

# Optimization of Vehicle Routing in Simultaneous Pickup and Delivery Service: A Case study

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## ABSTRACT

*In this case study, considered the vehicle routing problem with pickup and delivery which is a generalization of the capacitated vehicle routing problem (CVRP). The vehicle routing problem with pickup and delivery (VRPPD) arises whenever pickup demand and delivery demand is to be satisfied by the same vehicle. The problem is encountered in many real life situations. In this paper problem arises from the distribution of beverages and collection of recyclable containers. It can be modeled as a variant of the vehicle routing problem with a heterogeneous vehicle fleet, capacity and volume constraints, and an objective function combining routing distance or minimizing the total travel distance to serve customers located to different locations. Three construction heuristics and an improvement procedure are developed for the problem and designing a set of routes with minimum cost to serve a delivery of beverages and a collection of recyclable material with a fleet of vehicles. The aim of this paper is to develop a vehicle routing Problem (VRP) model that addresses simultaneous pickup and delivery in the beverage distribution. To this effect, a mathematical model is adopted and fitted with real data collected from MOHA Soft drinks Summit Plant located in Ethiopia, and solved using Clark-Wright saving algorithm. The form-to-distance is computed from the data collected from Google Earth and the customer's data from the MOHA. The findings of the study show that the model is feasible and showed an improvement as compared to the current performances of the plant with respect to product distribution and collection and the total distance covered is minimized about 27.79%. The average performances of the model show that on average 5 routes are required to serve customers' demands.*

**Keywords:** *s. Vehicle Routing, pickup and delivery, Distance Coverage,*

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## 1. INTRODUCTION

Distributors' service routes were designed to fulfill orders from stores, bars, and restaurants. The sequences of the routes vary with the seasons. A variety of routes is used in each season to meet changes in demand. Vehicles serving the routes are constrained by time windows during which they must deliver the orders originating from customers. The vehicles are limited by the load capacity as designed by packaging sizes. Distribution system (DS) refers to the movement of finished goods outward from the central finished goods store to the customer, frequently via intermediaries. It subsumes the delivery of finished products to customers through the distribution networks. The activities within the distribution system include warehousing, transportation (often undertaken by third-party logistics providers), customer service and administration. A product may pass through a number of intermediate warehouses before reaching at customer or can also be sold directly to the customer from the central finished goods store. Therefore, a product can follow different distribution system in order to arrive at customer hand. Product delivery is the ability to manage distribution channels to ensure the timely delivery of products (beverages) to the customers and activities refers to choosing the distribution channel to deliver the products to the customers. Pick-ups of the Product logistic have three primary activities: managing cycle (waiting) time, managing product capacity, and providing product delivery. Managing waiting time refers to methods used to reduce the time customers must wait to consume the products i.e. to reduce order cycle time in the flow of goods. Product capacity is defined as the managing, scheduling, and staffing of people and products so that the product response logistics network can meet customer demands. The main purpose of this study is to develop a daily truck routing and scheduling model, which improves the delivery and pick-up efficiency of the company. The scheduling will be done in such a way that it can satisfy the orders (both pick-up and delivery), while in the meantime, will attempt to improve quality of service with

respect to distance and/or cost. This case study focus the routing optimization of any Beverage Company which need reverse logistics of recyclable materials which need to return to the plant for the re-filling of the beverage by applying particular variant of the VRP known as the pickup and delivery problem. The research mainly giving attentions to route optimization and vehicle assignments for respective destinations based on the minimum distance and cost of transportation with capacity constraints.

## 2. LITRATURE RIVIEW

The vehicle routing problem (VRP) is often described as the problem in which vehicles based on a central depot are required to visit a set of geographically dispersed customers in order to fulfill known customer demands. The objective is to construct a low cost, feasible set of routes – one for each vehicle. A route is a sequence of locations that a vehicle must visit along with the indication of the serve it provides. The vehicle must start and finish its tour at the depot (Marinakis and Migdalas, 2002). The vehicle routing problem (VRP) plays a central role in distribution management and has for a long time attracted attention in the field of Operational Research. The classic problem can simply be described as the problem of designing a set of routes from a depot to a set of locations. (Holborn, 2013). A Vehicle Routing Problem (VRP) can be considered as a m-TSP where a demand is associated with each city. In a VRP a number of vehicles are stationed at one or several depots and these vehicles need to visit a number of geographically dispersed clients. A specific set of routes for each of the vehicles has to be determined in order to serve all the clients. (Zhou, 2010). According to statistics, the fuel cost could take up about 50% of the total operation costs for any model of car and the ratio will intend to increase with the climb of international oil price undoubtedly (Yu and Wang, 2013). VRP aims at planning the routes of a fleet of vehicles on a given network to serve a set of clients under side constraints and a reasonable route plan could reduce the transportation cost and energy consumption effectively. (Zhifeng Langa, 2014). Given the large amount of published research tackling the various types of VRPs it becomes increasingly difficult to keep track of all problem types and underlying solution methods. However, a general classification of the basic routing and scheduling problems and their interconnections is shown in Figure 1.

