

Strategic Improvements for a Wholesale Trading Company, focusing on logistics.

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Abbreviations

CCP – Capacitated Clustering Problem

CPT – Cape Town

DBN – Durban

DC – Distribution Centre

DRAI – Dynamic Routing and Inventory

HS – Heneck Sacks

HTTP – Hypertext Transfer Protocol

IRP – Inventory Routing Problem

JHB – Johannesburg

JMC – J. Melnick & Co.

LTL – Less than Truck Load

MS - Microsoft

PE – Port Elizabeth

PTA – Pretoria

TCS – The Crazy Store

TL – Truck Load

TSP – Travelling Salesman Problem

VRP – Vehicle Routing Problem

URL – Uniform Resource Locator

XML – Extensible Markup Language

Executive Summary

Melbro Holdings (Pty) Ltd., a South African wholesale trading company, house distribution centres throughout South Africa. Deliveries are made from four distribution centres to respective customers throughout Southern Africa. The company consists of six divisions, two namely being; JMC and Heneck Sacks. In this paper, these two divisions are investigated in order to make strategic logistical improvements to better the current situation. Recent sales agreements have been lost which has decreased the volume of goods that Melbro consolidate and deliver to customers. The current process is manual and together with this decrease in sales, has resulted in a low vehicle utilisation and unnecessary costs. This therefore has a major effect on the deliveries but yet no correction or investigation has been made.

This document identifies how the typical vehicle routing problem together with shipment consolidation will be solved. As a first phase of the project, the problem aim and scope were identified to clarify the expectations and activities that need to be met. Hence, the key outcome of this project was identified as developing a generic tool for the company to determine the optimal consolidation and routing scheme for shipments.

The second phase of this document includes literature review on three parts, namely; the Clustering Problem, Assignment Problem and the Vehicle Routing Problem. Typical industry applications of these combined problems were also discussed. The Analytical Hierarchy Process (AHP) was used to determine which software should be selected for the purpose of the tool. The AHP solution showed that *MS Excel* was the best possible option.

The third phase of this document, explicitly defines how the model concept was developed from a "Systems perspective" as well as a functional perspective. The consolidation and routing tool was broken down into four particular parts: Data, Clustering, Assignment and Routing. Required information, mathematical models are outlined for Part 2, 3 and 4 of the model. Integration of the

four parts is illustrated by means of inputs and outputs into each part of the model. A complete analysis on the flow of the system is also shown by using a Basic Flow Diagram.

In the fourth phase, the physical model is discussed. A systematic approach was taken by using the principles of the model. Each MS Excel model tab is defined and clearly discussed with relation to the four parts already mentioned.

The fifth phase discusses the results with relation to validation and testing, the case study comparison and implementation benefits that may be gained by use of the model. Finally, the last phase of this report, expresses the future recommendations that should be considered when implementing and working with this model on a daily basis.

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Chapter 1

1. Introduction

1.1 Industry Context

According to Langley, et al (2008) a logistics channel can be defined as simple, multi-echelon or complex where “the logistical channel refers to the means by which products flow physically from where they are available to where they are needed”. Realistically, the paths that goods follow through a supply chain are complex in nature and need to be fully understood and properly utilized in order to optimize business processes. To enable the goods to reach the target market, freight services and wholesale traders often form part of the supply chain and distribution. Their business operations include activities related to warehousing, consolidation of goods, and distribution to the consumer.

In the current economic climate it is often hard to stay competitive. Companies in this industry are continuously looking for ways to cut cost and time. Logistics is one of these key areas to do so.

1.2 Company Background

Melbro Holdings (Pty) Ltd. is a wholesale trading company that provides perishable and non-perishable goods to Southern Africa. The head office is based in Cape Town, with other branches of the company in Johannesburg, Port Elizabeth and Durban.

The divisions that make up Melbro Holdings (Pty) Ltd. are the following:

- * Heneck Sacks (HS)
- * J. Melnick & Co. (JMC)
- * The Crazy Store (TCS)
- * Melbro Corporate Services (MCS)
- * Melbro Logistics Services (MLS)

These divisions are equally important in the company as they are all responsible for various aspects within:

- * HS: Deals in all non-perishable items from stationery to kitchenware or even hardware, while also supplying goods to TCS and Khoki.
- * JMC: Supply perishable brands such as; Mars, Wrigleys and Evian, to a diversity of companies, including: Pick n Pay, Checkers and other independent shop owners. A complete list of these brands can be found in Appendix A.
- * MLS: Focuses on warehousing and distribution for the company.

