

## **Solving Capacitated Vehicle Routing Problem by Using Heuristic Approaches: A Case Study**

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*This research work is considered a single distribution center that provides the customer demands at various sales points. Due to capacity of the vehicles it's may need several trips from distribution center to demand centers for replenishment. The objective of this research is to determine an optimal distribution network to meet demands by travelling minimum distance. This research work is proposed heuristic approaches to get an optimal distribution network that minimize the total travelling distance.*

**Keywords:** Network optimization, capacitated vehicle, Heuristic approaches.

### **1. Introduction**

Solving capacitated vehicle routing problem (CVRP) is the most important operational decision related to transportation in a supply chain which means the routing and scheduling of deliveries. CVRP is a Vehicle routing problem (VRP) in which a fixed fleet of delivery vehicles of uniform capacity is used to provide known customer demands for a single commodity from a common depot by travelling minimum distance and as well as minimum transit cost. That is, CVRP is like VRP with the additional constraint that every vehicle must have uniform capacity of a single commodity. 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. Managers must be planned to provide customer's delivery at right location at right time to draw the attention of customer satisfaction. In order to provide customer service timely it is necessary to follow a specific route and proper vehicle schedule. The success of its operation turns on its ability to decrease transportation and delivery cost while providing the promised level of responsiveness to the customer. Given a set of customer orders, the goal is to design a route and scheduled delivery vehicles such that the costs incurred to meet delivery promises are as low as possible.

Abdul Monem Group Bangladesh Ltd. is a well-known company of Bangladesh. It is mentioned that Coca-Cola is the worldwide popular cold drink which is imported by this company. There are ample numbers of distribution center at different cities in Bangladesh. Rajshahi is one of the most important distribution centers of this company. The distribution center of Coca-cola in Rajshahi city supplies their product in 15 important places of Rajshahi City Corporation.

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The distribution center is used 4 vehicles in two days to supply 350 cases of their product to these places. But the problem is that this distribution center does not follow any optimized routes to deliver their product. That's why the total transportation distance is large enough to deliver their product. As transit cost depends on travelling distance that's why their transit cost is also high that puts a great impact on their profitability. So the authors feel that there is a scope to carry out a research work on this area. Hence the authors get great motivation and interest to carry out a research work on this problem area to search a proper solution. The significance of this study is that after getting a solution it will be possible to serve the customer demands by travelling minimum distance that will be very cost effective. So authors feel that to overcome this problem a specific vehicle routing and scheduling of deliveries in transportation is necessary. Finally the authors confined the objective of this research work is that to solve capacitated vehicle routing problem of Coca-Cola distribution center in Rajshahi City Corporation by applying various heuristic approaches to minimize the travelling distance and to determine an optimal distribution plan that meets all the demands. For the completion of this research work three heuristics approaches named Clarke and Wright Algorithm, Holmes and Parker Algorithm and Fisher and Jaikumar method are applied. This study finds out optimum routes by comparing these three algorithms that minimizes the travelling distance of Coca-cola deliveries of Rajshahi distribution center.

The rest of this paper is organized as follows; section 2 represents literature review, section 3 represents research methodology, Section 4 represents data collection and result analysis. Section five represents the discussion and conclusion and finally references are mentioned after the conclusion portion.

## 2. Literature Review

Amberg et al (2000) have been described on capacitated arc routing problem with multiple centers (M-CARP) and the objective is to find routes starting from the given depots or centers such that each required arc is served, capacity constraints are satisfied and total travel cost is minimized. A heuristic transformation of the M-CARP into a multiple center capacitated minimum spanning tree problem with arc constraints that called arc-constrained CMST. An algorithm for determining initial feasible solutions as well as an improvement procedure for this problem are described and the re-translation of CMST solutions into the CARP context is explained. It is shown that the objective function value of the obtained CARP solution is easily derived from the respective value of the corresponding heuristic CMST solution. Furthermore, the possibility of including side constraints and the consideration of additional objective functions are discussed. Computations on real-world benchmark problems compare the results of the Tabu search and simulated annealing Meta strategies embedded in the improvement procedure. They considered the capacitated arc routing problem (CARP) which belongs to an important class of vehicle routing problems with a great variety of real-world applications. In general, the CARP can be characterized as follows: A set of customers have to be served by a fleet of vehicles operating from one or more depots. Each vehicle starts and ends its route at the depot it is assigned to. Furthermore, it has given capacities with respect to time i.e. maximal allowed time duration and quantities i.e. a maximal allowed capacity for satisfy able demand. An additional side constraint such as restricting the assignment of customers to vehicles is considered. The objective is to find routes for the vehicles where each route