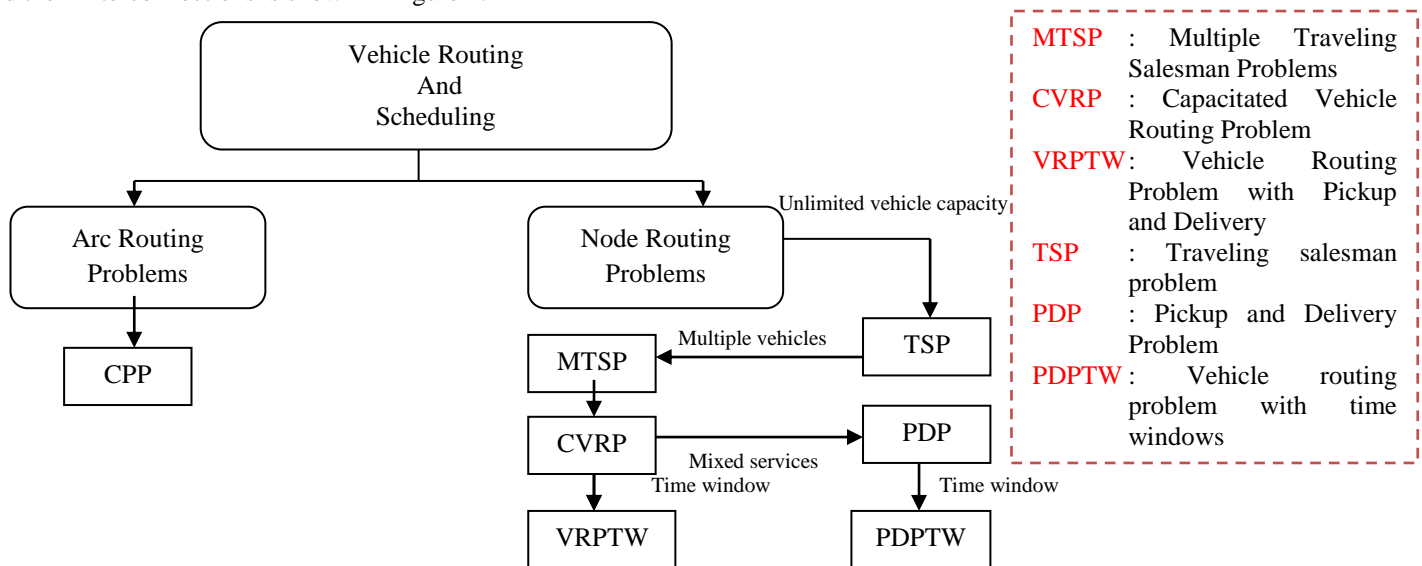


Figure 1: Vehicle routing and scheduling problems

Two main problem categories are distinguished in this figure 1, based on the observation that routing and scheduling problems are usually represented as graphical networks, in which pickup and/or delivery points are represented as nodes connected with line segments called arcs. The first category is called node routing problems, in which the service demand is associated with nodes (locations). The second category is called arc routing problems, in which the service demand is associated with the arc connecting two nodes. (Gendreau, 2005). The Vehicle Routing Problem with Pickup and Delivery (VRPPD) is a variant in which the possibility that customers return some commodities is contemplated, so it is necessary to take into account that the goods that customers return to the delivering vehicle must actually fit into that vehicle. (El-Sherbeny, 2010). The VRP with pickup and delivery (VRPPD) is a variant of the VRP where each request is defined by a pickup location and a corresponding delivery location. (Bräysy, 2005). In the Vehicle Routing Problem with Time Windows (VRPTW), there is an additional restriction that states that customer  $v_i$  has to be served within a specific time window. This interval is always within the scheduling horizon: the bounds of the time window of the depot:  $[ev_0, lv_0]$ . The definition of the feasibility constraints of the VRP is extended with the notion that each customer should be served within the bounds of its defined time window (Takes, 2010). The extension to the VRP is the capacitated VRP (CVRP) in which a vehicle capacity constraint is imposed. This ensures that at any point in time the loads of all items present within a vehicle cannot exceed the capacity of that vehicle. Depending on the vehicle capacity and loads to be carried, this constraint could limit the number of requests that can be serviced by each vehicle. (Holborn, 2013)

## 3. METHDODOLOGY

The study addresses the existing product distribution and its performance based on secondary data. Related operation and finance is examined to evaluate the nature of the problem affecting the existing network or routes and number of vehicles assigned to each route. Based on the existing routes and by considering the number of boxes of beverages in each route, an improved model is

adopted to serve in an optimum way customers in a given route. The improvement made was analyzed against the current performances of the enterprise. This approach provides an improved solution for MOHA soft drinks in Summit plant to serve the customers' demand within the improved routes. Finally, based on considerations of simultaneous pickup and delivery, the distance between the origin-destination of routes, a new model is developed for one of summit distribution center. The solution of the new VRP model may propose new routes which may be different from the existing one. If the improvement is significant, any beverage company that operates by distributing products and collecting empty bottles can adopt it through time to implement the findings of this model. In a real situation, the distances should be the actual mileage travelled by vehicles in the distribution operations. Since the distances can be measured easily on a road map, although this is very time-consuming and could not be undertaken for large applications it is computed by taking the approximate longitude and latitude of origin-destination of each route in summit depot. This is because the adopted model is designed to minimize the distance traveled. The research framework of this paper is designed based on consideration of the concepts of different theories, VRP/SDPVRP models and real-world situation in beverage industries. The following assumptions are also considered in designing the research framework is shown in Figure 2. The Framework of the VRP software as shown in Figure 3.

