A METAHEURISTIC APPROACH TO DELIVERING STOCK TO CUSTOMERS

by

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Executive Summary

The project handles the improvement strategies of the current distribution of products to customers and it is carried out at a branch situated in Alrode in the outskirts of Johannesburg.

Tabu Search TS algorithm is used to find the best route to deliver products. The problem is formulated as a Travelling Salesman problem TSP and the objective is to minimise the total distance travelled. The clustering and insertion heuristic is also modelled into the solution to adhere to the time and capacity constraints. The problem illustrates the distribution from the depot (factory) to the top thirty customers. The bencmark results are from existing tours and they show significant improvement.

The project will discuss methods that will enable reduction of the current lead time of seven days towards the vision of one day lead time. Customers in the same geographical area will be grouped so that an area can be visited once. The proposed method of distribution will enable adherance to urgent orders without disturbing the process flow of attending other orders.

Acronyms

TS	Tabu Search
TSP	Traveling Salesman Problem
VRP	Vehicle Routing Problem
CPP	Chinese Postman Problem
VeZA	Visit and Explore South Africa
CG	Centre of Gravity
GS	Genetic Search
SA	Simulated Annealing
OR	Operations Research
LIFO	Last in First Out
KPI	Key Performance Indicator
GPS	Global Positioning System

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Chapter 1

Introduction

1.1 Introduction

Aluminium products are commodities that are high in demand due to more constructions taking place for the South Africa 2010 football tournament. This creates a duty for companies to satisfy their customers and attract more through effecient service delivery.

There is a high competition amongst aluminium products selling companies since their products range about the same price and quality therefore the service delivery can act as a good marketing startegy.

Scheduling of trucks consist of:

- Delivery trucks getting to a customer location before they close.
- First stock to be loaded on the truck is the last stock to be offloaded.
- Multiple trucks being sent to different areas.

The factory does not keep any records to state if an order was urgent or normal therefore it complicates schedule planning. With the current system an order can only be delivered after seven days even if it is an urgent order. The customers are then notified on the delivery date to expect their order. There are however some orders that are made on time and the required delivery date set by the customer which gives ample time to plan the delivery.

When special orders are made e.g. when special features are desired by a customer, the order is done on time therefore it gives allowance to manufacture the product. If any of the normal products are out of stock, they can be produced within a short time as the plant operates 24 hrs. This furthermore shows how critical the delivery system is as it currently a bottleneck to the flow of goods to customers.

1.2 Distribution of products

The project is done at a factory that consists of two distribution sectors which are internal and external. The project focuses on the external distribution where the extruded products are delivered to customers. There are six trucks that are being used for local delivery around the Gauteng province and contractor trucks for the rest of the parts around South Africa. The distribution service operates from 7am to 4pm from Monday to Friday and this excludes public holidays.

The current system of delivering products include clustering of customers regionally by just looking at the map and assigning trucks. There is no particular sequence that is followed to serve customers to minimise the distance and promote effective resource utilisation.

1.3 Problem definition

The customers are currently not grouped in terms of their geographical areas and trucks frequently travel to the same area unnecessarily. This also causes late deliveries as at times the customers close before the delivery. The schedules for delivery planning is currently difficult as the job card only has the address of the delivery place and the planner has to manually look at the map and try find the place.

Experiments show that decisions done under opportunity cost time pressure reveal a poor performance[4]. This is the same scenario that might occur if the planer has to layout a distribution plan for normal orders, urgent orders and group the orders using a map. In addition to potential loss of customers this creates a stressful working environment. There is a huge potential loss of customers if the products are not delivered on time and also potential to increase and keep customers if the service is good. Furthermore time is money therefore it is very crucial for the routing to be close to optimal.

It will focus of the improvement of the current system of delivering to customers and planning of distribution to customers. The routing problems consist of constraints such as truck capacity and delivery times. The customer areas will be grouped in order to assign one truck to a particular area.

Frthermore the truck drivers have to study directions on maps before departure and determine where their destination is. This is both time consuming and tedious as they might even forget the route on their way. Even if truck drivers knew their routes fairly well that does not imply that they use the shortest route.

1.4 Research design and methodology

The design model will determine the optimal routes to customers as well as the optimal grouping and the allocation of trucks to different groups.

