Capacitated Transport Vehicle Routing for Joint Distribution in Supply Chain Networks

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***Abstract*— This paper addresses the problem of capacitated transport vehicle routing for joint distribution of different suppliers. Although all suppliers distribute similar products to cities within the same region, each supplier has an extensive distribution network. In this paper, we develop solution procedures that guide the problem-solving process and quickly lead to a good routing solution. A case study is introduced with three real-world case problems for illustrating the applicability and suitability of the proposed approach. The results show that solution procedure approach is more than reasonable for quickly constructing good transport vehicle routes.**

***Keywords*—** *Routing; Scheduling; Joint Distribution; Transportation*

1. Introduction

Transportation routing is critical task in supply chain management. Firms that distribute large variety and volume of products to widely spaced geographical customer base must perform detailed distribution route analysis. For companies with private fleets, transportation routing has been recognized as pivotal in fully leveraging the significant investment made in transportation equipment and facilities operations.

In supply chain management, vehicle routing is a key transportation and distribution routing function. This function involves determining the geographic route a vehicle will travel to reach the delivery destination. Whether using private fleet or for-hire service, supply chain planners face the problem of minimizing the distance a vehicle can travel to reach all delivery destinations in which a set of customers is to be satisfied in the demand constraint within distance and vehicle's load capacity constraints. If a vehicle had unlimited capacity to deliver all customer orders on a single route, these constraints would not apply. In reality, firms must determine specific routes that are to serve specific customers, as well as the sequence in which they are to be visited to minimize the total distance traveled.

Transport vehicle routing primarily accounts for order or shipment consolidation. Consolidation is basically the process of combining vehicle's load to multiple destinations. The logic of consolidation is simple, the larger the load in relation to vehicle capacity, the lower the transportation cost. And the larger the load, the more deliveries can be made along the transportation route. In today's time-based distribution, consolidating deliveries to simplify vehicle routing and reduce transportation costs has been challenging with customers' requirements for smaller lot sizes and deliveries that are more frequent.

A number of routing algorithms have been developed to solve this problem, which can essentially be divided into two classes. In the first class, simultaneous methods, solutions are determined by computing all feasible routes to satisfy distribution requirements, and then the route that collectively yields the lowest cost is selected. Solving the problem with this method requires complex mathematical calculation. The second type, sequential approach, attempts to overcome the problems associated with simultaneous methods by either dividing delivery in to smaller geographical regions of customers that can be connected in a feasible route, or by constructing routes one at a time, adding contiguous links to a single route until distance and vehicle capacity constraints are reached.

This research is concerned with a joint distribution routing problem for multi-distribution warehouses, which is particularly interesting in the city and town logistics context in several trips where customers are located in cities within a certain region. The aim of this work is to solve a real-world joint distribution routing problem for two companies operating in the State of North Carolina such that the total distance traveled by multiple vehicles is minimized while satisfying distance and transport vehicle capacity constraints.

In this paper, we consider two companies each with extensive route network for the distribution of packaging and janitorial items in a local area. The products that both companies distribute are similar, and though each company has its own distribution route structure. Both companies operate within the same jurisdiction of Central North Carolina. Company A has a warehouse located in Colfax, North Carolina while company B has a warehouse located in Graham, NC. Each company has distribution network for serving customers in towns and cities within a seventy-five mile radius. Each route consists of specified towns or cities to which products are distributed on daily or weekly basis. It could be a single trip from the warehouse to a town or city and back to the warehouse, or a trip from the warehouse through multiple towns and cities and back to the warehouse to be re-loaded before starting another service trip. Both companies are planning to merge their operations. This will create an extensive route structure and therefore, require a route analysis to determine if the process could be streamlined, and whether it is cost effective to use vehicles with specific load capacity for the delivery once their operations are merged in order to reduce the overall transportation cost. We primarily focus on the development of general models to design a joint distribution network for both companies, and determine the geographic route a vehicle would travel through multiple towns and cities to reach and serve set of customers in an attempt to achieve the goal minimizing total distance travelled.