1. The customers demand at each route (delivery and pick up) of the given depot was collected. This help to model the need of demands at each node or customer destination.
2. The number of routes and their characteristics, the number of vehicles used to distribute products and collect recyclable materials, the number of products per route are collected from the route performance report of the given company.
3. The current operational and financial performances of the case company were analyzed; and an LP model was developed for the existing system to determine the optimum number of vehicles for each route and time period or shift.
4. The capacity of the vehicles (during route selection and assigning of vehicles) has also been taken under consideration. Each vehicle can carry an optimum number of beverages with their cases.
5. By considering the nature of customers a new route was designed with SDPVRP approach that can take into consideration of real simultaneous pickup and delivery of beverage products.

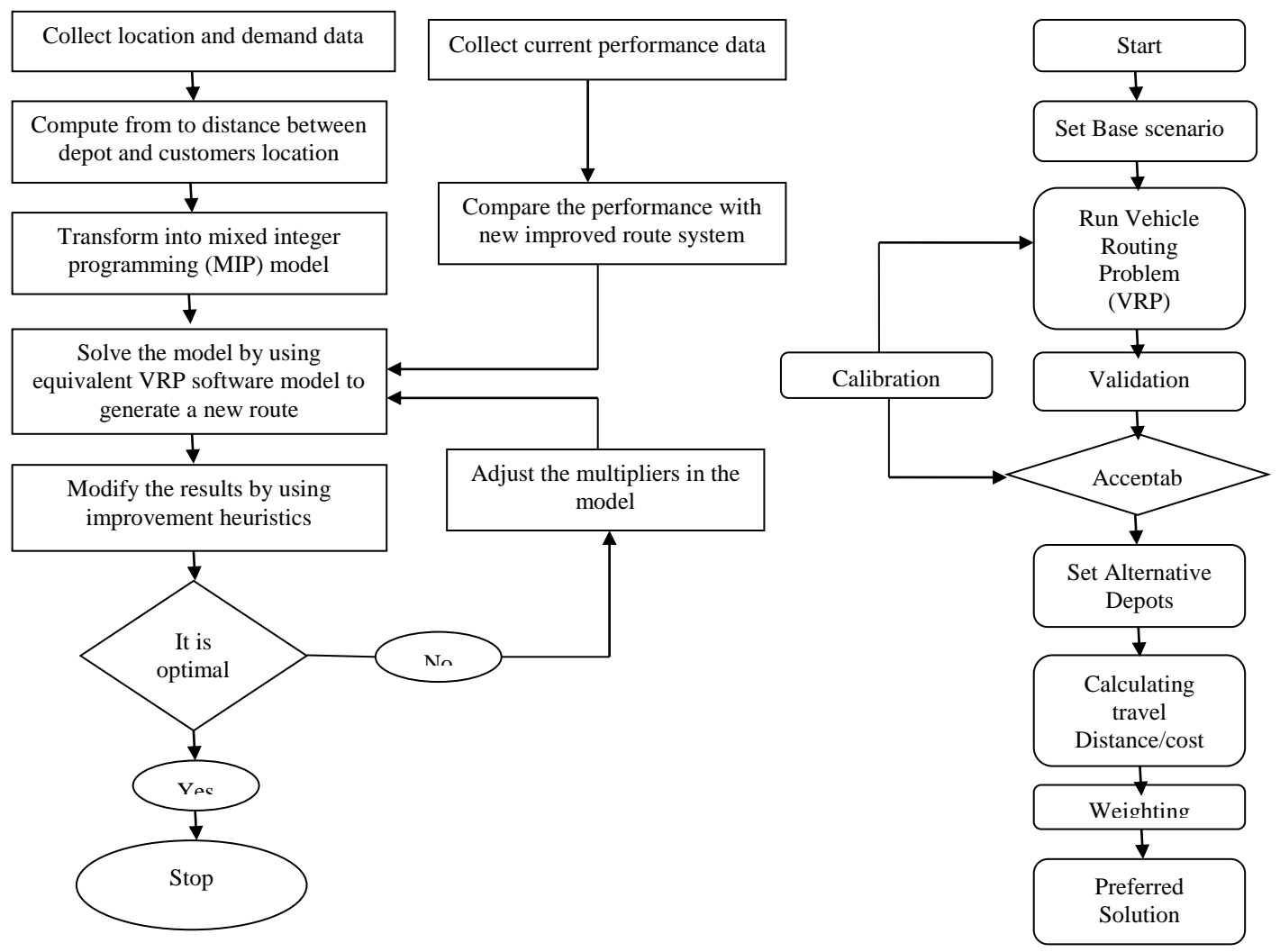


Figure 2: Frame work of the Stud

Figure 3: Framework of the VRP soft ware

The methodology employed different approaches to achieve its objectives. The following methodologies are used to secure both the quantitative and qualitative and/or primary and secondary data. Necessary data are then either collected or simulated

depending on their availability. This may include generation of simulation data from the already available data. The different methodologies used in this paper are explained. In the literature review, different articles, proceedings, books, manuscripts, web-sites and other materials were surveyed in order to assess the state-of-the-art of distribution problems together with vehicle scheduling models and different variants of VRPs. The literature review examined different working models and algorithms and modified them to suit the considered distribution nature of the beverage company. For the purpose of this thesis, the theory of VRP with some of its major variants were also surveyed so as to identify the appropriate model that can best serve the context of case company, such as, nature of demand, and vehicle types. Apart from the literature review, various secondary data which are relevant to the study were also collected from the case company to validate the model. The primary data are a real-life instance of VRPSDP originating from the case company to validate the model, interviewing the responsible persons from the distribution department of the case company and direct Observation of the company distribution activities. In order to test and simulate the models developed, secondary data were collected. The secondary data required are the current routes, the number of delivery beverages and pick up recyclable materials in each route for a period of 6 months of year 2009 E.C. Simulation software such as MS-Excel and VRP software were used to simulate the demand distribution by giving the simulated demand, alternative solutions were generated. This was done by changing the different parameters of the model as well as the demand for different routes at different times on number of routes taking a unique or single distribution center as depot.