Cape Town, Johannesburg, Durban and Port Elizabeth are all home to Melbro's distribution centres, where they supply goods to different parts of the country and into Southern Africa (especially Namibia). Due to the differing consumer environments, each DC including their deliveries, are unique in their operations.

Melbro is a growing business, especially with the amount of new stores to be opened in the line of 'The Crazy Store' and Khoki.

1.3 Distribution and Transport at Melbro

As previously mentioned MLS are responsible for all transport and can further be split into two distribution channels: The Crazy Store network and all other direct sales. TCS network is serviced by two major transport industry players, whereas the direct sales are generally serviced by what is known as "the bakkie brigade". TCS transporters are country-wide distributors, where Melbro's goods are consolidated with other companies' deliveries. All schedules and consolidation is done

by the transporters themselves, and therefore Melbro has minimum involvement in this decision. “The bakkie brigade”, however, is made up of smaller vehicles, as the amount of goods required to be transported for JMC and Heneck Sacks are lower in volume as in comparison to TCS goods.

Vehicles used as part of “the bakkie brigade” tend to be insulated due the perishable goods (such as chocolates), which need to be kept at a regulated temperature in order to be delivered in good condition.

Deliveries at Melbro are categorized into three areas, based on the final destination relative to the DC. The three categories are as follows:

1. Local – less than 50km radius
2. Country – between 50 and 100km
3. Far country – over 100km

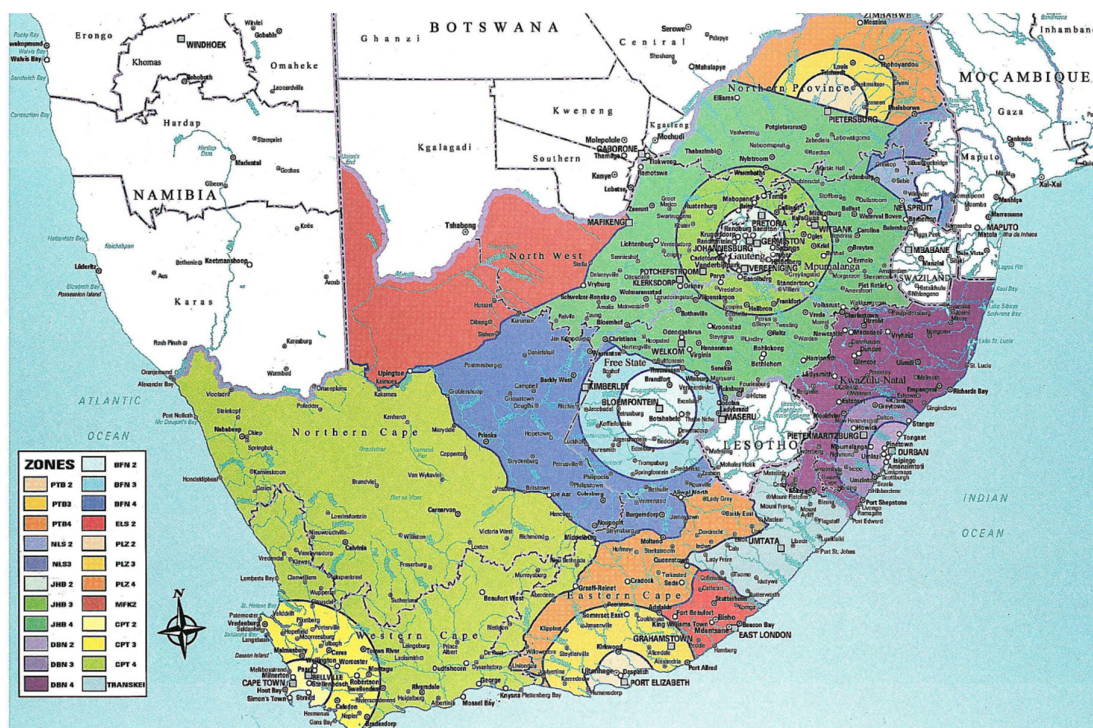


Figure 1 Melbro's Designated Zones throughout SA

Since 2012, transport has been a major concern for Melbro. Analyses have been done on the TCS transport providers to determine whether or not they are competent and cost effective for the company. All aspects are being investigated to try and reduce costs in

order to make logistics more efficient. Due to the already mentioned fact that TCS transport is outsourced, this will not be considered in the scope of this dissertation. Therefore, other ways of improving transport and logistics need to be explored. JMC and Heneck Sacks together with the 'bakkie brigade' allow room for improvement in this regard.