The remainder of this paper is organized as follows: In Section 2, we briefly review the studies related to routing problem. In Section 3, we present a solution procedure for solving the problem. We illustrate our approach using a real case study of joint distribution vehicle routing is Section 4. Finally, we highlight the contributions and conclusions reached.

2. Literature Survey

A number of routing algorithms have been developed to solve the problem that can essentially be divided into two classes. In the first, simultaneous methods, solutions are determined by computing all feasible routes to satisfy distribution requirements, and then the route that collectively yields the lowest cost is selected. The problem with this method is the complex mathematical calculation that must be performed. The second type, sequential approaches, attempts to overcome the problems associated with simultaneous methods by either dividing delivery in to smaller geographical regions of customers that can be connected in a feasible route, or by constructing routes one at a time, adding contiguous links to a single route until distance and vehicle capacity constraints are reached.

Many exact, heuristic and metaheuristic approaches have been proposed to solve Vehicle routing problem [1]. Most successful solution methods for solving large vehicle routing and scheduling problems are based on local search. These approaches are designed for specific types of vehicle routing problems [2]. Gromicho et al [2] presented a framework for solving the problems that can handle a wide range of different types of vehicle routing problems. Cattaruzza et al. [3] proposed a hybrid genetic algorithm for the multi trip vehicle routing problem in which a set of geographically scattered customers have to be served by a fleet of vehicles. They introduced a local search operator based on the combination of standard VRP moves and swaps between trips.
Jin et al. [4] presented a parallel tabu search algorithm that utilizes several different neighborhood structures for solving the capacitated vehicle routing problem. Ribeiro and Laporte [5] presented an adaptive large neighborhood search heuristic for the cumulative capacitated vehicle routing problem is a variation of the classical capacitated vehicle routing problem in which the objective is the minimization of the sum of arrival times at customers, instead of the total routing cost. Subramanian et al. [6] proposed hybrid algorithm for the problem composed by an iterated local search (ILS) based heuristic and a set partitioning (SP) formulation. The SP model is solved by means of a mixed integer programming solver that interactively calls the ILS heuristic during its execution. Subramanian et al [7] proposed a hybrid algorithm for a class of vehicle routing problems with homogeneous fleet where routes found by a metaheuristic approach are solved, not necessarily to optimality, using a mixed integer programming solver.

Macedo et al. [8] propose an exact iterative algorithm for the problem that relies on a pseudo-polynomial network flow model where nodes and arcs represent time instants feasible vehicle routes respectively. Baños et al. [9] proposed a pareto-based hybrid algorithm that combines evolutionary computation and simulated annealing for solving multi-objective formulations of the Capacitated Vehicle Routing Problem with Time Windows.

A capacitated distribution routing problem is one of the important problems in distribution and supply center management. The only published article that addresses the distribution routing problem proposed a method based on a three-step. First, a sector clustering model is developed to transfer the multi-supply center problem to single supply center problems which are easier to be solved, second a vehicle routing model with time constraints is developed and then a genetic algorithm was developed [10] (Hwang, 2005).

No attention was devoted to the capacitated distribution routing problem for combined distribution of different companies. This paper addresses this problem and presents solution procedure that quickly leads to a good solution for constructing feasible capacitated vehicle routes used for comparative analysis.

3. Proposed Closest-First Route-Finding Approach

Due to the complex nature of route structure and product variability and for quick route finding, the closest-first route-finding (CFRF) approach is presented here for solving distribution routing problem and compare the results with ones obtained using IP-CVR approach. The CFRF is a heuristic-based approach that resembles the most widely-known form of depth-first search, it prefers to follow a single path all the way from starting node/city. However, CFRF approach evaluates nodes/cities by determining how far a node/city is from the preceding nodes/cities while stratifying capacity constraints.