#### 4. MODEL DEVELOPMENT AND VALIDATION

The model development in this paper considers VRP with real simultaneous pickup and delivery at each customer locations considering as a node, the pickup and delivery demand at each point is determined. In this model formulation a generic a simultaneous pick-up and delivery vehicle routing problem (VRPSDP) is considered and especially in bottled drink routing problem, the delivery and pick-up system is based on a single depot so as to serve a set of customer with a homogeneous fleet of vehicle the customer also requests to pick-up of the empty box or packs of the drinks.

##### 4.1 Model Fitting

This paper considered summit Pepsi Plant as depot and routes that originate and finalized at summit plant depot are treated as customers locations point or vertex where delivering of beverages and pick up of recyclable materials are collected. Customers and depot:  $V = \{v_1; v_2. . . . . v_{36}\}$  is a set of nodes with node  $v_1$  denoting the depot, which is summit plant depot, and nodes  $v_2. . . . . v_{36}$  correspond to the locations of products to be delivered or collected These locations are origin-destination points from summit. It is assumed that all nodes, including the depot, are fully interconnected and there are customers required for both delivery and collection of goods except the depot. Demands: customers have demined demands for both beverage and recycle material with simultaneous customers demand for both delivery and pick up. Vehicles and capacity constraint: The vehicle has a limited capacity of  $Q = 120$  cases. If the total number of case (the cumulative of the difference between delivered and collected up that is  $d_i - p_i$ ) exceeds the vehicle capacity, route failure is said to be occurred. But no penalty cost assumed in this case. At each stop when  $d_i - p_i > 0$ , which indicates that more number of products are delivered than collected; decreasing vehicle capacity, then the vehicle capacity is updated to  $Q - (d_i - p_i)$  and  $(d_i - p_i)$  becomes the net demand at that node. Whereas when  $(d_i - p_i) < 0$ , which means more number of Products are collected than delivered; increasing vehicle capacity, then the vehicle capacity is updated to  $Q + (d_i - p_i)$  and the demand will be zero. Route: A route must start at the depot; visit a number of customer's location (nodes) and return to the depot. This assumption is very important during searching of possible routes that can minimize the total distance. Distance to be minimized: let  $A = (i; j): i, j \in V, i \neq j$  is the set of arcs joining the nodes and a nonnegative matrix  $C = \{c_{ij}: i, j \in V; I \neq j\}$  denotes the traveling distances between nodes  $i$  and  $j$ . Further, assumes the distance matrix  $C$  is symmetric and satisfies the triangular inequality. The from-to-distance of a sample of origin-destination are computed from the digital latitude and longitude data using great circle computation.

##### 4.2 Solving the model

The LP model developed is solved based on the average daily demand for the last 6 months in a single operating shift time. The daily customers' demand for the last 6 months was collected and then the average daily beverage demand of each month was computed. **Model input parameters** to run and test the model, different input parameters that have to be substituted to the model are required. These inputs are either collected or generated/computed. **Customer's demands** the customers' demand are collected from the distribution depart of the summit plant and the depot agents of the plant. The net customers' demand distribution is calculated by subtracting the number of collected recyclable material in box from the total delivered beverage number of boxes at each customer location. **From-To-distance matrix** the from-to-distance computational input parameters of each location is computed by taking the longitude and latitude location of each point using Great Circle distance formula that considers the circular nature of earth. Each  $c_{ij}$  is defined as the distance from  $i$  to  $j$ , which can be directly considered as the cost associated to transport the beverage and recyclable materials including depot 1. Further, it assumes the distance is symmetric, that  $c_{ij} = c_{ji}$  and  $c_{ii} = 0$ . The other inputs are the standard capacity of trucks to be considered in the model. The model considers a truck capacity of 6 in unit volume or 180cases of beverages. This capacity is determined based on the international allowable capacity of loading trucks with their dimension, although Summit PEPSI depot currently considers the capacity of trucks as 120 boxes of beverages or 4 in unit of volume which accounts 66.66% of utilization. The total operational trucks used for local product distribution inside Addis Ababa city around Bole sub-city is 18 trucks.

##### 4.3 Solution Approach



A heuristic procedure developed for the classical VRP has been extended to solve VRPSPD developed above. The heuristics adopted is Clarke-Wright algorithm. The Clarke-Wright algorithm is iteratively repeated for each node as a starting node with the objective of improving the quality of the solution. The following assumptions were considered during solving the model.

- All routes start and end at the node of origin, also known as depot.
- Each node visited exactly once by a vehicle.
- The cumulative demand along the route or demand at any node shall never exceed the vehicle capacity Q.
- All vehicles have the same capacity and are stationed at the node of origin.
- Split delivery is not permitted.
- Each vehicle makes exactly one trip.

