by reducing the cost of the transportation and various other costs.

Watanabe and Sakakibara (2007) in the present paper mainly focused on the ways of translating single objective optimization problem into multi objective optimization problem and by using various evolutionary algorithms he stated that the results of multi objective optimization are far better than single objective optimization. Further he also described the differences of dividing the problem into subways and compared them with the traditional methods of solving the problems.

Mohibul Islam, Sajal Ghosh (2015) in his paper also dealt with the case of capacitated vehicle routing problem. In this basically a real time data of a Coca-Cola distribution company in Bangladesh are taken at various nodes and analyzed and evaluated using various heuristic algorithms like Clarke and wright algorithm, Holmes and Parker algorithm and Fisher and Jaikukumar algorithm and compared the results among them and concluded that Clarke and wright algorithm proved to be more effective for his work and also mentioned that these heuristic algorithms might provide better results for small instances and might be ineffective when the problem becomes complex.

III. METHODOLOGY AND METHODS

For solving the capacitated vehicle routing problem (CVRP) three heuristics named Clarke and Wright Algorithm, Holmes and Parker Algorithm and Sweep Algorithm methods are applied and are compared with a Meta Heuristic Algorithm - Ant Colony Optimization. This study finds out the optimum routes by comparing these three algorithms that minimizes the travelling distance of service delivery of the Logistic Company.

A. Clarke & Wright Savings Algorithm

In 1964 Clarke & Wright published an algorithm for the solution of vehicle routing problem, which is often called the classical vehicle routing problem. This algorithm is based on a so-called savings concept. The distance matrix identifies the distance between every pair of locations to be visited. If the transportation costs between every pair of locations are known, the cost can be used in place of distance.

The distance d_{ij} on a grid between a point i with a coordinates (x_i,y_i) and a point j with a coordinates (x_j, y_j) is evaluated as:

$D_{ij} = \sqrt{((x_i - x_j))^2 + (y_i - y_j)^2}$

1. Starting solution: each of the n vehicles serves one customer.
2. For all pairs of nodes i,j, i…j, calculate the *savings* for joining the cycles using edge [i,j]:

$S_{ij} = C_{0i} + C_{0j} - C_{ij}$.

3. Sort the savings in decreasing order
4. Take edge [i,j] from the top of the savings list. Join two separate cycles with edge [i,j], if
   (i) The nodes belong to separate cycles
   (ii) The maximum capacity of the vehicle is not Exceeded.
   (iii) i and j are first or last customer on their cycles
5. Repeat '4' until the savings list is handled or the capacities don't allow more.

B. Homes & Parker Algorithm

Clarke and Wright algorithm has its own limitations sometimes. It may not give us a very good solution sometimes. People try to work better, get better solutions compared to the Clarke and Wright. It is possible to get better solution by Holmes and Parker algorithm which is better than the Clarke and Wright solution.

1. This is an extension of Savings Algorithm, the first step in this is we will eliminate the first highest saving considered in the optimum Iteration of Savings Algorithm.
2. Now after the elimination we will initiate the iteration from the next highest saving.
3. Follow the same procedure of Clarke & Wright method.
4. Follow Step 3 & 4 until you get an optimum solution.
5. Terminate the iterations if you are left with an optimum solution.

C. Sweep Algorithm

This heuristic is of the type "clustering first, route later". Assume the customers are points in a Plane with Euclidean distances as costs. The distance between (x_i, y_i) and (x_j,y_j) is calculated.

1. Compute the polar coordinates of each customer with respect to the depot. Sort the customer by increasing polar angle.
2. Add loads to the first vehicle from the top of the list as long as the capacity allows. Continue with the next vehicle until all customers are included. Now the customers have been clustered by vehicles.
3. The value of Angle (θ_i) is given by $\theta_i=\tan^{-1}(Y_i/X_i)$.

i	X	Y	d_i	Angle (θ)	q
1	-4	5	9	141.34°	30
2	6	1	7	10°	40
3	0	-4	4	0°	45
4	3	-9	12	288°	30
5	6	-9	15	301°	20
6	1	-15	16	274°	40
7	4	-15	19	285°	35
8	10	-15	25	304°	30
9	-3	-15	18	259°	35