The CFRF is a straightforward approach tries to expand the node/city that is closest to a warehouse, and then continue expanding node/city closest to the preceding one while accumulating the volume of items delivered to the expanded cities such that the total volume must not exceed the vehicle's load capacity. It therefore, attempts the closest city/node first to guide problem-solving process. On the ground, this is likely to lead to a quick solution while satisfying load capacity constraint. The key steps and the basic structure of CFRF approach are outlined in Figure 1 whereas the detailed steps of the CFRF approach are defined formally in the next section

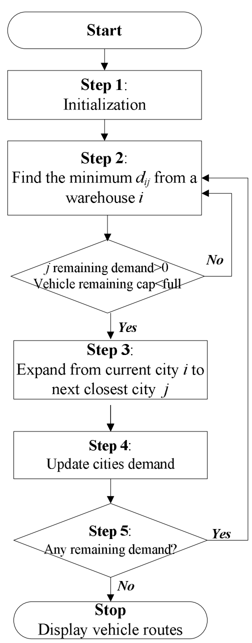


Figure 1. CFRF Overall Steps

<u>CFRF Heuristic</u>

Given:

- set of cities I served by the companies, each city $i \in I$ *and* $i = 1, 2, \ldots, I$
- set of warehouse cities W, each warehouse city $i \in W$ and $W \subset I$
- set of vehicles V and load capacity l_k of each vehicle $k \in V$ *and* $k=1, 2, .., V$
- demand volume m_i for each city $i \in I$ served by the warehouses of the companies

***Step 1*: Initialization:**

- the distance d_{ij} between each city i and all cities j_s $\forall$ i *and* $j \in I$
- the total demand M of all customers in all cities $i_s \in I$

Step 2: A reasonable thing to try first is the city with shortest distance travelled from one of the warehouses. Find the minimum distance travelled d_{ij} from a warehouse i to city j.

Step 3*:* City j will be the first city to be expanded from to construct a distribution route structure. The next city to be expanded to will be the closest one to city j and has a remaining demand. The route total volume TV, is computed by accumulating the demand of the cities visited. We repeat this step until the total volume of the route reaches the maximum vehicle's load capacity l_k. A demand cannot be partially delivered in case of the remaining vehicle's load capacity is less than demand of the next city to be expanded to.

It turns out this strategy of adopting the most widely-known form of depth-first search is more than just reasonable.

Step 4: Update the demand of all cities visited.

- If the demand of city j is fully delivered then updated $m_j = 0$

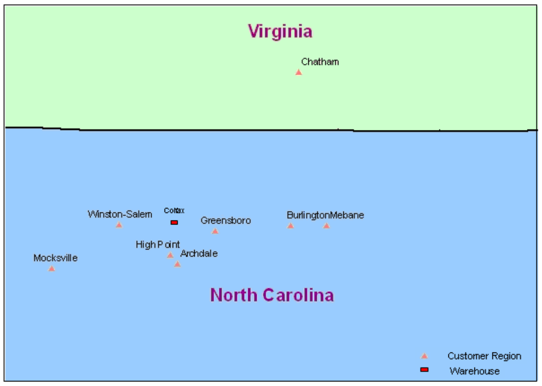
Step 5: Check termination condition

- If $\sum_{i=1}^{I} m_i = 0$, then **Stop** else repeat **Steps 2 to 5** until the termination condition is met

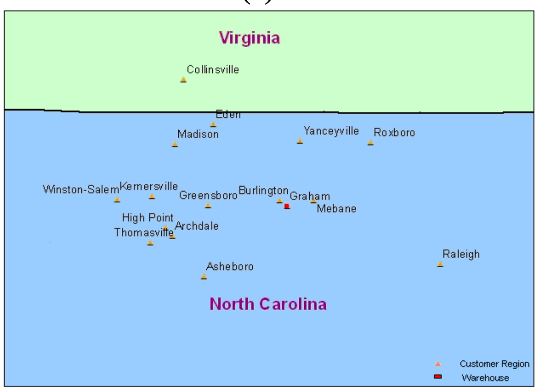
4. Joint Distribution in Supply Chain: Case Study

This case study considers two companies, each with extensive route network for the distribution of packaging and janitorial items in a local region. The products that both companies distribute are similar, and though each company has its own distribution route structure, both companies operate within the same jurisdiction of Central North Carolina. Company A has a warehouse located in Colfax, NC while company B has a warehouse located in Graham, NC, both warehouses serve towns and cities within 75 miles radius in Central North Carolina. The distribution networks of cities served in North Carolina and Virginia states by individual companies are shown in Figure 2. Furthermore, the combined distribution network of all cities served jointly in North Carolina and

Virginia states by both companies are shown in Figure 3.