The problem is identified in OR context; Research is done to perform optimal capacitated routing problems and time indications to avoid late deliveries. Heuristics are carried out to search for global optimums within the optimal region from computations. The tours are designed to serve customers by travelling the shortest distance. To improve the model the clustering and insertion heuristic is introduced.

An assumption is done to incorporate traffic uncertainties. Due to intense traffic the distribution will be assumed to be carried out from 08h00 to 15h00. The graph below shows the traffic intensity distribution throughout the day. This shows that there is no control over time during rush hours as traffic cannot be eliminated.

For data preparation VeZA was used to calculate the distance between customers. Visit and Explore South Africa (VeZA) is a vector data mapping system software by the CSIR and TMI. The program is actually designed for finding accommodation and attraction places and it serves a good purpose in finding routes and adding way points to the route.

VeZA will be used to calculate the shortest route distance between two locations. The program enables on to search for a location by either inserting an intersection of two streets or first identify the province and town then select a street. The advantage of this software is that a route can be saved and edited anytime. A route can be edited when a certain customer within a grouped area has not ordered anything for that period.

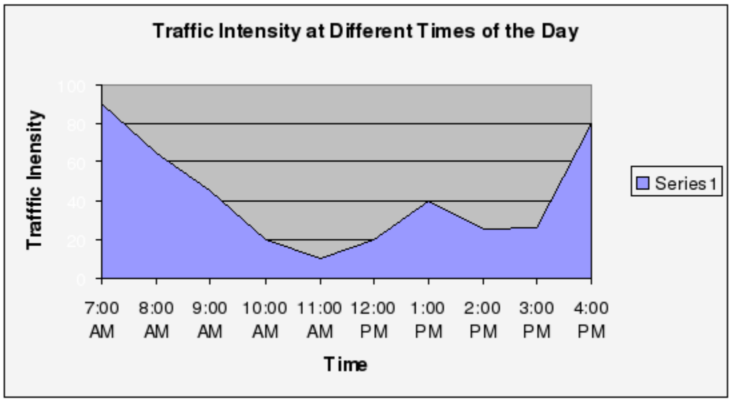

Figure 1.1: Traffic Intensity Indication During the Day

1.5 Improvement Opportunities

The VeZA software is used to calculate distances and it can be used to find alternative routes to a customer location by adding way points if there is major traffic or constructions. The traffic information or any road constructions can viewed on news24 website where they stipulate the nature and duration of the construction[1].

Secondly the trucks are able to carry more than one order and do multiple stops by the customers. These further gives a task to the distribution manager use the LIFO principle when packing the stock on the trucks and determine which route to take[3]. The trucks can be assigned to different customer clustered locations thus enabling proper utilisation of resources. The objective is to serve all customers with minimal expenses and enable easier planning of scheduling.

With an efficient way of delivering products implemented, the planning of scheduling becomes easier and cuts down workload. The various goals can be stated as follows;

- Determine fuel efficiency of delivery trucks and best routing of trucks to customers.
- Be able to handle urgent orders without disturbing process flow of other orders.
- Group customer areas.
- Deliver products before customers close.
- Reduce the seven day lead time towards the aimed one day lead time.
- Limit the number of times an area is visited when delivering.
- Attempt to escape traffic jams during delivery.

1.6 Document Structure

The literature review of identical problems are covered in chapter 2. The problem is also put in the OR context and methods used to solve its different elements. Chapter 3 covers the mathematical formulation of the problem and various metaheuristics applied. The computational evaluation is done in chapter 4 to dicuss the improvements by the model. Chapter 5 which is the last chapter focuses on future improvements that can be undertaken to improve the design model to obtain better results.

Chapter 2

Literature Study

2.1 Literature Review

The problem is defined as a capacitated TSP. The locations of customers and the factory are shown below to illustrate the manner in which the locations are scattered. The problem is therefore classified to be NP-hard.