The task is to determine a route for each vehicle so as to serve a set of nodes such that the total distance traversed is minimal. The initial solution using a Clarke-Wright algorithm is obtained using the following steps:

1. Select the warehouse as the central city.
2. Calculate the savings  $s_{ij}=c_{i1}+c_{j1}-c_{ij}$  for all pairs of cities (customers)  $i, j$  ( $i=1, 2, \dots, n; j=1, 2, \dots, n; i \neq j$ ).
3. Order the savings,  $s_{ij}$ , from largest to smallest.
4. Starting with the largest savings, do the following:

Using the Clarke-Wright savings algorithm, route is constructed by incrementally selecting passengers along the nodes until the cumulative number of customer demands reaches the vehicle capacity or all customers are visited. Initially each vehicle starts at the depot summit (v1) with full capacity ( $Q= 120$  cases) and set customers included in the tour. The algorithm selects the next customer to visit from the list of feasible locations and the capacity of the vehicle is updated before another location is selected. The vehicle returns to the depot (summit) when the capacity constraints of the vehicle is met or when all the customers are served at each location. Finally the total minimum distance  $C_{ij}$  is computed as the objective function value for the complete route of the vehicle.

#### 4.4. Model Output

The Clarke-Wright savings algorithm constructs complete tour for the first vehicle prior to the second starting its tour. The procedure continues until all the customers' locations are included in the tours or until all the demands are served. The first run of the algorithm terminates with 6 possible routes. Since the number of vehicles is not limited, it will be determined by the number of routes formed. The algorithm first solves the problem using the nearest saving heuristic to create sub cycles that are both delivery and pick-up feasible at each node with vehicle capacity  $Q = 120$  cases. This gives the following six routes:

- Route 1** : 1 → 2 → 12 → 13 → 10 → 19 → 17 → 1  
Distance Traveled = 4.59 Total number of boxes demand = 113
- Route 2** : 1 → 3 → 5 → 8 → 18 → 7 → 4 → 1  
Distance Traveled = 1.91, Total number of boxes demand = 108
- Route 3** : 1 → 6 → 1  
Distance Traveled = 0.99, Total number of boxes demand = 18
- Route 4** : 1 → 21 → 22 → 25 → 29 → 28 → 11 → 36 → 9 → 1  
Distance Traveled = 4.33, Total number of boxes demand = 118
- Route 5** : 1 → 16 → 15 → 14 → 20 → 24 → 27 → 26 → 1  
Distance Traveled = 6.28, Total number of boxes demand = 119
- Route 6** : 1 → 30 → 31 → 34 → 32 → 33 → 35 → 1  
Distance Traveled = 3.06, Total number of boxes demand = 112

It was observed that in the above route and data presented above all the six routes are feasible load in terms of vehicle capacity and can be used as a feasible solution. If route one is considered, the tours are formed from depot 1 and visit the last customer at location point 17 and returns back to the depot. The overall tour for route or sequence of travel is: 1 → 2 → 12 → 13 → 10 → 19 → 17 → 1. Along the tour, the vehicle carried 113 beverage cases and travels a total distance of 4.59Km. Total demand in each route is less than the vehicle capacity. The overall summary of a the first run shows that the trucks travel an average distance of 21.15 Km , carried 581 cases of beverages along the route; and the run was performed with 0.04 seconds of CPU time. The figure 4 and 5 shows that view of this run in comparison to the existing and improved solution.

#### 4.5. Solution Improvement

After having an initial solution based on Clark and Wright method, the local search improvement heuristics deployed based on (i) intra-route and (ii) inter-route operations to improve the solution. While applying the improvement heuristics, instead of choosing the best pairing of route at each step, randomly select a pair of routes so as not to be trapped locally and choose the best overall solution. Improvement local search heuristics known by their short hand notation of k-Opt or r-Opt and with a value of (k or r= 2or 3) popularly accepted. For the implementation of improvement heuristics the 2-Opt and Or-Opt heuristics are used.

##### 2-Opt

The 2-Opt operation is a way of improving an existing solution. It involves swapping a pair of edges between any four nodes to reduce the distance in the VRP and the objective function. The algorithm involves looping through all pairs of edges. The first switch that reduces the objective function is accepted and the loop is ended. The swaps could be between routes (inter routes) or within a route (intra route). If the swap is within a route then the total drop off amount in the route remains the same, however, the order in which the vehicles visit every customer is changed. If the swap is between routes then the total drop off amount in each route can change. The swaps with maximum gain are exchanged. The 2-opt algorithm basically removes two edges from the tour, and reconnects the two new sub-tours created. This is often referred to as a 2-opt move. The 2-opt method returns local minima in polynomial time. It improves the tour by reconnecting and reversing the order of sub-tour.

**Or-Opt**

As a modification of K-Opt and being of the subset of 3-Opt the Or-Opt algorithm on the other hand has an advantage over the 3-Opt. in 3-Opt it is must to reverse the direction of route and there is a possibility of obtaining infeasible solution whereas the Or-opt operator can keep the route direction and guarantee a feasible solution. Hence Or-Opt are part exchange of the 3-Opt operator i.e. a section of route/s (one, two or three continuous points) between two points. The best solution is selected and improvement heuristics are run on

**4.6. Model Validation**

The outputs of the model are then evaluated using different performance measuring parameters.

**Distance Coverage**

The average total distance covered per day per depot for the improved system is 146.2 kilometers; while for the existing system is about 105.3km per day per depots kilometers per day for six trucks. This shows a reduction of 27.79% in the daily distance coverage to serve the same number of customers. Total kilometer covered for the given depot one per day is the sum of kilometer covered during the given period of time. Figure 6 shows the total distance coverage of the current and the improved systems for a single depot.