(a)



(b)

Figure 2. Distribution network of Cities served in NC and VA states by (a) Company A (b) Company B

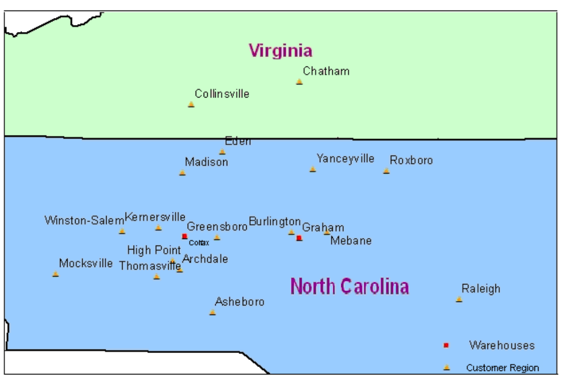


Figure 3. Combined network for customers in NC and VA States served by both Companies

Each company has routes for distributing products to customers that consists of specified towns or cities to which products are distributed on daily basis. A route could be a single trip from the warehouse to a town or city and back to the warehouse, or a trip from the warehouse through multiple towns and cities and back to the warehouse. Both companies use 27ft-truck with total load capacity of 2650 ft^3 to distribute products to customers.

The two companies, A and B, are planning to merge their operations. This will create an extensive route structure and therefore, require a route analysis to determine if the process could be streamlined and whether it is cost effective to use trucks for the delivery once their operations are merged in order to reduce the overall transportation cost. Furthermore, the two companies are also planning to maintain both warehouses for the first 12 months after merger. That requires developing distribution network for the joint operations of the two companies, and solving the vehicle routing problem based on conducting their operations from two warehouses in Colfax and Graham city using 27ft-truck.

However, after 12 months the two companies will conduct all their operations from a single warehouse. That also requires developing distribution network for the combined operations of the two companies, and solving the capacitated vehicle routing problem, but based on two possible scenarios: (a) Using 27ft-truck from company A warehouse in Colfax city; (b) Using 27ft-truck from company B warehouse in Graham city.

Therefore, three different vehicle routing case problems are to be considered and solved using the two proposed approaches, IP-CVRM, and CFRF for comparative analysis. To determine the distribution network and routes for conducting the joint distribution operations for the first year using the two warehouses, and after the first year using a single warehouse. The total distance travelled and associated transportation cost are calculated and discussed in the following sections.

5. Computational Work

This research is to design a joint distribution network, and to define vehicle routes for the joint distribution operations of merged companies to determine an approximate minimum distance travelled required for distributing products to customers in different cities while considering vehicle's load capacity constraints. Given a set of 19 cities and towns served by 2 warehouses located in two different cities, Colfax and Graham, the vehicle's load capacity l_k which is 2650 ft^3 for the 27ft-truck. In addition to a list of products and their unit volumes, total volume of demand v_i for each city i, total weekly demand of each item to each city, and transportation cost per mile for the vehicle, we solved the three vehicle routing case problems using the two proposed approaches.

The distances d_{ij} between the set of 21 cities are given in Table 2. Furthermore, The total volumes of 27 items demanded by each city or town are summarized in Table 3.

