APPLICATION OF VEHICLE ROUTING IN A BREAD DELIVERY SYSTEM AT BAKERS INN 15TH AVENUE FACTORY IN BULAWAYO

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Abstract

This study involves designing a vehicle routing and scheduling system to improve the utilization of a fleet of delivery trucks at the same time reducing delivery costs in bread delivery. Data was collected from Bakers Inn 15th Avenue Bulawayo Bakery and the deliveries it made to 20 outlets around the city. A savings algorithm, co-joined with a neighborhood search, was adopted to solve the problem and LINDO software program was used to accelerate the computation of the costs and the routes with ease. The results were then compared with the current manual system at the company and it was found that the software-based vehicle routes improved performance and reduced cost indicating a major need for the manufacturing company to manage its supply chain well. Recommendations include immediate adaption of the software-based bread delivery system because the importance of vehicle routing was recognized.

Key words:

Supply chain, Delivery system, Vehicle routing, Savings based algorithm, Neighborhood search algorithm.

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1.0 Introduction

In the last 30 years, designing an efficient supply chain and operating the chain efficiently has become one of the most important issues for an increasing number of companies. The increasing economic challenges and pressure from competitors has forced manufacturing companies to devise better ways of controlling every step in their supply chain from their warehouses to customers. Delivery costs have a significant impact on the operating costs of the firm. On realization of this, many companies and practitioners are seeking new and better ways to gain competitive advantage over competitors in their distribution networks. Integration and organization of various aspects of distribution have become critical in reducing operational costs and increase efficiency. Due to recent fluctuations in the Zimbabwean economy, matching supply to demand has become even more challenging. Nowadays there is a growing need for more robust supply chains that are responsive to the changes in the market conditions. The usual models of supply chain management have strong assumptions, as a result, practitioners often disapprove them, among which is full knowledge of the underlying demand distribution. In most real world applications, scarcity demand data makes it very hard to determine a demand distribution that fits the observed data. This result in the logistics and inventory managers to make important decisions using partial or even inaccurate information such as inaccurate forecasts about future demands resulting in unnecessary measures been put in place. This ultimately has an overbearing effect on any organization, as it not only undermines the decision maker and researchers' capabilities but in loss of the so limited but much needed monetary resource. With the economy still recovering from recession, most industries are struggling and competition to gain large stake in the consumer market is high, thus resources need to be managed and used well.

Bakers Inn 15th Avenue Factory is one of the production and manufacturing companies that are in a similar supply management situation. It supplies bread to Bakers Inn shops (outlets) in and around Bulawayo Metropolitan province. Bread is moved between different stages incurring holding costs and inventory costs. The supply chain of Bakers Inn consists of a manufacturing shop, two distributors and the shop outlets. The distributors are within the yard of the manufacturing plant and they become immediate customers of the manufacturing plant. They warehouse the bread that is then delivered to the shop outlets. Effective management of such a supply chain is a key success factor for the company to strengthen its position in the industry and increase its market share. Many companies have to consider designing their distribution network in order to reduce high logistics costs and increase the service level to their customers. New network designs will reduce the logistics cost to a considerable amount, because of consolidated demand at the shops and making palletized high volume transportation possible. In this study, we consider a Vehicle Routing Problem (VRP) at Bakers Inn manufacturing plant to shop outlets together with transportation costs between them. The system resembles a popular approach called vendor-managed inventory in literature. A vendor manages the inventory levels of its customers by considering current inventory at their depots and locations. The aim is to minimize the system wide cost by simultaneously considering inventory and transportation components. Thus, a distribution system has to be designed between Bakers Inn factory and the shop outlets by determining the amount of delivery to each shop outlet and construct cost effective delivery routes.

The vendor is synonymous to the Bakers Inn factory whilst the customers to the shop outlets. There are two possible approaches to such a system. The first one is the direct delivery approach whereby each customer is allocated a truck. The dedicated truck will directly deliver the quantity ordered by a customer and then directly come back to the factory. The second approach is to deliver orders placed by different customers using the same truck and this is called a milk run system. Meanwhile the truck carries different customers' loads and delivers them in a sequence. This requires determining a route for each truck. In these scenarios, the problem will be composed of both inventory decisions and routing decisions. This study considers a milk run system, which will then be compared with the current bread delivery system in order to measure its effects on the current supply chain, in terms of performance measures. However, the company has always been more concerned with increase in profitability, and not much attention on management of inventory routing. Vehicle routing in today's business environment has financial implications on all parties concerned. Research on and implementation of VRP principles in improving it is of great strategic significance to any production company today.