Consolidation of goods is currently a big problem as this process is controlled manually which leads to a very low utilisation level of vehicles and high distribution costs, as too many vehicles are being used for delivery purposes. In addition to this, brands such as Lindt and Red Bull have discontinued their contract with Melbro and created their own international agencies in the country. These losses have decreased the volumes of goods that are sent in deliveries. Since the volume decreases have occurred, no relook at proper consolidation has been pursued. Underutilized vehicles often deliver goods to stores, together with goods that are not required to be delivered using an insulated vehicle. This not only brings a problem of poor freight consolidation but also a problem regarding innovation, as techniques to perhaps only insulate the chocolates may be required as a possible solution to good consolidation. Being a manual procedure, this also brings about room for error, favouritism within drivers and hence, a lack in productivity.

It has also been found by the company that routing and logistics throughout South Africa is not at its optimum level. Vehicle routing is not standardized across regions, and delivery schedules are not uniform. This can be classified as a typical Vehicle Routing Problem (VRP). According to Savelsbergh (2002) the objective of a typical VRP is to “minimize the total distance” that delivery vehicles will travel. Figure 2 created by Diaz (2007) illustrates how VRP networks are formed around a central point such as one of Melbro's DC where the nodes forming the several optimal routes represent each of their customers. Beyond the typical VRP classification, transportation needs to also consider traffic problems, high risk theft areas etc., making it difficult for companies to solve their logistical dilemmas.

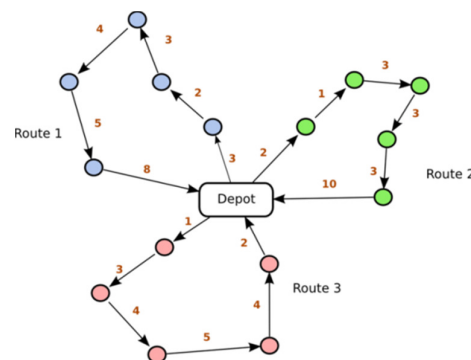


**Figure 2 Typical VRP taken from
Metaheuristics in Dynamic Environments**

1.4 Project Aim

The aim of the project is to consolidate orders placed with Melbro divisions: JMC and Heneck Sacks, improve the vehicle routing and scheduling of deliveries for the DCs throughout South Africa.

The aim is to use Johannesburg's local despatch information to develop a generic model that could be also be implemented for Johannesburg country zone as well as DCs in Cape Town, Durban and Port Elizabeth.

1.5 Project Scope

Outcomes Based Scoping Technique (Steyn, et al., 2010) can be used to define a project scope. Using this approach, the scope of the project will involve development of an optimal model for the distribution of Melbro's freight deliveries. Ultimately, increased profitability and productivity are expected as outcomes. The scope of this project includes developing a generic solution to optimise Melbro's delivery system from the consolidation of orders to the delivery scheduling and vehicle routing throughout PTA's customer network.

Within the provided scope, there are certain inclusions, exclusions and constraints, which will be addressed in the below consecutive paragraphs (1.5.1,2 and 3).

1.5.1 Inclusions

- * Research of methodologies, tools and techniques to be highlighted (section 2).
- * Data gathering and analysis of relevant information and statistics.
- * A generic tool that will help Melbro determine the optimal daily consolidation plan and vehicle routing and delivery schedule outputs by entering or selecting specific inputs and constraints that are relative to the distances to fulfilling customer orders and costs involved therein.
- * From the above, utilisation levels of vehicles used for distribution should be calculated to determine whether a decrease in the number of vehicles would be satisfied.
- * Sensitivity analysis of the above mentioned model to determine its reliability.
- * Calculation of total possible cost savings that could be achieved by implementing the model at Melbro.

- * Suggestions for continuous improvement should be made to ensure that the tool designed is beneficially in a never-ending manner.

1.5.2 Exclusions

- * Only company sections JMC and Heneck Sacks will be evaluated, therefore excluding TCS from the project scope.
- * Any internal DC operations will not be considered due to the nature of the project outcome.

1.5.3 Constraints

- * Location of DC as only Johannesburg DC is in close proximity to the University of Pretoria.
- * It is assumed that data collected is correct due to time constraints of the project.