Table 2. From-To Distances Chart

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
From \ To		**Archdale**	**Asheboro**	**Brown Summit**	**Burlington**	**Chatham**	**Colfax (*WH*)**	**Collinsville**	**Eden**	**Graham**	**Graham (*WH*)**	**Greensboro**	**High Point**	**Kernersville**	**Madison**	**Mebane**	**Mocksville**	**Raleigh**	**Roxboro**	**Thomasville**	**Winston Salem**	**Yanceyville**
1	**Archdale**	-	19.3	29.0	37.6	81.6	15.5	63.0	53.5	39.0	39.0	17.2	3.6	19.4	37.0	47.9	39.7	96.1	82.1	10.5	26.0	57.0
2	**Asheboro**	19.3	-	39.2	46.9	91.7	36.6	81.8	63.6	48.9	48.9	27.2	22.8	39.8	56.2	57.2	47.5	71.4	91.5	27.2	49.8	67.2
3	**Brown S.**	29.0	39.2	-	22.7	54.0	28.6	45.7	26.0	32.9	32.9	12.4	29.2	31.4	26.3	41.9	65.3	90.0	50.9	36.8	41.4	27.4
4	**Burlington**	37.6	46.9	22.7	-	60.5	34.3	58.6	38.9	3	3.1	24.0	39.7	40.7	49.9	10.2	74.6	62.3	36.1	47.3	50.7	27.7
5	**Chatham**	81.6	91.7	54.0	60.5	-	82.0	35.9	37.9	61.3	61.3	66.0	82.7	84.9	58.6	60.1	118.9	104.0	46.7	90.4	95.0	33.1
6	**Colfax (*WH*)**	15.5	36.6	28.6	34.3	82.0	-	50.1	36.9	37.3	37.3	10.0	17.0	3.5	24.4	44.5	39.4	94.4	80.4	23.2	15.3	56.6
7	**Collinsville**	63.0	81.8	45.7	58.6	35.9	50.1	-	20.4	75.1	75.1	51.0	58.8	48.6	28.5	71.7	80.9	115.7	65.4	79.5	56.7	44.7
8	**Eden**	53.5	63.6	26.0	38.9	37.9	36.9	20.4	-	41.8	41.8	36.8	53.5	35.5	15.5	48.9	67.8	101.0	54.8	61.1	43.6	33.3
9	**Graham**	39.0	48.9	32.9	3.1	61.3	37.3	75.1	41.8	-	1	24.0	39.3	40.3	49.4	9.6	74.2	57.8	35.9	47.0	50.3	27.5
10	**Graham (*WH*)**	39.0	48.9	32.9	3.1	61.3	37.3	75.1	41.8	1	-	24.0	39.3	40.3	49.4	9.6	74.2	57.8	35.9	47.0	50.3	27.5
11	**Greensboro**	17.2	27.2	12.4	24.0	66.0	10.0	51.0	36.8	24.0	24.0	-	17.3	18.8	25.6	32.2	52.7	80.4	66.4	24.9	28.8	40.5
12	**High Point**	3.6	22.8	29.2	39.7	82.7	17.0	58.8	53.5	39.3	39.3	17.3	-	13.5	33.0	48.3	41.6	96.5	82.5	8.5	20.2	57.4
13	**Kernersville**	19.4	39.8	31.4	40.7	84.9	3.5	48.6	35.5	40.3	40.3	18.8	13.5	-	23.0	49.0	34.7	97.2	83.3	20.0	10.5	59.4
14	**Madison**	37.0	56.2	26.3	49.9	58.6	24.4	28.5	15.5	49.4	49.4	25.6	33.0	23.0	-	58.0	54.9	106.2	63.7	53.6	30.7	42.3
15	**Mebane**	47.9	57.2	41.9	10.2	60.1	44.5	71.7	48.9	9.6	9.6	32.2	48.3	49.0	58.0	-	82.9	50.4	30.1	55.6	59.0	26.7
16	**Mocksville**	39.7	47.5	65.3	74.6	118.9	39.4	80.9	67.8	74.2	74.2	52.7	41.6	34.7	54.9	82.9	-	131.0	117.1	29.6	25.0	93.2
17	**Raleigh**	96.1	71.4	90.0	62.3	104.0	94.4	115.7	101.0	57.8	57.8	80.4	96.5	97.2	106.2	50.4	131	-	52.2	104.1	107.4	70.6
18	**Roxboro**	82.1	91.5	50.9	36.1	46.7	80.4	65.4	54.8	35.9	35.9	66.4	82.5	83.3	63.7	30.1	117.1	52.2	-	89.9	93.2	22.0
19	**Thomasville**	10.5	27.2	36.8	47.3	90.4	23.2	79.5	61.1	47.0	47.0	24.9	8.5	20.0	53.6	55.6	29.6	104.1	89.9	-	19.8	65.0
20	**Winston S.**	26.0	49.8	41.4	50.7	95.0	15.3	56.7	43.6	50.3	50.3	28.8	20.2	10.5	30.7	59.0	25.0	107.4	93.2	19.8	-	69.7
21	**Yanceyville**	57.0	67.2	27.4	27.7	33.1	56.6	44.7	33.3	27.5	27.5	40.5	57.4	59.4	42.3	26.7	93.2	70.6	22.0	65.0	69.7	-