2.0 Current Bread Distribution System

Shop outlets place their orders to the management at the factory. The management transfers the orders to the distributors after some necessary adjustments. Orders are processed; the distributors form truckloads and delivery patterns. They operate a dedicated fleet of vehicles for the company. The costs incurred by the company are based on total distance travelled (kilometers) regardless of load carried. According to this transportation scheme, deliveries are in full truckloads. Distance travelled is calculated as the total length of the route from the factory to shop outlets and back to the factory. This means that the company incurs cost for the empty vehicles coming back from shop outlets. Shop outlets hold inventories in their own warehouses. They are free in determining their inventory levels and ordering decisions. Transportation costs related to bread movement between factory and shop outlets is covered by the factory. The company utilizes about 4 ton trucks for transportation. Since there is no transportation cost incurred by the customers, they place orders in an irregular manner. The main attraction in the ordering decision is to gain incentives related to ordering quantities. However, this practice results in high fluctuations in delivered orders and very high inventories in their warehouses depending on their sales. That is, the system is operating as a push system. The shop outlets place orders every day. According to these orders, the factory plans tomorrow's production. The responsibility of the production department is to manufacture bread according to this daily plan and ready for delivery on the following day. Thus, the factory faces two main problems. Planning periods do not coincide with periods of forecast prospect because productions are done daily that is production is almost uniform. The monthly total of production orders is usually greater than monthly sales targets due to rationing game among shop outlets in case of scarce inventory at the warehouse. In addition, the distributors do not consider load in the truck but distance covered and randomly plans the mode of transport as well as the routes. As a result, the cost effectiveness of the delivery system to all the shop outlets needs some improvement.

In such situations, it is wise to consider the common ingredient in all success, of which Grant (2005) highlighted as the presence of a soundly formulated and effectively implemented strategy. For Bakers Inn 15th Avenue Factory, development of a VRP algorithm can be such a strategy. VRP has drawn the attention of many researchers and business leaders regardless of them not offering insight into the implementation thus benefiting on costs reduction. Supply chain management is an important area that helps maximize profits for the company as well as other supply chain members, which integrate and coordinate across their whole network (Lambert et al., 1998). Managing the supply chain has become a way of improving profits by reducing uncertainty and enhancing customer service. The inventory decisions of upstream and downstream members of supply chain and transportation techniques among them constitute the focus of this study. According to Global Supply Chain Forum, supply chain management is the integration of key business processes from the end user through to original suppliers that provide products, services and information that add value for customers and other stakeholders. This framework includes eight key supply chain management processes, which are customer relationship management, customer service management, demand management, order fulfillment, manufacturing flow management, supplier relationship management and returns management (Lambert, 2008). Supply chain management is mainly concerned with distribution logistics that includes transportation management and inventory control. Early research concentrated on treating these two logistical aspects separately. However, the inventory allocation and vehicle routing decisions are connected in the following ways: In order to determine which customers must be served and the amount to supply each selected customer (the inventory allocation decision), the routing cost information is needed so that the marginal profit for each customer can be accurately computed. On the other hand, delivery cost for each customer depends on the vehicle routes, which in turn requires information about customer selection and amount of inventory allocated for each customer.

Masache et al. (2012) released an article where they used the Clark and Wright's savings algorithm co-joined with the sequential insertion algorithm to solve the routing problem of efficient ARV distribution in the Limpopo province of South Africa citing a high mortality rate in the region due to the inefficient drug distribution system that was in operation. In a similar endeavor, this study explores an efficient bread delivery system but will differ on the choice of methods used to solve the problem. The savings algorithm is still a good algorithm to find an initial feasible solution but owing to its weaknesses, a neighborhood search algorithm will be applied on this initial feasible solution to find the optimal solution to this bread delivery system.

3.0 Assumptions

The following assumptions are considered in this study.

- The quantity delivered per visit is maximal.
- Trucks are sent out with a full load.
- Only one type of bread is distributed from the depot to all respective customers, i.e. there are no product to product exclusions.
- Reduction in the total distance travelled directly means a reduction in delivery costs.
- Bread is distributed from one plant in Bulawayo to all customers in the same city of Bulawayo.