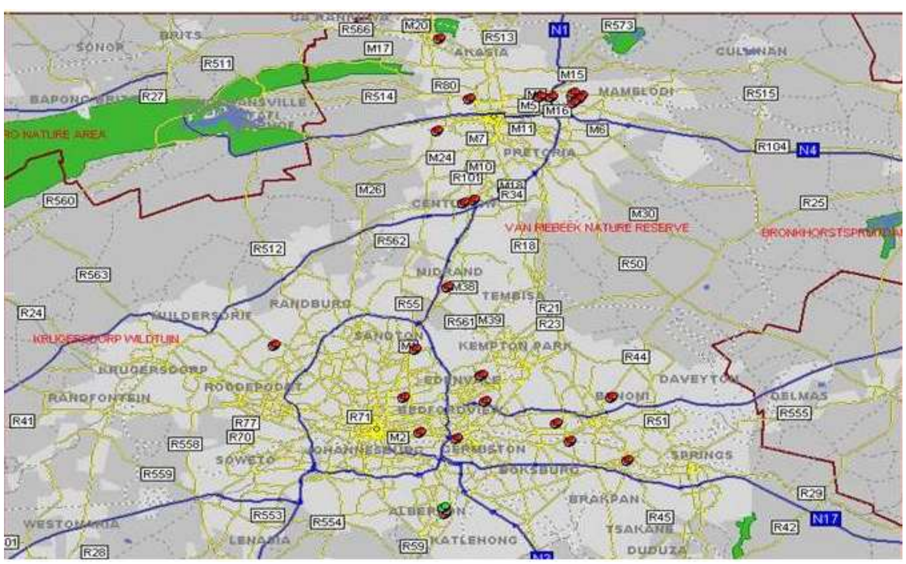

Figure 2.1: Customer Locations

The figure above represents different locations of customers where customers are in red dots and the factory is in green. The tours shall therefore consist of edges that link the customer locations from the factory then final destination back at the factory.

To get a better understanding of the problem, literature study was done on other problems that are similar to TSP. They are part of OR disciple and they are namely the CPP and VRP which will be described below.

2.1.1 Chinese Postman Problem (CPP)

An example to describe CPP is by a postman who delivers mail to clients and is supposed to serve all of them and visit their location only once[8]. The tour starts and ends at the post office and the objective it choose the shortest route.

CPP is solved by mathematical graph theory $G = \{V, E\}$ where G is the graph, V is set of n vertices and E is the set of edges connecting the vertices (i, j) given that $i \neq j$ and $i < j$[8]. To enable the formulation to serve a client only once the vertices has to have an even number of edges in it[8]. The objective function entails a pair of vertices to minimise the total distance, where each vertex is linked to another vertex in pairs[8].

The graph can have both directed and undirected edges whereby the problem result in an NP-hard problem. The constraints for this problem are:

- capacity of the trucks
- certain number of trucks avalaible to serve customers.

2.1.2 Vehicle Routing Problem (VRP)

Vehicle Routing Problems (VRPs) objective is to formulate a solution that serves a customers with the available trucks and minimise cost. The demand is known by the supplier therefore the demand can be classified as deterministic.

In scenarios where there is a fixed number of trucks is known the formulation minimises the time travelled when the trucks are doing non-productive work 'dead head travel time'[6]. On the contratry if the truck quantity is not known the objective minimises both the number of trucks and idle time.[6].

The constraints are as folows:

- capacity of trucks
- each route begin and end at the factory(depot)
- A route is limited to a particlar distance criteria

VRPs all fall under NP-hard problems. The NP-hard problems are problems that increase in complexity as they are solved. Formulating the solution also entails clustering of locations and assining it to a particular route[6].

2.2 Travelling Salesman Problem (TSP)

This can be explained as a problem whereby a salesman serves a certain number of customers and visit each once having used the shortest route.[10]. d_{ij} denotes the travelling distance from customer i to j.

The mathematical formulation as by Winston[10] (2004):

$$x_{ij} = \begin{cases} 1 & \text{if the truck goes from customer}\, i\, \text{to}\, j \\ 0 & \text{otherwise} \end{cases} \tag{2.1}$$

$$\min z = \sum_i \sum_j d_{ij} x_{ij} \tag{2.2}$$

subject to

$$\sum_{i=1}^{N} x_{ij} = 1, \quad j = 1, 2, ..., N \tag{2.3}$$

$$\sum_{j=1}^{N} x_{ij} = 1, \quad i = 1, 2, ..., N \tag{2.4}$$

$$u_i - u_j + N x_{ij} \leq N - 1, \quad (\text{for} i \neq j;\ i = 2, 3, ..., N;\ j = 2, 3, ..., N) \tag{2.5}$$

$$\text{All}\, x_{ij} = 0\, \text{or}\, 1,\ \text{All}\, u_j \geq 0 \tag{2.6}$$

The objective function minimises the total distance. The first constraint restricts trucks to only one arrival and the second to only one departure. The third resticts subtours within the route and all moves that form a tour are feasible.