satisfies the capacity constraints of the respective vehicle, each customer is served and all side constraints are fulfilled such that the total transportation cost is minimized. The main distinguish characteristic in this research study compare to previous one is that a single depot/ single center is considered to solve capacitated vehicle routing problem and the objective is to find the optimal routes starting from the single depot that each and every customers are served that's transportation cost is minimized and the main constraints are the capacity of the truck and number of vehicles. For solving the capacitated vehicle routing problem three heuristics named Clarke and Wright Algorithm, Holmes and Parker Algorithm and Fisher and Jaikumar method are applied. Finally optimum routes are found out by comparing among three algorithms that minimizes the travelling distance of Coca-cola deliveries of Rajshahi distribution center.

Alba and Dorronsoro (2005) proposed a cellular Genetic Algorithm (cGA) which is a decentralized population based heuristic used for solving CVRP, cGA, called JCell2o1i. In JCell2o1i, solutions are represented as permutations of integers. Each permutation will contain both customers and route splitters, so they used a permutation of numbers  $[0 \dots n-1]$  with length  $n = c+k$  for representing a solution for the CVRP with  $c$  customers and a maximum of  $k+1$  possible routes. Customers are represented with numbers  $[0 \dots c-1]$ , while route splitters belong to the range  $[c \dots n-1]$ . Each route is made of the customers situated between two route splitters in the individual. In their basic cGA, the population is structured in a 2D toroidal grid, and the neighborhood defined on it and always contains individuals. The first parent is chosen by using binary tournament selection (BT) inside this neighborhood, while the other parent is the current individual itself. The algorithm iteratively considers as current each individual in the grid. The two parents (Cross over & Mutation) can be the same individual (replacement) or not. In this study proposed an algorithm based on heuristic for solving CVRP in which determine a seed point corresponding to the center of the trip taken by each vehicle using the following procedure, the insertion cost for each and every customer and finally assign customers to route by solving an objective function (Solver Excel) to find the minimum distance of each route as well as the minimum cost.

Tam and Ma (2004) considered combining of the two well-known methods which are guided local search and tabu search for solving vehicle routing problem with time windows (VRPTW) where the choice of the search method is controlled by simulated annealing. The initial solution is obtained by push-forward insertion heuristics and the virtual vehicle heuristics. The approach is verified on the standard Solomon's benchmark. The push-forward insertion heuristic (PFIH) introduced by Solomon in (1987), is an efficient method to compute a feasible solution for any VRP by assuming an infinite number of vehicles. The PFIH starts a new route by selecting an initial customer, usually farthest from the delivery depot, and then iteratively inserts any unassigned customer into the current route until the capacity of the current vehicle is exceeded or the waiting time for any newly added customer will exceed its associated duration constraint. At this moment, a new route will be created. And this process repeats until all customers are served. They examined two well-known meta-heuristics, namely the guided local search (GLS) and Tabu search (TS), which are based on completely different memory-like control mechanisms to restrict the local search operator in continuously optimizing the current solution, after input from the heuristic initialization method, until an optimal solution is obtained to solve the VRPTWs successfully. TS used a short-term memory-like Tabu list to avoid cycles in

search. On the other hand, GLS used a long-term memory-like penalty scheme to memorize all the undesirable features occurring in the previously visited local minima. The push-forward insertion heuristic is an efficient method to compute a feasible solution for any VRP by assuming an infinite number of vehicles. The major difference of this study from mentioned paper is that the number of vehicle is considered as a fixed to solve CVRP but in studied paper considered it as infinite number.