4.0 Methodology

4.1 Model formulation

If we define K as the total fleet of vehicles that are homogenous in their carrying capacities, fuel consumption, efficiency etc. then we can have the following binary variable.

$$x_{ij}^{k} = \begin{cases} 1, & \text{if vehicle } k \text{ travels from node } i \text{ to node } j \\ 0, & \text{otherwise} \end{cases}$$

Where $(i,j) \in$ D={1,2,…, N} for $i \neq j$ and N is the total number of shop outlets plus the factory as the VRP nodes. D is defined as the set of connection arcs in the truck delivery network. We can define the cost per truck of travelling from node i to node j as c_{ij} such that the objective of minimizing the delivery cost is mathematically expressed in the following way.

$$\text{Minimise } : Z = \sum_{\forall (i,\, j)}^{N} \sum_{k=1}^{K} c_{ij}\, x_{ij}^{k}$$

subject to

$$\sum_{k=1}^{K} x_{ij}^{k} = K \quad (1)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N} d_i x_{ij}^{k} \le v \quad \text{for all} \quad k \in \{1,2,\ldots,K\} \quad (2)$$

$$\sum_{j=1}^{N} y_{ij} \le 1 \quad \text{for all} \quad i = 1,2,\ldots,N \quad (3)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N} y_{ij} = K$$

$$x_{ij}^{k} = 0,1$$

Where the constraint (1) ensures that the total number of vehicles routed balances out the available fleet of trucks. If suppose that the maximum capacity of each truck is v then constraint (2) stipulates that the total demand from shop outlet k must not exceed the capacity of the truck k assigned to deliver the shop outlet's order. The variable y_{ij} takes the value of 1 if some vehicle travels from point i to another delivery point j, or zero otherwise, such that constraint (3) stipulates that one and only one truck travels in any one delivery arc (i, j).

4.2 Savings Based Algorithm

The savings algorithm expresses a saving obtained by combining two routes. It can be applied when the number of vehicles is a decision variable. The algorithm merges pairs of routes so that the end of one route continues with the beginning of the other route in order to maximize savings derived from merging. Savings is a measure of cost reduction obtained by the process of merging two routes. The algorithm can be summarized using the flow chart in figure 1 below. Initially the algorithm starts with a solution in which each customer is served alone on a route. The alternative is to try to find improvements to this solution by combining customers of two trips into one without changing order in which customers are visited (Poot et al., 2002). Then savings that result from using the merged routes instead of two routes are calculated. Denoting the transportation cost between two given points i and j by c_{ij} , the total transportation costs, TC_a, of using two routes is given by:

$$TC_a = c_{0i} + c_{i0} + c_{0j} + c_{j0}$$

Equivalently the transportation cost, TC_b, of using one merged route is:

$$TC_b = c_{0i} + c_{ij} + c_{j0}$$

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

$$S_{ij} = TC_a - TC_b = c_{i0} + c_{0j} - c_{ij}$$

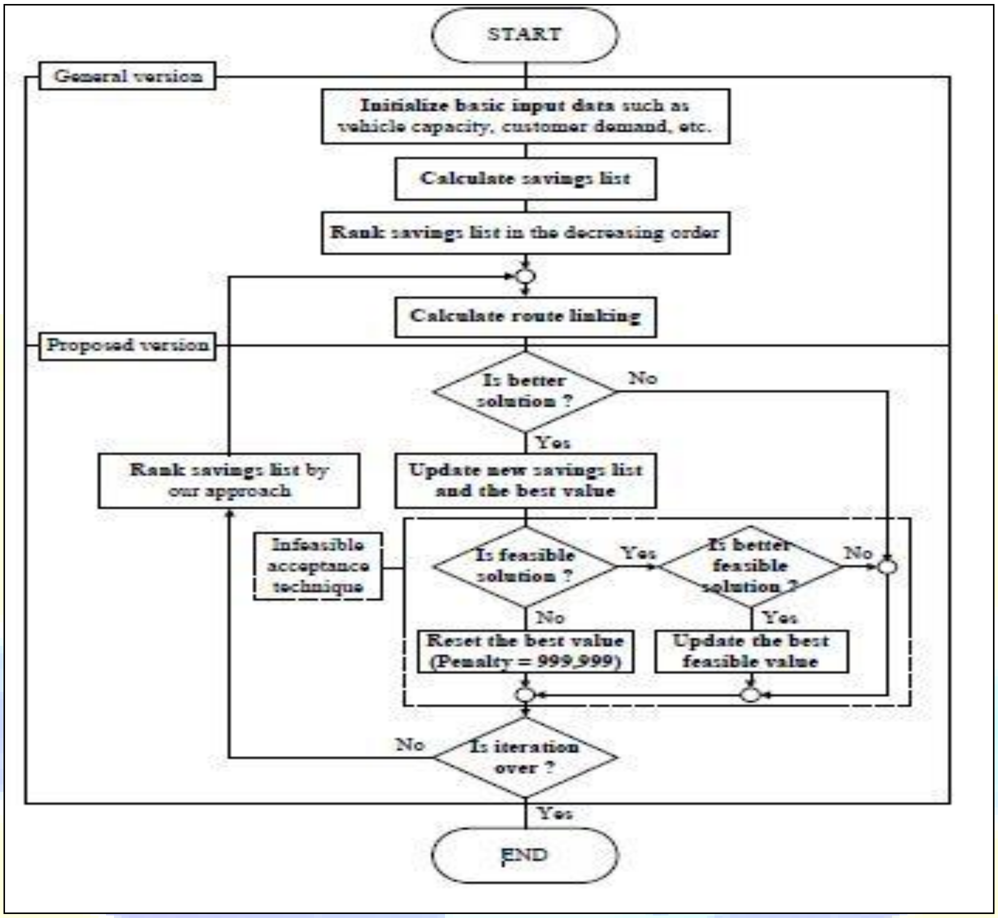

Figure 1. Savings based algorithm flow chart

Relatively large values of S_{ij} indicate that it is attractive, with regard to costs, to visit points *i* and *j* on the same route such that point *j* is visited immediately after point *i*. However, *i* and *j* cannot be combined if in doing so the resulting tour violates one or more of the constraints of the VRP.

Merge Feasibility Concept

Initialisation Step: Each vehicle serves exactly one customer. That is, for each vertex $i = 1,\dots, n$ generate a route (0, *i*, 0) iteration. The connection (or merge) of two distinct routes can determine a better solution (in terms of routing cost).

Step 1: Calculate the savings $S_{ij} = TC_a - TC_b = c_{i0} + c_{0j} - c_{ij}$ for every pair (*i*, *j*) of demand points.

Step 2: Rank the savings S_{ij} and list them in descending order of magnitude. This creates the savings list. Process the savings list beginning with the top most entry in the list (the largest S_{ij}).

Step 3: For the savings S_{ij} under consideration, merge routes servicing customers *i* and *j* if no route constraints will be violated through the merge of the two routes.

Step 4: If the savings list S_{ij} has not been exhausted, return to Step 3, processing the next entry in the list; otherwise, stop: the solution to the VRP consists of the routes created during Step 3. (Any points that have not been assigned to a route during Step 3 must each be served by a vehicle route that begins at the depot D and visits the unassigned point and returns to D.)

4.4 Neighborhood Search Algorithm

Neighborhood search algorithms are a wide class of improvement methods that at each iteration search the "neighborhood" of the current solution to find a better solution (Ahuja et al., 2002). A neighborhood search algorithm for an optimization problem (where we wish to minimize an objective function) starts with a feasible solution x^1 of the problem. For each feasible solution x, an associated neighborhood of x', denoted $N(x)$, is a set of feasible solutions that can be obtained by perturbing solution x using some pre-specified scheme. Elements of $N(x)$ are called neighbors of x. The neighborhood search iteratively obtains a sequence x^1, x^2,… of feasible solutions. At the k^{th} iteration, the algorithm determines a solution x^{k+1} with a lower objective function value than x^k. The algorithm terminates when it finds a solution that is at least as good as any of its neighbors. Typically, multiple runs of the neighborhood search algorithm are performed with different starting solutions, and the best locally optimal solution is selected. The algorithm can be outlined as follows;