2.3 Clustering and insertion heuristic procedure

The procedure enables the model to do multiple tours which basically allocates a truck per tour. A furthest position from the factory is chosen then stops around this are possible candidates for the route and this is decided by using CG[5]. Some stops are temprorarily added to the tour and this are variable stops then a final clustering is done when a CG mechanisim is applied to all varaible stops and stops that were previously not assigned to tours[5]. The decision depends on the minimum distance therefore variable stops are then assigned to tours permanently. The heuristic has two elements which are the time and capacity elements. For this problem capacity is fixed to eight customers.

2.3.1 Time Constraint as by Chung[5]:

Parameter	Description
2	accounts for round trip
k	transit time factor
a	real distance approximation
s	standard driving speed
n	number of customers assigned to a route
$t(i)$	sum of travel time from prior stop + delivery time at customer i
$u(i)$	delivery time estimate at customer i
$d_1(i)$	distance from factory to customer$i$
$d_2(i)$	distance prior stop to next stop

Formulas for calculating time to serve a route as by Chung[5]:

$$f(n) = f(n-1) \ + \ t(n) \tag{2.7}$$

$$f(1) = 2kad_1(1)/s \quad + u(1) \tag{2.8}$$

$$t(i) = a\{d_1(i) - d_1(i-1) + d_2(i)\}/s \quad + u(i) \tag{2.9}$$

The first equation estimates the time it take to complete a tour serving all customers. The second equation estimates the time for the first stop of the tour refeffed to as the seed stop. The last equation incoporates the time a truck spends at the customer location offloading and filling paperwork etc.

2.4 Heuristics

Heuristics are techniques used to assist in improving solutions. Most problems are not solved to optimality as the objective function gets trapped in the local optimum. The heuristics assist in searching in neighbouring regions for the global optimum.

2.5 Metaheuristics

These consist of a part of heuristics that are better in finding solutions as they use calculated moves[10]. Metaheuristics are formulated with steps that allow them to move to the neighbouring region even if it is necessarily not better than the prior solution and this in future will lead to other optimal regions. Some of the metaheuristic are explained below.

2.5.1 Simulated Annealing (SA)

SA is heuristic method that is used to study the natural behaviour of atoms whith their thermal condition in equilibrium at a certain temperature T_p where the energy state is E_0[10]. The general move to solve the problem is to begin with a certain atomic arrangement and then randomly change the form to a sequence that is in a random order. If the energy level E_i at the new configuration is lower than the initial energy level then the process is repeated again using the new energy level. On the other hand if $E_0 < E_i$ then E_i is accepted with a certain level of confidence[10]. This is done so that the search can further be carried out in the neighbouring regions and forbids it from being stuck in one region[10].

2.5.2 Genetic Search

GS is adopted from the natural behaviour of genes; following their elite pattern and their behaviour of development. The method as by Winston and Venkataramanan; "the method randomly produce a sample of chromosomes which are a parent being of genes"[10]. The chromosomes are a set of possible solutions to a given problem. The population is then assessed by a given criteria where the best solution strives to be the incumbent and is implemented on the chromosomes. A second sample is produced from the first sample by mating with the prior incumbent group[10]. The chromosomes are partnered up to identify the best mutation where this is likely to be selected to reproduce[10].

2.5.3 Tabu Search

This is a metaheuristic approach that is used to search for solutions beyond local optimality[9]. The method uses a short term and long term memory to enable it to escape a the region of solution in the belief to obtain better solutions[10]. The short term memory enables the method not to be trapped in a region of local optimums and the long term memory allows searches in the neighbouring regions[10].

2.6 Conclusion

TS will be used to improve the TSP and additional factors such as truck capacity and the number of available trucks will be used in the model.

The cluster and insertion heuristic is also used to improve the model to optimality.