Table 3. Aggregated total demand

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
City	**Archdale**	**Asheboro**	**Brown Summit**	**Burlington**	**Chatham, VA**	**Colfax**	**Collinsville, VA**	**Eden**	**Graham**	**Greensboro**	**High Point**	**Kernersville**	**Madison**	**Mebane**	**Mocksville**	**Raleigh**	**Roxboro**	**Thomasville**	**Winston Salem**	**Yanceyville**
Volume (ft^3)	653.8	108.6	106.8	1187.1	440.5	0	213.2	106.8	213.2	973.8	1414.4	106.8	106.8	653.8	881.1	1490.8	213.2	106.8	653.8	106.8

We solved the three vehicle routing case problems using the proposed CFRF approach. The solution procedure developed in section 3 is employed to guide the problem-solving process. CFRF approach leads to a quick solution for constructing feasible vehicle routes.

To illustrate how CFRF approach works for vehicle-routing problem, we consider the first case problem of conducting distribution operations from the two company warehouses in Colfax and Graham cities using 27ft-truck. We will need to know the distances d_{ij} between the set of cities I, which are initialized in step 1 as given in Table 3. For example, the distance between Graham and Asheboro d_{92} is 48.9 miles.

In step 2, the shortest distance from the two warehouses is from Graham warehouse to the same Graham city. The first vehicle route begins from Graham to Graham city itself as the first segment on this route and, therefore, Graham city will be the first city to be expanded from to proceed in constructing the distribution route structure.

According to the first vehicle routing case problem, a 27ft-truck is used which has maximum load capacity of 2650 ft^3 whereas the total demand of Graham city is 213.2 ft^3 (refer to Table 3). Thus, the first route will be used for fully delivering Graham's demand and that reduces the remaining demand of Graham to zero. Since the full vehicle load capacity was not reached and there are still 2436.8 ft^3 remaining, we can expand to more cities before the vehicle returns back to the Graham Warehouse. Next, we can look into Table 2 for the closest city to Graham. Table 2 shows that Graham is the closest city to Burlington (3 miles away) than the two warehouses in Colfax and Graham cities (34.3 and 3.1 miles away respectively). The total demand of Burlington city is 1187.1 ft^3 (refer to Table 3) which is less than the remaining load capacity of the 27-ft truck. Thus, we expand to Burlington city at which the total route volume becomes 1400.3 ft^3 and that reduce the remaining load capacity of the truck to 1249.7 ft3. It can be expanded to the next closest city if Burlington is the closest city to it, and its total demand is greater than zero and less than the remaining vehicle's load capacity to be fully delivered. Looking into Table 2, Mebane city is the closets one to Burlington, 10.2 miles away. However, Mebane city is just 9.6 miles away from Graham warehouse. Therefore, it cannot be expanded from Burlington to more cities as expanding to Mebane city from Graham warehouse would be with less distance travelled. Then, the route total volume (TVR) is determined to be 1400.3 ft^3.