Table 1

D. Ant Colony Optimization

1. Ant Colony Optimization a Meta heuristic algorithm was proposed by Gambardella Dorigo in the year 1997.
2. This is a Probabilistic technique in which search for optimal path in the graph based on the behavior of ants seeking path between their colony and source of food.
3. Each ant moves at random and navigate from the nest to food source, shortest path is discovered via pheromone trails, Pheromone is deposited on the path, and more pheromone on the path increases the probability of path being followed.
4. An ant will move from node i to j with a probability of

$$p_{ij}^{k} = \frac{\tau_{ij}^{\alpha} \cdot \eta_{ij}^{\beta}}{\sum_{l \in N_i^k} \tau_{il}^{\alpha} \cdot \eta_{il}^{\beta}}$$

Where $\eta_{ij} = 1 / d_{ij}$,$\eta_{ij}$is the visibility of city j from i. τ_{ij}^{α} is the intensity of pheromone trail between i and j

α is the parameter to regulate the influence of pheromone, usually it will be between 0 and 1.

β is the parameter to regulate the influence of visibility , usually between 0 and 1.

5. These parameters are the random numbers [0,1].
6. Initially by using this formula the probability of all the possible nodes are calculated by satisfying the demand and the capacity constraints.
7. Then the ant tends to choose the path with highest probability.
8. This process is carried out until the capacity of the ant is fulfilled and next iteration starts from the starting node for another ant.
9. Same process is repeated for the next upcoming ants until all the demands at different nodes are fulfilled.
10. Stop the process after all the nodes get allocated to required number ants, which provides us with an optimal route.

IV. DATA COLLECTION

The data of the demand at each nodal points are taken from the Logistics Service and a Forecasted demand at each node point is calculated and tabulated. There is a capacity constraint of 75 orders per vehicle. The co-ordinates of the nodes are taken from the logistics service and a distance matrix and Coordinate table are prepared.

A. Clarke & Wright Method

Capacity of each vehicle/delivery Person: 75

C_{ij}	0	1	2	3	4	5	6	7	8	9
0	-	9	7	4	12	15	16	19	25	18
1	9	-	16	13	21	24	25	28	34	27
2	7	16	-	11	19	22	23	26	32	25
3	4	13	11	-	10	13	14	17	23	16
4	12	21	19	10	-	3	4	7	13	6
5	15	24	22	13	3	-	7	10	16	9
6	16	25	23	14	4	7	-	3	9	2
7	19	28	26	17	7	10	3	-	6	5
8	25	34	32	23	13	16	9	6	-	11
9	18	27	25	16	6	9	2	5	11	-

Table 1. Distance matrix (From warehouse at "0"to 9 different nodes) in K.ms

i	1	2	3	4	5	6	7	8	9
D_i	30	40	45	30	20	40	35	30	35

Table 2. Demands at different nodes:

- Using the distance matrix and demand table initially we need to find the list of savings for every node using the formula $S_{ij} = d_{0i} + d_{0j} - d_{ij}$.
- After calculating all the savings sort out the savings based on decreasing order of savings.
- Now based on the capacity constraint and the demand at particular nodes assign the vehicles such that it would come up with an optimal route.

B. Homes & Parker Algorithm:

- The main reason for introduction of this algorithm is that , Clarke and Wright Savings method is a greedy heuristic which tries to capture the highest savings initially , which in turn leads to exemption of many small individual savings that might come up with an optimal solution.

- Hence the initial saving from the Savings Algorithm is exempted and Savings Algorithm is applied from the next highest value and repeated until we get the optimum solution.

C. Sweep Algorithm

In this algorithm initially we will find the values of all the angles and from the increasing order of the (θ) we will start assigning the nodes to the vehicles based on the demand and the capacity constraints of the vehicles. In this way optimal route is evaluated using Sweep Algorithm.

i	X	Y	d_i	Angle (θ)	q
1	-4	5	9	141.34°	30
2	6	1	7	10°	40
3	0	-4	4	0°	45
4	3	-9	12	288°	30
5	6	-9	15	301°	20
6	1	-15	16	274°	40
7	4	-15	19	285°	35
8	10	-15	25	304°	30
9	-3	-15	18	259°	35

Table 3. Value of 'θ' Using Sweep Algorithm

D. Ant Colony Optimization

NODES	PROBABILITY
1	0.1258
2	0.1473
3	0.206
4	0.1059
5	0.0932
6	0.0894
7	0.080
8	0.0685
9	0.08323

Table 4. Probabilities at various Nodes.

- Ant Colony Optimization technique is purely Probabilistic in nature, here the selection and assigning of vehicles are purely based on the probability value at each node without violating the demand and the capacity constraints at nodes.