1. *Initialize*: find an initial feasible solution (using the savings based algorithm)
   i.e. $x, k \leftarrow 1$
2. *Shake*: generate a random solution
   i.e. $x', N_k(x)$
3. *Local search*: $x' \rightarrow x''$
   If
   x' is better than x then $x \leftarrow x''$ and $k \leftarrow 1$ (center the search around x'' and search again with a small neighborhood)
   else
   $k \leftarrow k + 1$ (enlarge the neighborhood)
   end if
   $k = k_{max}$

5.0 Results and Discussions

The study considered 20 major shop outlets and the only available trucks for deliveries, each with a capacity of 2800 loaves availed. The shop outlets are distributed relatively evenly with 5 in the city centre, 5 in the northern suburbs, 5 in the eastern suburbs and 5 in the western suburbs of Bulawayo. The geographical location of these shops and the manufacturing plant is as shown in the appendix. More information was obtained from the distance logbooks of the truck drivers. The logbooks however, were not as accurate as desired and so distances travelled were calculated using latitudes and longitudes of customer locations shown in table 1 below.

Table 1. Shop outlet geographical positions

Shop	Latitude	Longitude	Demand	Shop	Latitude	Longitude	Demand
1	19.824599	31.041473	500	11	19.841541	430.667667	520
2	19.824599	31.03496	800	12	19.794213	31.04423	400
3	19.824599	31.043265	600	13	19.770309	31.177739	440
4	19.834395	31.054741	500	14	19.835468	30.928716	480
5	19.830762	31.055123	400	15	19.830762	31.101175	450
6	19.7535	31.101175	320	16	19.865098	30.994179	320
7	19.769767	30.990796	500	17	19.851541	31.110039	400
8	19.77236	31.076909	650	18	19.85197	31.056909	480
9	19.82122	31.033892	600	19	19.828487	31.07739	560
10	19.841616	30.990796	500	20	19.863316	31.065323	480
Depot	19.841641	31.043265					

Then distances from one point to another were calculated using the following Vincenty's.

Distance(km)=ACOS(COS(RADIANS(90-Lat1)COS(RADIANS(90-Lat2))+SIN(RADIANS(90-Lat1))SIN(RADIANS(90-Lat2))COS(RADIANS(Long1-Long2)))R

The calculation was done in MS Excel and the distances were averaged out against corresponding ones from the divers' logbooks in order to improve accuracy. Since the current process is that managers from shops place orders to the warehouse then they are free in determining their ordering decisions. That is, the orders placed are in an irregular manner. On the other hand, the process of transportation and delivery of orders is done by any person on duty responsible for scheduling the orders at the warehouse. A driver is

Table 2: Results on the manual routing

Truck Number	Route	Delivery Size	Distance Travelled (km)	Capacity Usage (%)
One	Depot-C3	800	4.8	
	C3-C8	650	8.3	
	C8-C9	600	7.2	73.21
	Sub-total		**20.0**	
Two	Depot-C1	500	1.6	
	C1-C3	600	3.2	
	C3-C14	480	9.3	
	C14-C19	560	7.2	76.34
	Sub-total		**21.3**	
Three	Depot-C4	500	5.4	
	C4-C5	400	2.2	
	C5-C6	300	8.3	
	C6-C10	500	14.2	
	C10-C11	520	7.3	
	C11-C17	400	6.8	93.57
	Sub-total		**44.2**	
Four	Depot-C12	400	10.3	
	C12-C13	450	4.2	
	C13-C15	450	4.4	
	C15-C16	320	8.5	
	C16-C18	480	5.7	
	C18-C20	480	6.5	92.14
	Sub-total		**39.6**	
TOTAL			**125.1**	

assigned a group of shops to deliver of which he has to find on his own how to route his truck. Each driver has an average of 5 shops to serve each day. Thus, 4 vehicles are used every day for delivering the products. This process is done according to human discretion where the person responsible groups orders according to areas where they are supposed to be delivered. That is, the driver is not given a delivery