Chapter 3

Formulation

3.1 Travelling Salesman Problem (TSP)

The problem is described as a salesman who wishes to visit each place once travelling from customer i to customer j where the distance of travelling can be denoted by c_{ij} and the objective function minimises the total distance of the tours[7].

3.2 Mathematical Formulation

The mathematical structure of a TSP is obtained from a graph where each customer location is denoted by a point and lines called edges or arcs are used to connect the points. The graph is complete when the salesman can directly travel from every customer to every other customer as described in the OR encyclopaedia[7].

3.2.1 Model Formulation

The TS algorithm is combined with the clustering and insertion heuristic with respect to the TSP characteristics that have to be fulfilled. The time element is added in the formulation and it acts as an aid to the planner to show him/her if time allows all deliveries on time. Depending whether the order is urgent or not the planner can then decide to serve the incomplete tour or carry it out the following day.

This chapter entails the TS, clustering and insertion heuristic and the complete TS algorithm that includes everything introduced in the model. The table below shows some of the notations used to denote variables for the TS algorithm and the mixed multigraph.

Item	Description
v_1	Depot node
t	Number of available trucks
T	Set of Closed truck tour that begins and ends at v_1
C_i	Closed truck tour that begins and ends at v_1
d	The length of distance of a set of edges
$SP(v_i, v_j)$	Set of edges on the shortest path between $v_i$and v_j
G	Graph G
V	Set of nodes or customer edges
E	Undirected edges
R	The reguired set of edges
D	Distance matrix

Table 3.1: Terminology[6]

3.2.2 The TSP Algorithm

The mixed multigraph's notations are adapted from OR's enclyclopedia. There is the mixed-multigraph $G = (V, E, R)$ where V denotes a set of nodes, E is a set of vertices and R is a set of required edges[6].

The objective function of the TSP fromulation is to have $\widehat{T}$ which consists of $T = \{R_1, ..., R_k\}$such that the set comprises of the best combination of the sequence to yield the shortest distance. Only the customers that are served are included in the incumbent solution $\widehat{T}$. The basic rule of thumb of TSP is that R_i should start and end at the factory (depot). The objective function is then improved by the TS and cluster and insertion heuristic procedure.

3.2.3 TS Algorithm

Algorithm 1 shows TS algorithm as by R.Rardin (1998)[9]. The first step chooses any sequence of serving customers denoted by $T^{(0)}$and iteration limit t_{max}. There are no forbidden (tabu) moves at this stage and time is set as $t \leftarrow 0$.

The sequence of customers is changed in move set M to lead to a feasible neighbouring solution while step 4 keeps the best objective function $\widehat{T}$ thus far. Step 5 creates a tabu list that stops the moves from cycling around the same region of solutions and enable search for better solutions. Step 6 allows the algorithm to increment time of iterations until it stops at t_{max}.

Algorithm 1: Tabu Search
Step 0: Initialisation. Compute starting solution $T^{(0)}$.Iterate to $t_{\max}$ and set incumbent $\widehat{T} \leftarrow T^{(0)}$ and solution index $t \leftarrow 0$. No moves tabu. Step 1: Stopping. If no non-tabu move $\triangle T$ in move set M leads to a feasible neighbour of current solution $T^{(t)}$, or if $t = t_{\max}$, then stop. Incumbent solution $\widehat{T}$is and appropriate optimum. Step 2: Move. Choose some non-tabu feasible move $\triangle T \in M$ as $\triangle T^{(t+1)}$ Step 3: Step. Update $T^{(t+1)} \leftarrow T^{(t)} + \triangle T^{(t+1)}$ Step 4: Incumbent Solution. If the objective function value of $T^{(t+1)}$is superior to that of incumbent solution $\widehat{T}$, replace $\widehat{T} \leftarrow T^{(t+1)}$. Step 5: Tabu List: Remove from the list of tabu of forbidden moves any that have been on it for a sufficient number of iterations, and add a collection of moves that includes any returning immediately from $T^{(t+1)}$to T^{t}. Step 6: Incumbent. Increment $t \leftarrow t + 1$, and return to step 1.