- List of Probabilities from 0 to all nodes are calculated based on the formula mentioned earlier As the ACO algorithm says that ant tends to choose the shortest path , which has high probability value will be considered first and an optimal route is evaluated.

V. RESULT ANALYSIS

ALGORITHM	ROUTES AND VEHICLES (V)ASSIGNED	DISTA-NCE	LOAD	DISTANCE IN KM'S
Clarke & Wright Algorithm	0-7-8-0 (V1) 0-6-9-0 (V2) 0-4-5-0 (V3) 0-1-2-0 (V4) 0-3-0 (V5)	50 36 30 32 8	65 75 50 70 45	156
Homes and Parker Algorithm	0-6-7-0 (V1) 0-8-9-0 (V2) 0-4-5-0 (V3) 0-1-2-0 (V4) 0-3-0 (V5)	38 54 30 32 8	75 65 50 70 45	162
Sweep Algorithm	0-3-1-0 (V1) 0-2-9-0 (V2) 0-6-7-0 (V3) 0-4-5-0 (V4) 0-8-0 (V5)	26 50 38 30 50	75 75 75 50 30	194
Ant Colony Optimization	0-3-4-0 (V1) 0-2-1-0 (V2) 0-5-6-0 (V3) 0-7-9-0 (V4) 0-8-0 (V5)	26 32 38 42 50	75 70 60 70 30	188

Table 5. Results obtained from various Algorithms.

ALGORITHM	ESTIMATED DISTANCE	ACTUAL DISTANCE (KM)	DISTANCE SAVING (KM)	DISTANCE SAVING (%)
Clarke & Wright Algorithm	250	156	94	37.6%
Homes and Parker Algorithm	250	162	88	35.2%
Sweep Algorithm	250	194	56	22.4%
Ant Colony Optimization	250	188	62	24.8%

Table 6. Comparison of Distance travelled among Four Algorithms.

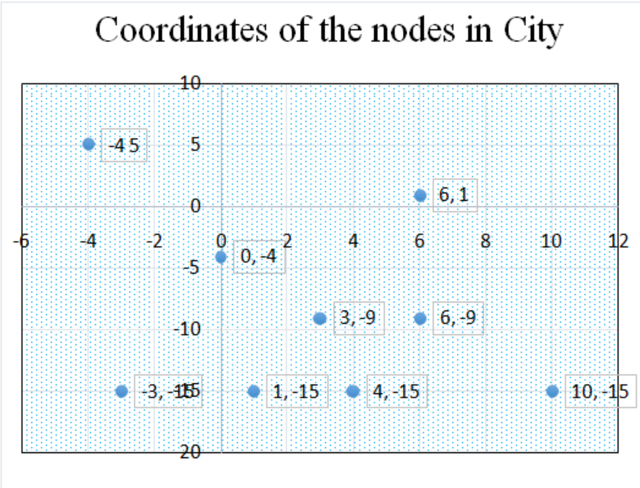

Fig 1:- Coordinate points of various nodes in the city.

Therefore from the analysis it is found that results obtained by applying Clarke and Wright are more suitable under the considered situation. The Meta heuristic algorithm – Ant colony optimization also gave us a feasible solution, but results obtained from Clarke and Wright gave us an Optimum value as mentioned earlier since this algorithm is a greedy heuristic which sometimes may not come up with a better solution. But in this case it gave us an Optimum solution. Results obtained from all the four algorithms are compared in Table 6.

VI. DISCUSSION AND CONCLUSION

A number of Heuristic approaches are available for solving CVRP. In this we used both heuristic and Meta heuristic algorithms. In general it is a known fact that we get optimum solutions from Meta heuristics and Holmes and Parker Algorithm but in this present situation Clarke and Wright algorithm produced better results due to its simplicity, greediness and robustness. The Capacitated Vehicle Routing Problem is a challenging unsolved problem and has attracted the attention of several researchers due to its immense practical importance.

The savings approach used by the Clarke and Wright algorithm can provide good solutions for small size instances. However for large instances calculating the savings may consider large values which affect the solution because the problem solving becomes complex. In addition, classical heuristics are easy to understand and implement compared to meta-heuristics. Meta-heuristics delivers better results in most of the cases. But in this study it is showed that classical algorithms can also provide accurate result which indicates that no single heuristic will always produce better result in a consistent manner. So a wide range of scope is available in this area and also various new Meta heuristic algorithms are also being introduced which might come up with better results.

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