Table 3: Results on the software based routing

Truck Number	Route	Delivery Size	Distance Travelled (km)	Capacity Usage (%)
One	Depot-C1	500	1.6	
	C1-C3	600	3.2	
	C3-C2	800	2.1	
	C2-C5	400	2.2	100.00
	Sub-total		**12.2**	
Two	Depot-C6	300	3.4	
	C6-C9	600	7.4	
	C9-C8	650	5.8	
	C8-C7	500	3.7	
	C7-C10	500	15.3	91.70
	Sub-total		**35.6**	
Three	Depot-C15	450	7.2	
	C15-C13	450	4.4	
	C13-C14	480	4.0	
	C14-C12	400	7.8	
	C12-C11	400	3.0	77.85
	Sub-total		**26.4**	
Four	Depot-C19	560	13.0	
	C19-C18	480	3.0	
	C18-C17	400	3.8	
	C17-C20	480	8.2	
	C20-C16	320	11.0	80
	Sub-total		**39.0**	
TOTAL			**113.2**	

schedule to follow when delivering the orders; instead, the driver has to plan their own sequence of delivering the bread. This supply chain is not systematic at all. Table 2 above shows the average distances and costs according to the current delivery system on an arbitrarily chosen day. In the proposed software based delivery system, management at the factory is responsible for delivering orders. Drivers would be instructed to follow specified routes that are pre-determined and each shop outlet is allocated enough stock for the day. Delivery points are divided according to their geographical positions and a truck is allocated to such a group of shop outlets. Both the savings based and neighborhood search algorithms were coded into LINDO software. After running the VRP model, the following results in table 3 were obtained. The total number of trips that the fleet undertook to complete delivery was also observed to be the same as that from the manual delivery system. The average load per vehicle differed with the manual routing producing results with average capacity utilization of 83.84 percent and the software routing having an average of 87.23 percent. Below in graphical form is the comparison between the overall utilization values for manual routing and the designed software routing.

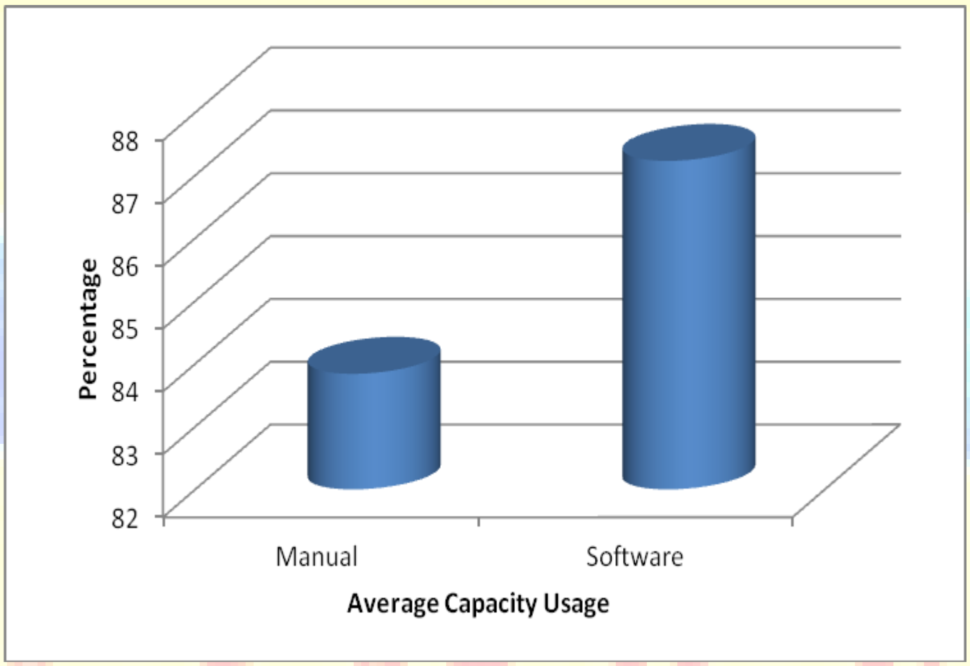

Figure 1. Capacity utilization analysis

Figure 2 below also shows a comparison between total distances travelled by all vehicles for manual routing and designed software routing. The total distance travelled, was different, with the fleet covering 125.1 km with manual routing in use, which is marginally higher than 113.2 km covered, by the fleet with the designed system being used. Since increasing the total distance travelled increases delivery costs then the manual routing is more costly than the software.