**Operating Cost**

The improvements made were also validated using the different operating costs of the plant. Total daily operating cost for each route is the sum of operating cost for the given time. From the comparison shown in Figure 4 and 5, the finding show that the average daily operating costs for the existing systems is 27,301.6 ETB while for the improved systems is 15, 798.22 ETB. As shown in Figure 7, the improvements made by the new systems are achieved nearly in all the operating costs of the enterprise.

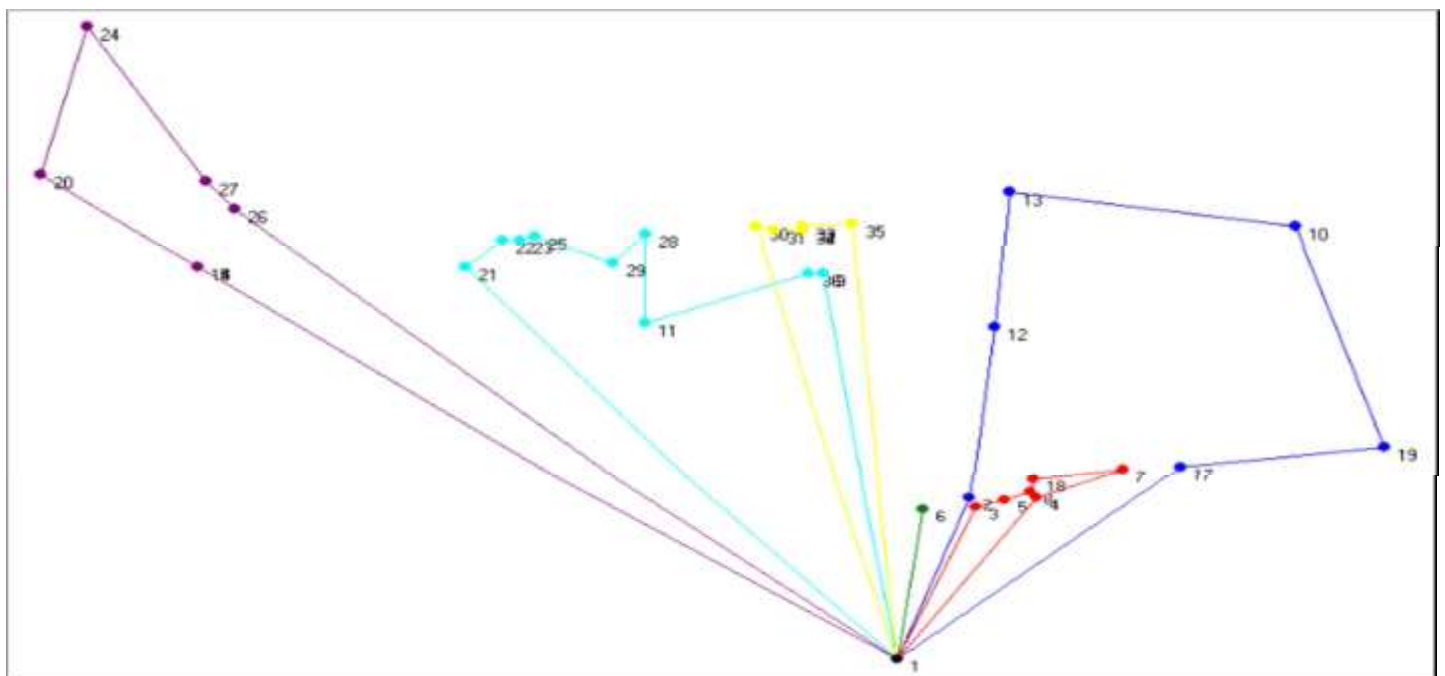


Figure 4: Graphical views of the existing model

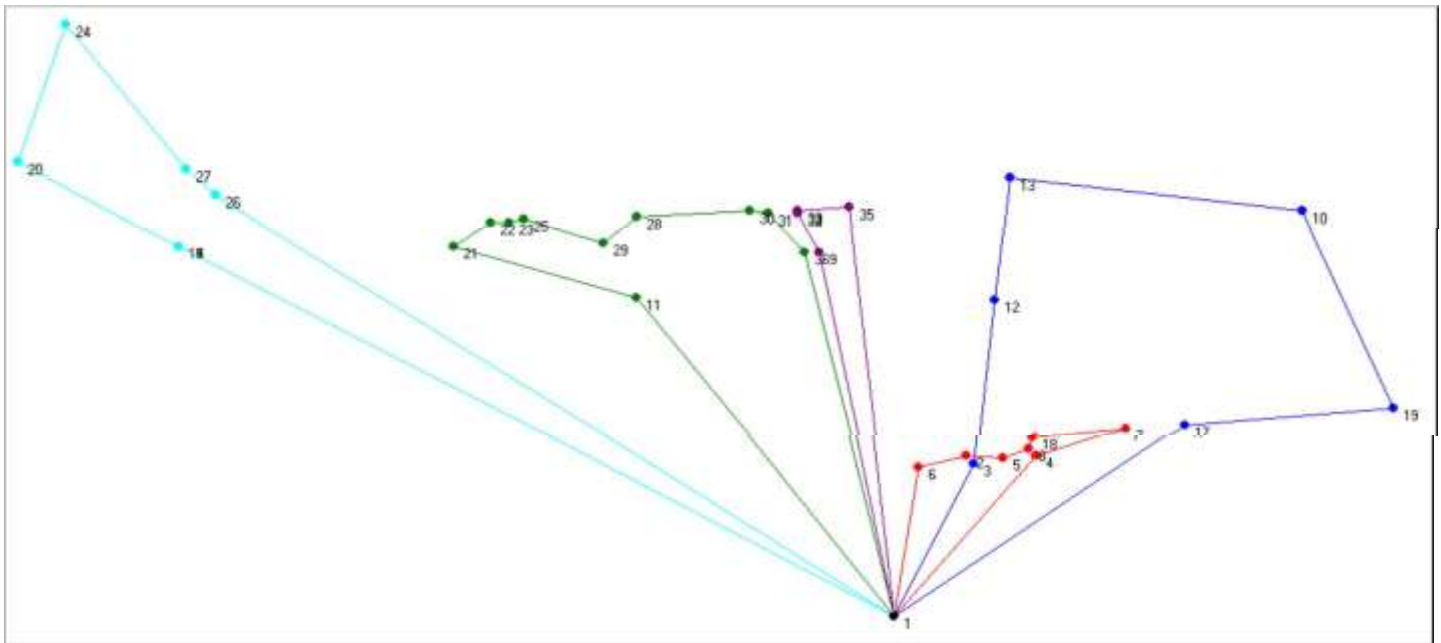


Figure 5: Graphical views of improved model

**Truck Utilization**

The average daily truck utilization of the existing and the improved systems are shown in Figure 8 the findings show that the improved system for the case depot has better truck utilization than the existing one. The average truck utilization for the improved systems is about 96.8% with less number of routes and for that of the existing systems is 80.69%. The existing systems have a maximum of about 16.14 % daily truck utilization. Table 1 show that the presentation of improved model.