Caricl et al (2007) presented an integrated modeling and optimization framework for solving complex and practical VRP. The modular structure of the framework, a script based modeling language, a library of VRP related algorithms and a graphical user interface give the user both reusable components and high flexibility for rapid prototyping of complex VRP. The algorithm and the performance measure protocol is explained and implemented on the standard benchmark and on practical VRPTW (vehicle routing problem with time windows) problems. Like many other programming languages, the Framework Scripting Language (FSL) has a core set of basic data types (boolean, int, double, string) and program control statements (if, for, while, repeat). The FSL structure is the improved version of the previously developed VRP solving oriented language. The VRP problem is described with Problem data structure which stores all customers in the list Customers and all vehicles in the list Vehicles. Each Customer and Vehicle is instances of the corresponding data type whose attributes describe in detail the concrete problem being solved. But in this study it is solved the Capacitated Vehicle Routing Problem (CVRP) without considering the time windows. Since the search space for all the possible (feasible or slightly infeasible) routes in VRPs or VRPTWs can be fairly large even for instances involving 100 customers or more, and the time-window constraints in the VRPTWs can be difficult to satisfy, the careful choice of a suitable heuristic to return only feasible, and possibly more optimal, solutions can be important for further optimization.

Watanabe and Sakakibara (2007) described, single-objective optimization CVRP problem is translated into multi-objective optimization problem using the concept of multi objectification. On the translated problem the evolutionary multi-criteria optimization algorithm is applied. Experimental results indicate that multi objectification using additional objectives is more effective than using either objective alone. Previous studies of multi objectification can be divided roughly into two categories as follows addition of new objectives to a problem and decomposing a problem into sub-problems. These multi objectifications have a number of effects, such as the reduction of the effect of local optima, making the problem easier, or increasing search paths to the global optimum.

Throughout the literature review it is observed that many models have been proposed for solving the vehicle routing problem where most of the proposed assumed that the number of vehicle is unlimited and the objective is to find out a solution that either minimizes the number of vehicles and total travel cost. The main distinct feature of this research work from the past study is that to solve a vehicle routing problem assume fixed number of vehicle with known capacity which are assigned for transport the goods to the customer points. The main objective of this study is to find out a specific route for specific vehicle to provide service for specific customer to minimize the total transportation distance as well as transportation cost.

### 3. The Methodology and Models

For solving the capacitated vehicle routing problem (CVRP) three heuristics approach named Clarke and Wright Algorithm, Holmes and Parker Algorithm and Fisher and Jaikumar methods are applied. This study finds out the optimum routes by comparing these three algorithms that minimizes the travelling distance of Coca-cola deliveries of Rajshahi distribution center.

#### 3.1 Clarke & Wright's 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:

$$D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (1)$$

Denoting the transportation cost or distances between two given points  $i$  and  $j$  by  $d_{ij}$ , the total transportation cost or distance is

$$D_a = d_{0i} + d_{i0} + d_{0j} + d_{j0} \quad (2)$$

Equivalently, the transportation cost or distances  $D_b$

$$D_b = d_{0i} + d_{ij} + d_{j0} \quad (3)$$

By combining the two routes one obtains the savings  $S_{ij}$ .

$$S_{ij} = D_a - D_b = d_{0i} + d_{j0} - d_{ij} \quad (4)$$

Relatively large values of  $S_{ij}$  indicate that it is attractive with regard to costs or distances to visit points  $i$  and  $j$  on the same route such that point  $j$  is visited immediately after point  $i$ .

##### 3.1.1 Assign Customers to Route

In the first step of the Clarke and Wright savings algorithm the savings for all pairs of customers are calculated and all pairs of customer points are sorted in descending order of the savings. Subsequently, from the top of the sorted list of point pairs one pair of points is considered at a time. When a pair of points  $i-j$  is considered, the two routes that visit  $i$  and  $j$  are combined (such that  $j$  is visited immediately after  $i$  on the resulting route), if this can be done without deleting a previously established direct connection between two customer points, and if the total demand on the resulting route does not exceed the vehicle capacity.

##### 3.1.2 Sequence Customers within Route

At this stage the main goal is to sequence customer visits so as to minimize the distance each vehicle travel. Changing the sequence in which delivers are made can have a significant impact on the distance traveled by vehicles. Route sequencing procedure help to obtain an initial trip for each vehicle .The initial trip is improved by using the route improvement procedure. They are as follow:

**i. Farthest Insert:** Given a vehicle trip for each remaining customer, find the minimum increase in length for this customer to be inserted from all the potential

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points in the trip that they could be inserted. Then choose to actually insert the customer with the largest minimum increase to obtain a new trip. This step is referred to as a farthest insert because the customer farthest from the current trip inserted.

**ii. Nearest Insert:** Given a vehicle trip for each remaining customer, find the minimum increase in length for this customer to be inserted from all the potential points in the trip that they could be inserted. Insert the customer with the smallest minimum increase to obtain a new trip. This step is referred to as a nearest insert because the customer closest from the current trip inserted. The process is continued until all remaining customers the vehicle will visit are included in trip.