Table 3.2: Algorithm 1[9]

3.3 Move M and step

The tabu list is updated for a certain $R_i$after a number of appropriate iterations. The number of iteration requires an intelligent decision based on the size of D. No major restrictions should be made on the algorithm and also prevent cycling around the same region of solutions. The major restrictions are caused by keeping a member of the tabu list for too many iterations whereby the available moves are restricted to limited members[9]. The cycling is caused by a member of the tabu list being kept in the list for a small number of iterations thereby the TS performing the same sequences repeatedly[9].

3.4 TS Algorithm

Algorithm 2 shows the mathematical representation of how the solution is formulated. This includes the clustering and insertion procedure to adhere to some of its characteristics. This helps it to focus in a resticted cluster to limit iterations before obtaining incumbent and it improves its solution.

The edges $v_i, v_j$are assigned to a tour where the shortest route from the depot is taken. Optimality of the tour lies in the combination or the sequence of customers locations to be served. D comprises of the shortest distance between the node points, it is therefore with the use of the algorithm to help us find a better combination of constructing a tour. The formulation includes the pairwise interchange where the sequence of serving customers within a certain path is changed by swapping the locations in the sequence. The objective function value of each iteration is calculated and an incumbent solution is obtained at $t_{\max}$.

Input:		Distance matrix
		Number of trucks
		Input graph $G = (V, E, R)$
		Number of iterations t_{max}
Output:		Incumbent solution $\widehat{T} = \{C_1, ..., C_k\}$
		Generate initial solution $(t, T^{(0)})$;
		$\tilde{T} \leftarrow \tilde{T}^{(0)}$;
		$Objective_{incumbent} \leftarrow Objective(T^{(0)})$;
		$t \leftarrow 0$;
	while	$t \leq t_{max}$ do
		(1) Pairwise Interchange;
		(2) Clustering and insertion heuristic;
		Improve $(\tilde{T}, \tilde{T}^{(t+1)})$;
		No tabu moves;
	if	$Objective < Objective_{incumbent}$
		$Objective_{incumbent} \leftarrow Objective$;
		$\widehat{T} \leftarrow \tilde{T}^{(t+1)}$;
	if	$t > 0$
		Introduce tabu list;
	end	
		Update tabu list;
		$t \leftarrow t + 1$;
	end	
	end	

Table 3.3: Algorithm 2[2]

Algorithm 3 illustrates the clustering and insertion heuristic procedure. The first step is to choose a customer location that is the furthest from the factory which is called the seed point[5]. CG mechanisim is computed to find neighbouring location that can be part of that particular route. Some stops are classified as variable stops, meaning they are temporarily part of the tour before a final computation of CG is done to decide whether to keep the stop or assign it to another route. The TS is applied to a group of potential stops that can be assigned to a route then $\widehat{T}$ assist in the decision criteria. The time element is calculated at the end to illustrate the total time that a tour is expected to take.

Input:			Time
			Capacity
			Distance Matrix
			Number of Trucks
			Mixed Multigraph $G = \{V, E, R\}$
Output:			A tour that comprises of a cluster of locations
	while		$i \leftarrow 1$ to all customers do
			$count \leftarrow 0$;
			$Capacity < 8Customers$ do;
			Choose furtherst customer location
		if	$((Customerlocation(i+1) > Distancelimit) == Discard)$
			Select fixed stop;
			Compute CG of Cluster;
			Add varaible stops to cluster;
			Perform TS with more stops;
		end	
			$count \leftarrow count + 1$;
			Update clustering sequence ;
			Replace variable stops with other varaible stops to optimality;
		if	count==All Customers
			Update new cluster sequence;
			Calculate time for serving customers in a tour;
		end	
	end		

Table 3.4: Algorithm 3[2]

3.5 Conclusion

This chapter illustrated the modelling of the solution to the problem and how TS and clustering and insertion heuristc are implemented in the formulation. The next chapter will cover the results of the model and their comparisons against the current procedures of distribution that are performed by the planning department.

Chapter 4

Findings

4.1 Analysis of Results and Evaluations

In this chapter the results of the model are analysed and evaluated by comparing them against other benchmark results. The benchmark results include the data obtained for April to June that shows the performance of the current distribution service.

The results are compared by the objective functions of the current system against the proposed method. The matlab was run for 300 iterations for each route.