1.6 Deliverables

After completing the project, the following can be expected:

- * An effective and efficient generic model to can determine the delivery routing schedule that may be used for the DCs in CT, JHB, DBN and PE
- * Proper consolidation of goods to ensure 'Truck Load' (TL) deliveries rather than 'Less than Truck Load' (LTL) deliveries where possible
- * Potential savings relating to the two deliverables as above
- * Physical project deliverables: Final report, poster and presentation

Chapter 2

2. Literature Review

2.1 Overview

From performing a literature review, it appears that there is a slight gap in research related to the development of models including consolidation of shipments to vehicles and route optimisation. Hence, each topic has been addressed individually and to some extent where applicable, combinations have been addressed and combinational assumptions have been made.

This chapter aims to clarify the context in which the problem is based, identify the specific methods for consolidation, vehicle routing and the combination of the two, and includes the various forms of available software, the selection thereof using AHP and a means to data collection through Google API.

2.2 The Wholesale Environment

“Wholesale trade is a form of trade in which goods are purchased and stored in large quantities and sold, in batches of a designated quantity, to resellers, professional users or groups, but not to final consumers.” (OECD, 2002)

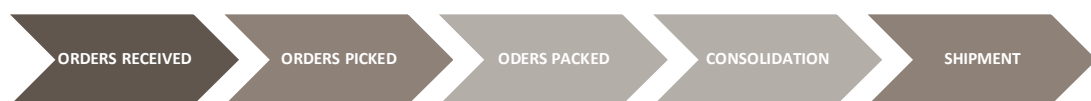


Figure 3 Wholesale Process Flow

Like Figure 3, at JHB Melbro, orders for JMC and HS products are received from manufacturers/suppliers. These orders are picked and packed by staff and forwarded to the

despatch area where there are separate zones for local deliveries created by sectioned cages for each of the delivery areas. These delivery areas are:

- * JHB North
- * JHB East
- * Pretoria
- * Vaal
- * JHB West

As for country deliveries, which includes; Mpumalanga, Polokwane, Rustenburg and Free State, two additional cages are provided in the dispatch area for such deliveries. Volumes delivered to country areas are far less than Gauteng itself, and therefore only 2 days per week do deliveries for these areas occur.

Once the goods have been divided into the individual cages dependent on their destination, goods are consolidated manually by the dispatch manager. This has come down to experience and knowledge of the manager and drivers. He must consider that each 1-ton “bakkie” must have a maximum of 15 stops and carry a minimum of R28000 value of goods.

For local deliveries, five independent vehicle suppliers are available and as for country, there are two. The vehicles supplied are a combination of 4-ton trucks and 1-ton “bakkies”. Listed below (See Table 1) are the local and country vehicle suppliers and all other relevant data is given in further detail in Appendix B.

Table 1 Local VS Country Vendor Companies

Company	Local	Country
Kargo	✓	✓
CCI	✓	✓
JM. OEL	✓	✗
Grolink	✓	✗
MXC	✓	✗
BJB	✗	✓

2.3 Mathematical programming techniques

2.3.1 Mathematical Models

Mathematical programming falls under the subject Operations Research. This is defined as being a “scientific approach to decision making that seeks to best design and operate a system” (Winston and Venkataramanan, 2003). Mathematical models are used to represent a real life situation in order to solve the given problem. Many different approaches to modelling exist such as dynamic programming, heuristic and meta-heuristic techniques. Integer Programming is a very popular method of modelling and often used for problems of clustering, assignment and vehicle routing and will be used as a solution technique for Melbro’s problem.

2.3.2 Integer Programming

According to Winston and Venkataramanan (2003), an integer programming problem is an optimisation program where all or some of the variables in the model must be nonnegative integers, this being either the objective function, or the left hand side of some of the constraints.

An integer programming problem typically involves variables in the model which must be either 0 or 1.

2.3.3 Other techniques

Dynamic Programming can be used to solve optimisation problems by using backward recursion in obtaining the solution.

Heuristics are used in the case where a given model may seem “hard” to optimise and may take a long period of time to compute. These problems are referred to as being *Nondeterministic Problems* (NP) which can be further classified as NP-*complete* and NP-*hard*.

Metaheuristics is a common term for methodologies based on *Artificial Intelligence* (AI). Metaheuristics uses the strategy behind natural adaptive systems to solve complex problems (Heuristics). Common Metaheuristics are; Genetic Search, Simulated Annealing, Neural networks, Tabu Search and Ant Colony Optimisation.

2.4 Shipment Consolidation

During the delivery process, consolidating orders is required in order to deliver goods in an effective manner with some sort of schedule in mind. Consolidation is a process of assigning orders to shipments by some sort of policy that has been put in place either by the company or by an optimal solution.