**iii. Nearest Neighbor:** Starting at the DC, this procedure adds the closest customer to extend the trip. At each step, the trip is built by adding the customer to the point last visited by the vehicle until all customers have been visited.

**iv. Sweep:** In the sweep procedure, at any point on the grid is selected (Generally the DC itself) and a line is swept either clockwise or counter clockwise from the point. The trip is constructed by sequencing customers in the order they are encountered during the sweep.

### 3.2 Holmes and 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.

### 3.3 Fisher and Jaikumar Method

The Fisher and Jaikumar algorithm (1981) is well known. It solves a Generalized Assignment Problem (GAP) to form the clusters. The algorithm can be described as follows:

#### 3.3.1 Assign Seed Points for Each Route

Chopra and Meindl (2004) mentioned that the goal of this step is to determine a seed point corresponding to the center of the trip taken by each vehicle using the following procedure:

- Divided the total load to be shipped to all customers by the number of vehicles to obtain the average load allocated to each seed point.
- Starting at any customer, use a ray starting at DC to sweep clockwise to obtain cones assigned to each seed point.
- Within each cone, the seed point is located in the middle (in term of angle) at a distance equal to that of the customer (with a partial or complete load allocated to the cone) farthest from the DC.

The angular position ( $\theta_i$ ) of customer  $i$  with coordinates  $(X_i, Y_i)$  is the angle made relative to the X axis by the line joining the customer  $i$  to the origin DC. The angular

position of each customer is obtained as the inverse tangent of the ratio of its Y coordinate to the X coordinate.

$$\theta_i = \tan^{-1}\left(\frac{Y_i}{X_i}\right)$$

### 3.3.2 Evaluate Insertion Cost for Each Customer

For each seed point  $S_k$  and customer  $i$ , the insertion cost  $C_{ik}$  is the extra distance that would be traveled if the customer is inserted into a trip from the DC to the seed point and back and is given by

$$C_{ik} = \text{Dist}(DC, i) + \text{Dist}(i, S_k) - \text{Dist}(DC, S_k) \quad (5)$$

Where the  $\text{Dist}()$  function is evaluated as in equation (1). For customer 1 and seed point 1, the insertion cost is given by

$$C_{11} = \text{Dist}(DC, 1) + \text{Dist}(1, S_1) - \text{Dist}(DC, S_1) \quad (6)$$

### 3.3.3 Assign Customers to Routes

The next step assigns customers to each of the vehicles to minimize total insertion cost while respecting vehicle capacity constraints. The assignment problem is formulated as an integer problem and requires the following input:

$C_{ik}$  = insertion cost of customer  $i$  and seed point  $k$ .

$a_i$  = order size from customer  $i$ .

$b_k$  = capacity of vehicle  $k$ .

Define the following decision variables

$Y_{ik} = 1$  if customer  $i$  is assigned to vehicle  $k$ , 0 otherwise.

The integer program for assigning customers to vehicles is given by

$$\text{Min} \sum_{k=1}^k \sum_{i=1}^n C_{ik} Y_{ik}$$

Subject to

$$\sum_{k=1}^k Y_{ik} = 1 \quad i = 1 \dots n$$

$$\sum_{i=1}^n a_i Y_{ik} \leq b_k \quad k = 1 \dots k$$

$Y_{ik} = 1 \text{ or } 0 \text{ for all } i \text{ and } k$

### 3.3.4 Sequence Customers within Route

At this stage the main goal is to sequence customer visits so as to minimize the distance each vehicle travel. Changing the sequence in which delivers are made can have a significant impact on the distance traveled by vehicles.