Parameter	Proposed Initial Solution	Current Sol.	Proposed Sol. (Incumbent)
Total Travel Distance in km	648.94	460.50	557.32
Total Travel Time in hrs	5.4	4.7	5.67
Number of Customers served	62	57	88
Served/Distance Travelled	0.0956	0.124	0.157

The initial solution is the solution obtained at the first iteration of the proposed model and the current method is results computed from the distribution service currently in place. There is an improvement by the proposed model in the number of customers served per distance travelled. This is just to check the efficiency of the model as serving more customers a day has more priority and since the model minimise the travel distance this can be implemented without risk of incurring unnecessary expenses.

4.2 Conclusion

The model shows improvement compared to the current distribution system. The data also enables management to make better planning and decisions. There are improvement opportunities on the proposed model and they will be discussed in the next chapter.

Chapter 5

Implementation and Future Improvements

The algorithms are clearly defined and integrated in a logical format. Since the 80/20 rule is applied on the 30 top customers, the techniques can be used as a specimen to the rest of the customers.

The algorithms can be integrated onto a database where it can retrieve all the information that can be linked to all customers and related information and constraints. The database can be constructed by the informatics experts as they deal with databases. They can further build a user friendly interface that can be used by distribution planners. This model will be tested using different scenarios to check for validity of its results.

The specifications for a CPU to run the model are as follows RAM>= 1 GB Hardrive>= 500 GB Windows XP Pentium (R) 4 CPU 3.06 GHz motherboard

The above specifications are based on knowledge from the PC that way running the algorithms. The processing speed to manipulate the data is fairly efficient. As for the disk space it will depend on the other data that is stored on the PC.

The information on traffic statistics will have to be viewed everyday and add way points to escape traffic. Subscribtion to news24 to receive all the traffic statistics can be done. This will be handled by the planner and make necessary adjustments on the route to the customers.

For future developments of the model, GPS tracker and KPI system can be installed on the truck to collect necessary distribution information.

These will include:

- Route taken
- Time travelled
- Number of stops
- Time to service each customer

The above data can be used in a simulation model that can be used to assist in improving strategies to save time.

Bin Packing Algorithms can be used to optimize the grouping of the customers so that shorter routes are taken to deliver to customers[2]. To improve the practicality of the model, forbidden U turns and turn penalties at busy intersections algorithms can be constructed.

For updated map routes Google earth can be used as a reliable resource. It can be used to find locations of customers and validate the routes. A GPS can also be used to validate the route distance calculated by the VeZA as it is mainly used for finding attraction places in South Africa and it is less accurate. An even better solution is GIS, whereby the customer locations can be captured and viewed as a softcopy. This enables easier management, manipulation, analysis and modelling of the data. The GIS has the advantage of showing the exact addreses and a means of calculating the estimated time between customer location.

The model should be altered to allow flexibility of different truck capacities. Research can also be done on integrating forecasted demand to the distribution cycle. Another aspect is finding the optimal number of trucks required to service the customer and not only base the model on the available ones.

Bibliography

[1] No author, May 2009.

[2] Botee and Bonabeau. Evolving ant colony optimisation. *Journal*, pages 149–159, 1998.

[3] Coyle J.J., Bardi E.J., and Langley Jr C.J. *The Management of Business Logistics*. Thomson South Western, 7th edition, 2003.

[4] Payne J.W., Bettman J.R., and Luce M.F. When time is money: Decision under opportunity cost time pressure. *Journal*, 66 No.2(number):131–152, 1996.

[5] Chung H. K. and Norback J. P. A large routing problem in food distribution. *Journal*, 42:588–562.

[6] Bodin L. Vehicle routing. In *Encyclopedia of Operations Research and Management Science*. Kluwer Academic Publishers, 2006.

[7] Hoffman K. L. Traveling salesman. In *Encyclopedia of Operations Research*. Kluwer Academic Publishers, 2006.

[8] William R. and Stewart Jr. Chinese postman problem. In *Encyclopedia of Operations Research and Management Science*. Kluwer Academic Publishers, 2006.

[9] Rardin R.L. *Optimisation in Operations Research*. Prentice Hall, 1998.

[10] W. Winston and Venkataramanan. *Introduction to Mathematical Programming*, volume 2. Brooks/Cole-Thomson, 2004.

Appendix A