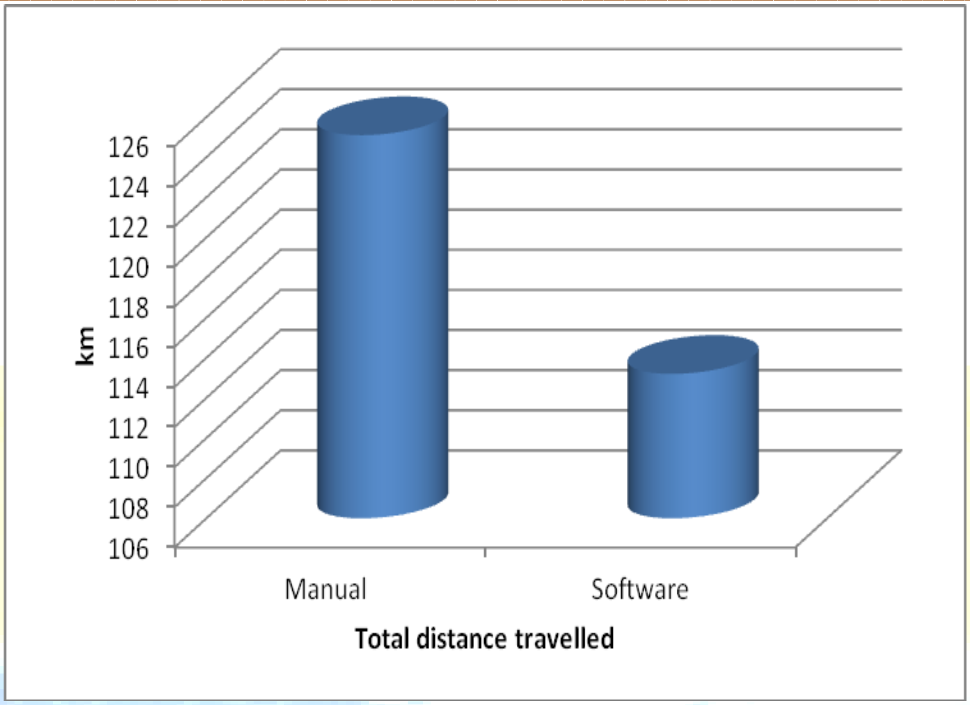

Figure 2. Total distance travelled analysis

It can be seen that software-based system developed performed much better than the manual routing system. Although the same number of vehicles was used in both systems, the software-based utilized the fleet in less distance travelled. The same number of trips was also made but the designed software-based system demonstrated to be more effective. Just as highlighted by Clark and Wright, combining routes results in a reduced total distance and thereby reduced delivery costs.

6.0 Conclusions

The results obtained in the study strengthen the argument of management that relates to the reduction of costs of logistics and transportation. The findings suggest that managers must consider vehicle routing as a significant element of their cost reduction process in their supply chain management. This will ensure that future distribution strategies are developed in collaboration with vehicle routing strategies in order to develop a comprehensive supply chain strategy that benefits every member of the chain. The results show that Bakers Inn 15th Avenue Factory has not fully grasped the importance of vehicle routing and incorporated it into its operations. A general challenge encountered was the continued use of manual routing instead of vehicle routing and an investigation into this has shown that the generality of management locally is ignorant to the use and benefits of VRP to the economic sector. That is, there is a need to create awareness in the sector of vehicle routing and other forms of heuristics as they can generate a great amount of savings in companies as well as improving management of resources and people.

When implementing VRP techniques it is recommended that accurate distances/ longitude and latitude points of customers must be obtained. On the other hand, it was assumed that there is a homogeneous fleet of trucks, a single depot, multiple customers and only one product was distributed. In reality, it might not be that simple, we can have non-homogeneous fleet, at least two depots and more than one type of product to be delivered. Time of delivery and other heuristic methods can also be considered when find the optimal routes. As a result, the study can be extended into the following areas.

- Multiple depot vehicle routing and scheduling.
- Vehicle routing and scheduling of more than one product thereby requiring product to product exclusions.
- Use of other solution methods like Ant Colony Optimisation, Simulated Annealing, Tabu Search, etc; and comparing to find the optimal solution amongst those optimal solutions.
- Vincenty's formula is accurate but not exact, therefore designing of software that would take the road distances from maps and use those distances to come up with a more accurate (exact) solution.
- Inventory routing should be considered as incorporation for optimality.