## 4. Data Collection and Results analysis

### 4.1 Data Collection

The data of order size of each customer point and the vehicle capacity are collected from the distribution center of Coca-cola in Rajshahi city. The coordinates of each

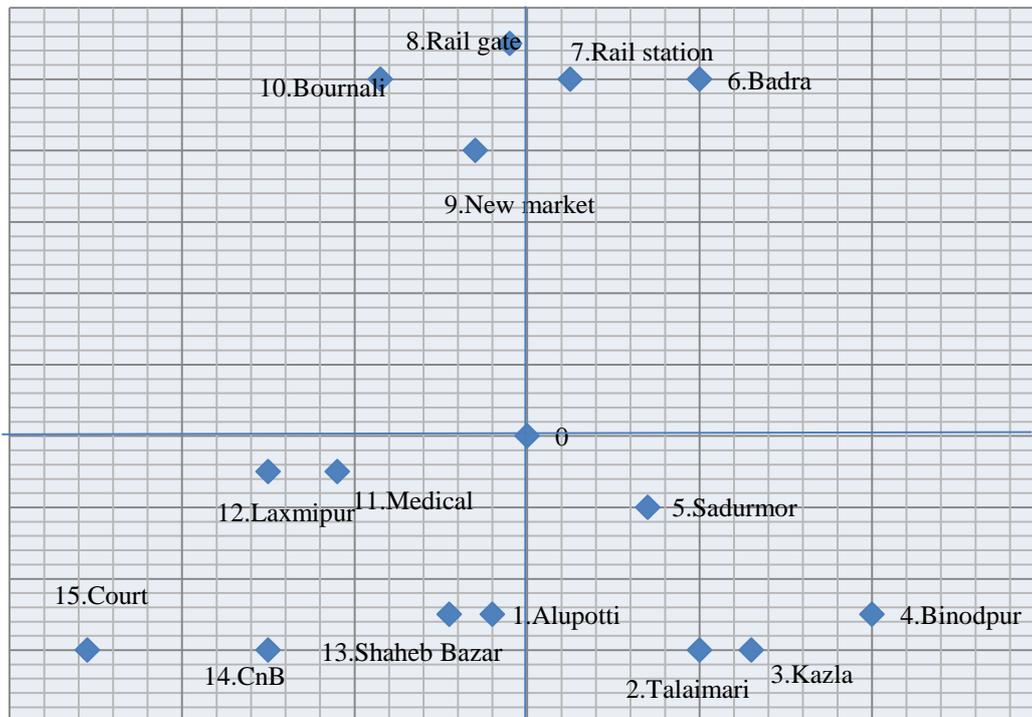
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customer points from Coca-cola distribution center are obtained from Rajshahi Development Authority (RDA).

**Table 1: Customer's Location and Demand from Warehouse in Rajshahi City**

Customer Point(i)	X-Coordinate	Y-Coordinate	Distance(di) (km)	Order Size (case)
Distribution Center	0	0	0	-
1. Alupotti	-0.40	-0.50	0.60	25
2. Talaimari	2.00	-0.60	2.10	25
3. Kazla	2.60	-0.60	2.70	20
4. Binodpur	4.00	-0.50	4.00	30
5. Sadurmor	1.40	-0.20	1.40	20
6. Badra	2.00	1.00	2.20	10
7. Rail Station	0.50	1.00	1.10	15
8. Rail gate	-0.20	1.10	1.10	10
9. New market	-0.60	0.80	1.00	30
10. Barnali	-1.70	1.00	2.00	10
11. Medical	-2.20	-0.10	2.20	30
12. Laxmipur	-3.00	-0.10	3.00	25
13. Shaheb bazar	-0.90	-0.50	1.00	50
14. Cnb	-3.00	-0.60	3.10	25
15. Court	-5.01	-0.60	5.10	25
<b>Total</b>			<b>32.60 km</b>	<b>350 cases</b>