Now we can proceed to step 4, and by updating the demand of the visited cities and computing the total demand. In step 5, we find that the termination condition is not satisfied as the sum of remaining demand values is greater than zero, and that leads to repeat steps 2-5. Repeating step 2 and 3 Colfax warehouse to Kernersville has the shortest distance of 3.5 miles. Then it will be the city to be expanded to from Colfax warehouse. The Kernersville city demand of 106.8 ft^3 will be fully delivered and that will reduce the vehicle load capacity to 2543.2 ft^3 which may allow to expand to the next city if Kernersville is the closest city to it, and its total demand is greater than zero and less than the remaining vehicle's load capacity to be fully delivered. Kernersville is the closest city to Winston Salem (10.5 miles away) than the two warehouses, the demand of Winston Salem is 653.8 ft^3 as a result this route can expand from Kernersville to Winston Salem and remaining vehicle's load capacity becomes 1889.4 ft^3. Again, the remaining load capacity may allow expanding to the next cities if Winston Salem is the closest city to it, and its total demand is greater than zero and less than the remaining vehicle's load capacity to be fully delivered. By following the same procedure, the route continues to expand from Winston Salem to Thomasville to High Point. Including High Point demand that fully delivered using this route, the remaining vehicle's load capacity becomes 368.2 ft^3. Considering Archdale city, High Point city is the closest city to Archdale than the two warehouses, however, Archdale demand volume is 653.8, which exceeds the remaining vehicle's load capacity. Therefore, this route will stop expanding at High Point city and the route total volume (TVR) becomes 2881.82 ft^3. We update the demand of the visited cities and compute the total demand in step 4. The termination condition in step 5 in turn is not satisfied yet as the sum of total volume of the remaining demand is greater than zero, and that leads to repeat steps 2-5. For the next repetitions, we keep repeating steps 2-5 using the same procedure until all cities are visited and demands are fully delivered.

Figure 4 shows the progress of CFRF search for constructing feasible vehicle routes as solution to the first vehicle routing case problem. Moreover, the graphical representation of the solutions to the second and third vehicle routing case problems are given in Figures 5 and 6. Whereas a summary of the solutions to the three case problems including the number of routes, number of trips on each route, and total distance travelled for each vehicle routing problem is given in Table 4.

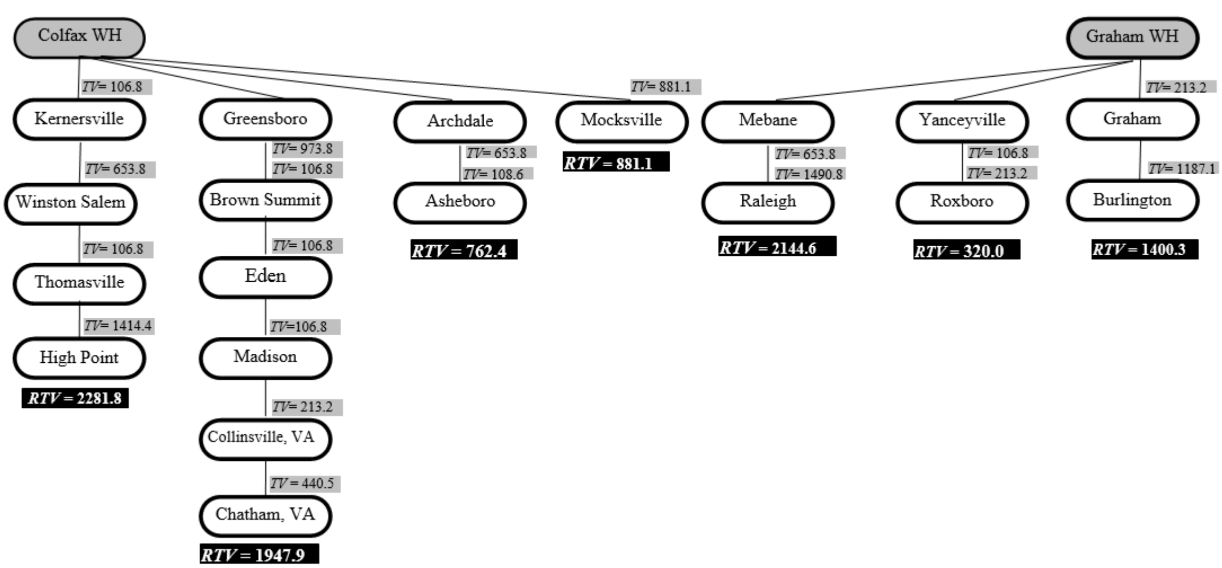


Figure 4. CFRF Route Solution to Case Problem 1: Using *warehouses in Graham and Colfax (first 12 months).*