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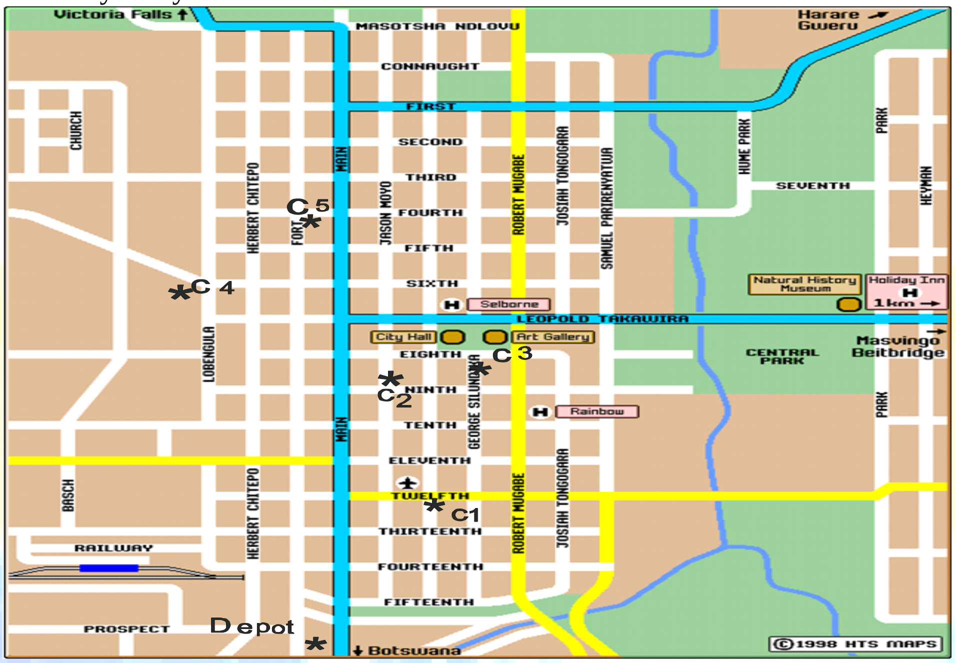
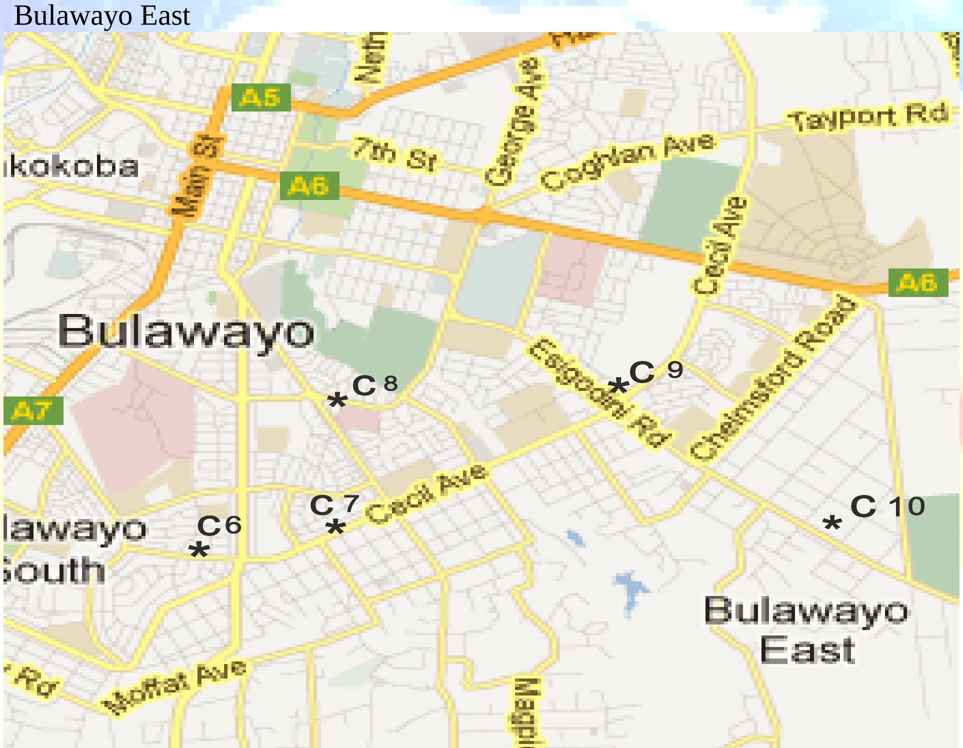
Appendix: Bulawayo Maps

Bulawayo City Centre



Bulawayo East



Bulawayo North

Bulawayo West