**Figure 1: Graphical Representation of the Customer Location from Distribution Center**



4.2 Result Analysis

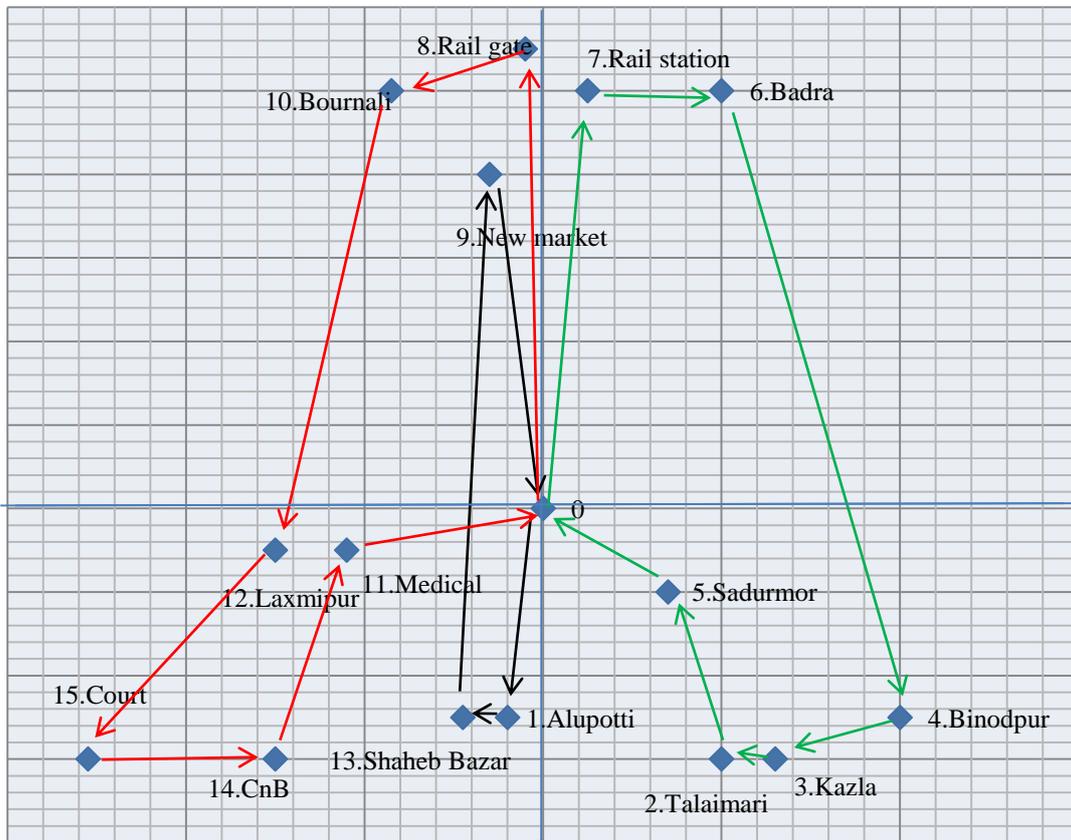
It is assumed that each customer points are delivered individually from the distribution center. Hence the total travelling distance is found around 65.2 km. From Clarke and Wright algorithm it is found that total travelled distance of vehicles is 24.3 km. Summary of the results applying Clarke and Wright algorithm is given in table 2.

Table 2: Optimum Route Sequence, Distance and Transportation Cost

Route	Vehicle	Distance (km)	Load (case)	Transportation cost (Tk.)
DC-7-6-4-3-2-5-DC	1 <sup>st</sup>	9.20	120	46.00
DC-8-10-12-15-14-11-DC	2 <sup>nd</sup>	11.70	125	58.50
DC-1-13-9-DC	3 <sup>rd</sup>	3.40	105	17.00
Total	3	24.30	350	121.50

\* Transportation cost Tk. 5.00 / km.