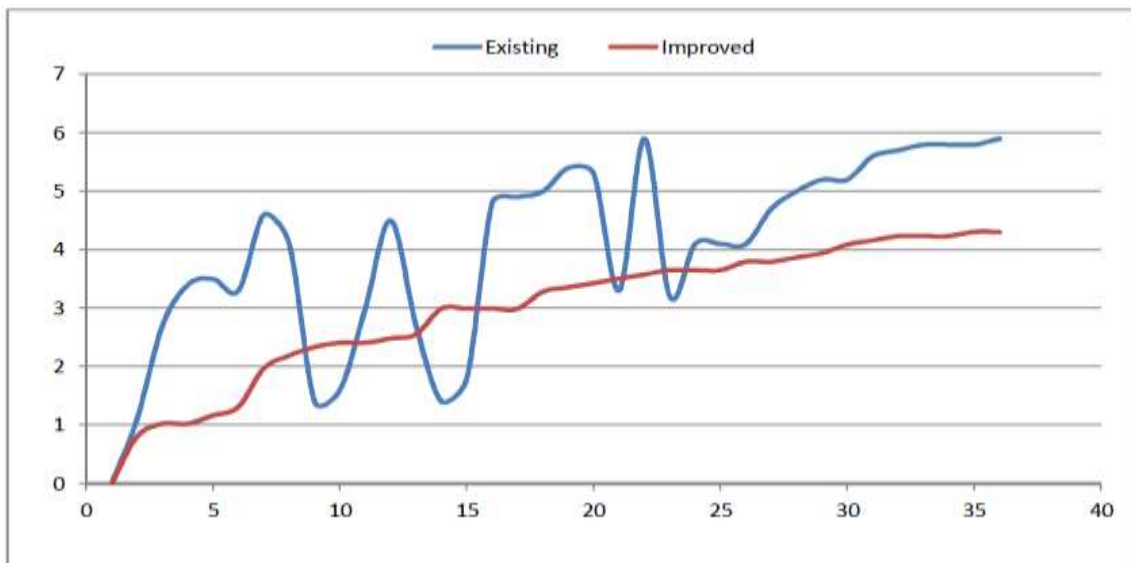


Figure 6: Comparison of existing and improved distance coverage

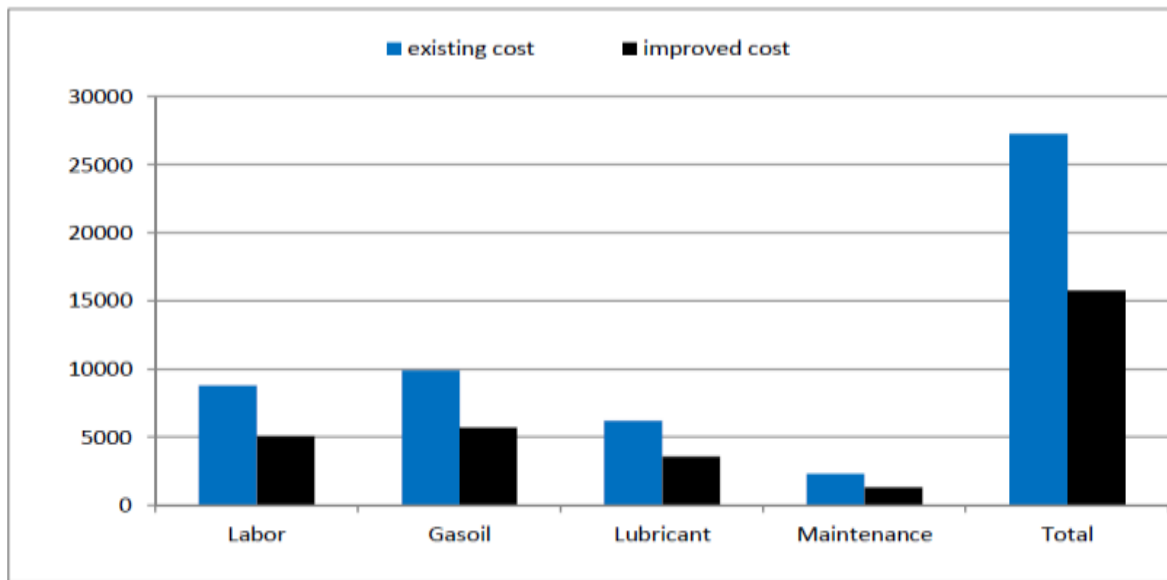


Figure 7: Operating cost of existing Vs improved system

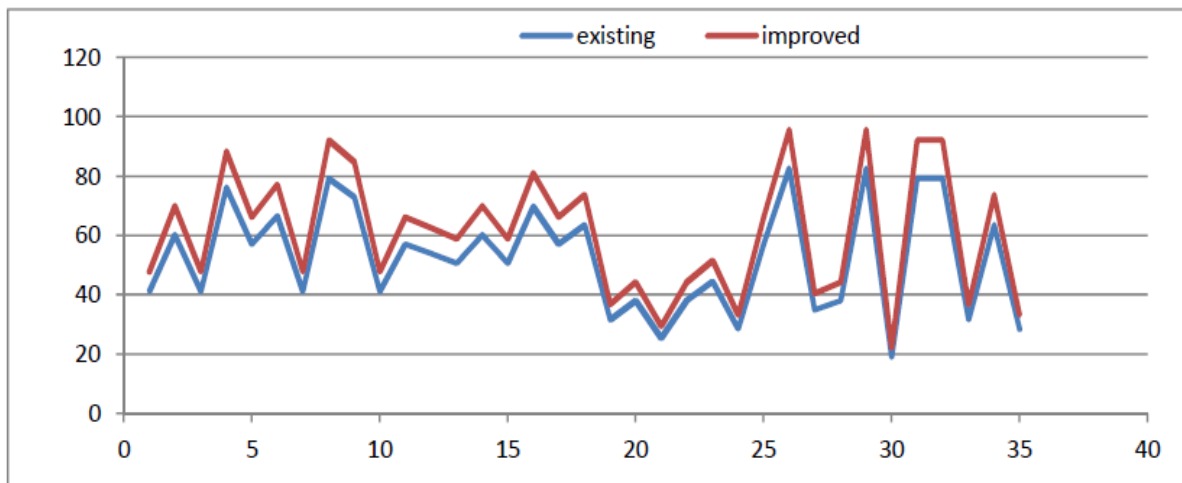


Figure 8: Truck utilization comparison of existing and improved system

Table 1: Tabular presentation of improved model

Route	Parameter	Route parameter									Total	
1	Tour	1 → 4 → 7 → 18 → 8 → 5 → 2 → 6 → 1										
	Demand	0	13	21	18	13	24	13	18	0	120	
	KM	0.66	0.26	02.5	0.04	0.08	0.10	0.14	0.49		2.02	
2	Tour	1 → 3 → 12 → 13 → 10 → 19 → 17 → 1										
	Demand	0	19	18	17	23	20	22	0		119	
	KM	0.55	0.55	0.40	0.81	0.71	0.57	1.60			4.6	
3	Tour	1 → 36 → 11 → 30 → 28 → 29 → 25 → 23 → 22 → 11 → 0										
	Demand	0	9	6	26	11	12	9	12	13	0	118
	KM	1.24	0.16	0.05	0.31	0.25	0.04	0.05	0.13	0.53	1.28	4.15
4	Tour	1 → 14 → 16 → 15 → 20 → 24 → 27 → 26 → 1										
	Demand	0	16	16	19	10	14	26	18	0	119	
	KM	1.73	0.13	0.05	0.04	0.23	0.13	0.27	0.48	0.04	1.23	6.28
5	Tour	1 → 35 → 33 → 34 → 32 → 9 → 1										
	Demand	0	20	25	10	25	25	0			105	
	KM	1.37	0.34	0.01	0.00	0.14	1.23	0			2.89	
Summary	(KM)	To Distance									19.94	
		Total customer demand									581	
		CPU time									0.12	



## 5. CONCLUSION

To solved a complex real-life problem arising in the distribution of beverages. A distinguishing feature of this problem is that vehicles must deliver goods and pickup recyclable materials at customer locations. To adopt model for this problem as a mixed integer program and also proposed three heuristics for its resolution. A construction heuristic and an improvement heuristics were developed. These were tested on a real-life case and on MOHA soft drinks summit plant with fifteen iterations and randomization. Results obtained on the real-life case show that a 27.97 % distance reduction can be achieved. Due to the minimized total distance for product distribution operations it reflects the minimization of the operation costs and the better utilization of resources. The findings of the study shows that the current scheduling system of MOHA soft drinks shows low performance on the truck utilization, operating cost and daily trips with respect to the standard. However the adopted model shows better improvement over the current system nearly with all the parameters of operating Costs. The current scheduling system has an average utilization of 80.69% while the improved system has 96.8% of utilization.

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