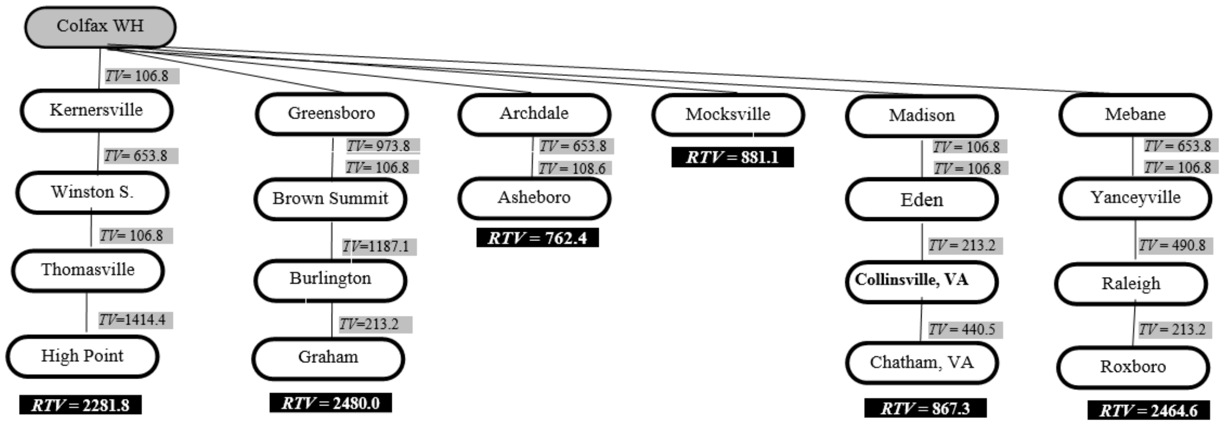


Figure 5. CFRF Route Solution to Case Problem 2: *Using Colfax warehouse (after the first 12 months)*

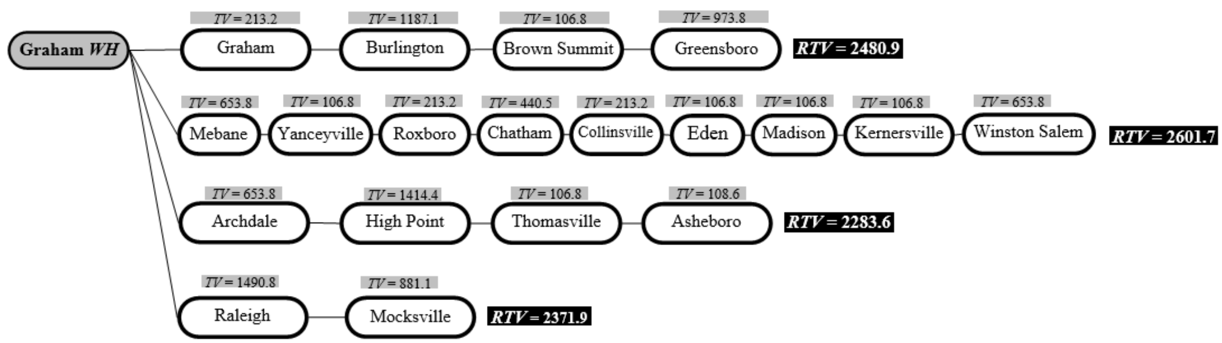


Figure 6. CFRF Route Solution to Case Problem 3: *Using Graham warehouse (after the first 12 months)*

Table 4. Summary of the solutions to the three Vehicle routing case problems

Case Problem No.	No of Routes	No of Trips	Total Distance Travelled
1	7	7	358.4
2	6	6	471.6
3	4	4	516.6

6. Conclusion

This paper addressed the problem of transport vehicle routing of joint distribution of different companies that distribute similar products and operate within the same region with extensive route network for the distribution.

The paper described the development of the closest-first route-finding (CFRF) approach as a promising heuristic-based solution procedures resemble the most widely-known form of depth-first search, which is used to guide problem-solving process, and quickly leads to a good solution for constructing capacitated vehicle routes.

The solution procedures of CFRF method developed in this research was experimented using a case study as an application scenario that includes three real case problems for illustrating the applicability and suitability of the proposed approach. The capacitated transport vehicle routes obtained as a final solution reflected the accuracy of the CFRF solution procedures.

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