Figure 2: Overall Optimum Routes Applying Clarke and Wright Algorithm

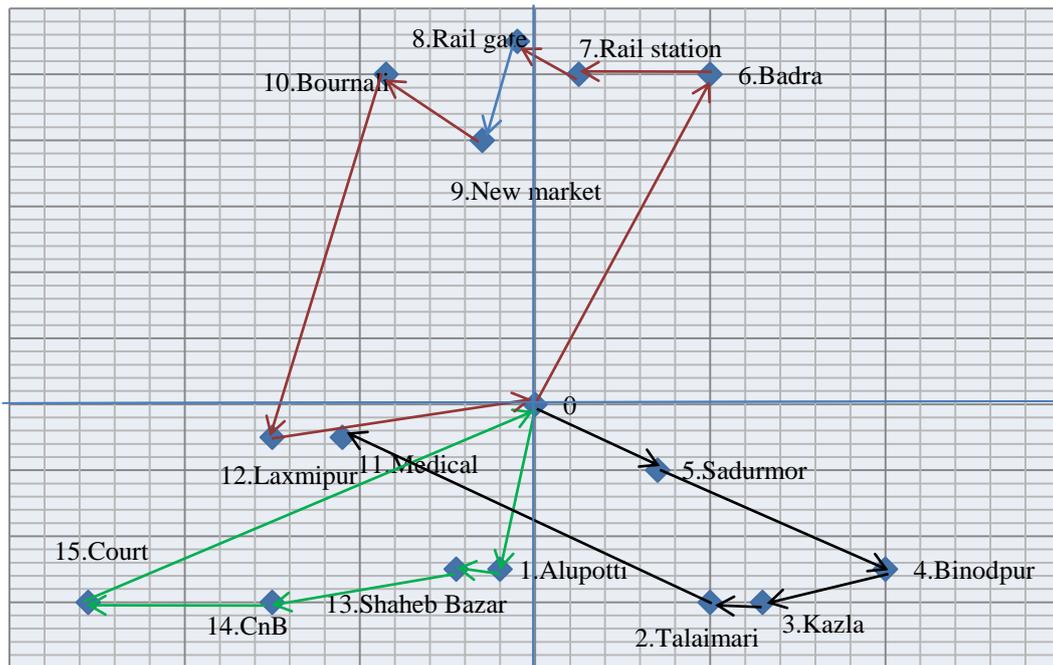


Applying Holmes and Parker algorithm it is found that total travelled distance of vehicles is 24.8 km. From Fisher and Jaikumar method it is found that total travelled distance of vehicles is 33.50 km. Summary of the results from Jaikumar method is given in table 3.

**Table 3: Optimum Route Sequence, Distance and Transportation Cost**

Route	Vehicle	Distance (km)	Load (case)	Transportation cost (Tk.)
DC-6-7-8-9-10-12-DC	1 <sup>st</sup>	10.70	100	53.50
DC-5-4-3-2-11-DC	2 <sup>nd</sup>	12.40	125	62.00
DC-1-13-14-15-DC	3 <sup>rd</sup>	10.40	125	52.00
Total	3	33.50	350	167.50

**Figure 3: The Overall Optimum Routes Applying Fisher and Jaikumar Method**



Summary of the findings after applying three algorithms are given in the table 4 and table 5 as follows:

**Table 4: Comparisons of Travelled Distance among Three Algorithms**

Algorithms/Methods	Estimated Distance ( km)	Actual Distance (km)	Distance Saving (km)	Distance Saving (%)
Clarke and Wright algorithm	65.2	24.3	40.9	62.73 %
Holmes and Parker algorithm	65.2	24.8	40.4	61.96 %
Fisher and Jaikumar Method.	65.2	33.5	31.7	48.62 %

**Table 5: Comparison of Transportation Cost among Three Algorithms**

Algorithms/Methods	Estimated Cost (Tk.)	Actual Transportation Cost (Tk.)	Total Cost Savings (Tk.)	% of Cost Savings
Clarke and Wright algorithm	326.00	121.50	204.50	62.73 %
Holmes and Parker algorithm	326.00	124.00	202.00	61.96 %
Fisher and Jaikumar Method.	326.00	167.50	158.50	48.62 %

Therefore from the analysis it is found that results obtained applying Clarke and Wright algorithm is more suitable under considered situation. It is observed that both the transportation distance and cost are always effective compare to others algorithms for the vehicle routing problem for Coca-cola distribution center in Rajshahi city.

## **5. Discussion and Conclusion**

### **5.1 Discussion**

A number of heuristic approaches are available for solving capacitated vehicle routing problem. In this problem classical heuristics have been used. It is mentioned better result is obtained applying Holmes and Parker algorithm than Clarke and Wright algorithms but under considered situation Clarke and Wright algorithm produce better result compare to other models. The main strength of the Clarke and Wright algorithm is its simplicity and robustness. It is also used two phase heuristic method named as Fisher and Jaikumar method to find the optimum distance travelled by vehicles. This method is more sophisticated and generally gives a better solution when the delivery schedule has no constraints other than vehicle capacity. So the essence of this study is that following the routes found by Clarke and Wright algorithm it will be possible to deliver customer demands by travelling minimum distance as well as minimum transit cost from distribution center of Rajshahi city.

#### **5.1.1 Limitation**

This research work is done on a bundle of assumptions that have been created some limitations which are as follows:

- It is considered that distances between customer points are linear. But in actual case the distances are non linear.
- Fisher and Jaikumar method for solving capacitated vehicle routing problem is more sophisticated and generally gives a better solution than Clarke and Wright algorithm. But in this case Clarke and Wright give the better solution.
- Google earth map is used to find the customer distance from distribution center so it is found near actual data but not purely accurate.

### 5.2 Conclusion

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 saving 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. In addition, classical heuristics are easy to understand and implement compared to meta-heuristics. Meta-heuristics can provide 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 is always produce better result consistently. So scopes are available for further research in this area that can improve upon these heuristics.

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