As Melbro is trying to consolidate their shipments in a one-to-many environment (i.e. one point of supply to many customers), this could also be viewed as an allocation or assignment problem. The outcome of this is to determine how to allocate inventory, relative to orders received, to the trucks available for delivery given the particular zone and value of stock.

2.4.1 The Transportation Problem

This problem could be defined as a typical *balanced transportation problem* which has been described by Winston and Venkataramanan (2003) as a problem with a set of m demand points and n points of supply where the supply equals the demand. The result of which determines how many units are sent from supply point i to demand point j .

2.4.2 The Assignment Problem

Another class of the *transportation problem* is the *assignment problem*. Again, as described by Winston and Venkataramanan (2003), “an *assignment problem* is a *balanced transportation*

problem in which all supplies and demands are equal to one". This problem is more applicable to Melbro's case as the demand delivered to one customer is fulfilled by one truck only and hence the orders are not split across vehicles.

The *assignment problem* therefore can help to determine which truck to use for which orders although this does not help to solve the problem that Melbro faces relative to routing and distance and may actually result in inaccurate optimal solutions when determining the routing. In order to successfully assign customers that are in a similar demographical zone, another method of assignment needs to be completed in conjunction with this.

2.4.3 Cluster Analysis

As described by Zurini and Sborra (2011), *cluster analysis* is defined as the "assignment of a set of objects into smaller subsets, called clusters, by the similarity between the objects from the same cluster and the differences among the clusters" and also by Hamerly and Elkan (n.d.) as "the task of finding natural groupings in data". *Cluster analysis* therefore uses defined data to group similar objects into such clusters.

Many different methods for cluster analysis exist although the most common one is *k-means clustering*. *K-means clustering* uses a centre based clustering approach by initially selecting *k* centroids, calculating the Euclidean distances between each given data location and the centroids, and using a programming model to optimise the position of the centroids therefore also determining to which cluster each location belongs.

"The Capacitated Clustering Problem (CCP) is one of the underlying optimisation problems for the efficient consolidation of customer orders to vehicle shipments." (Koskosidis and Powell, 1992)

2.4.4 The Combination

Therefore, Melbro's shipment consolidation can be completed by incorporating the techniques of *cluster analysis*, more specifically *k-means clustering* and the *assignment problem*. The specific technique of how this will be completed and the mathematical models for each of the problems will be further discussed in the project development (Section 3.6.2, and 3.7.2).

2.5 The Vehicle Routing Problem

A vehicle routing problem (VRP) is a mathematical model representation of a routing problem faced when travelling (i.e. which point do you visit first, and second, etc.). The VRP originates from the Travelling Salesman Problem (TSP) where a salesman is to visit a number of cities. In an m -TSP, m salesmen are required to visit a given number of cities only once. This is how the VRP originates as a number of customer orders (i.e. Cities) need to be met by a set of vehicles delivering these orders directly.

Customers, or points of delivery, are defined as the *nodes*, and the route that the set of vehicles would take to reach these nodes form the so-called *network*. The problem helps to identify a number of feasible routes from which the optimal solution is determined. The objective of the optimal route is to either minimize distance or costs.

Many variations of the VRP exist, where factors such as; the number of vehicles, the number of depots, type of delivery, etc. determine the variation. In Melbro's case, the VRP is a classic Capacitated VRP (CVRP). This is where each of the vehicles has a maximum capacity, usually measured in load but Melbro being an exception of basing this on product Rand value. This principle is currently what the capacity is based on but ideally, Melbro should aim to maximise the volume of the vehicle too together with the cost as a minimum constraint.

2.6 The Combined Problem

As Melbro faces a problem that involves allocation of inventory and vehicle routing, the problem can be classified as a *Dynamic Routing and Inventory Allocation Problem*. From this, methods to try and incorporate the two techniques need to be investigated further.

2.7 Industry Application

When combining consolidation and routing; Yanchun Pan, Ming Zhou, Zhimin Chen, and Hui Tan (2011) have developed a methodology to determine the optimal order consolidation policy as well as the optimal route for a given DC. Simulation and optimisation techniques were integrated to form a framework (See Figure 4). Three types of consolidation policies were simulated in Arena to determine the best one. With this, an addition of a Genetic Algorithm (GA) using Visual Basic for Application (VBA) was embedded into the Arena model to find the best vehicle route for the given consolidated orders. VBA was also used to create the interface between the two models as shown in the below diagram.

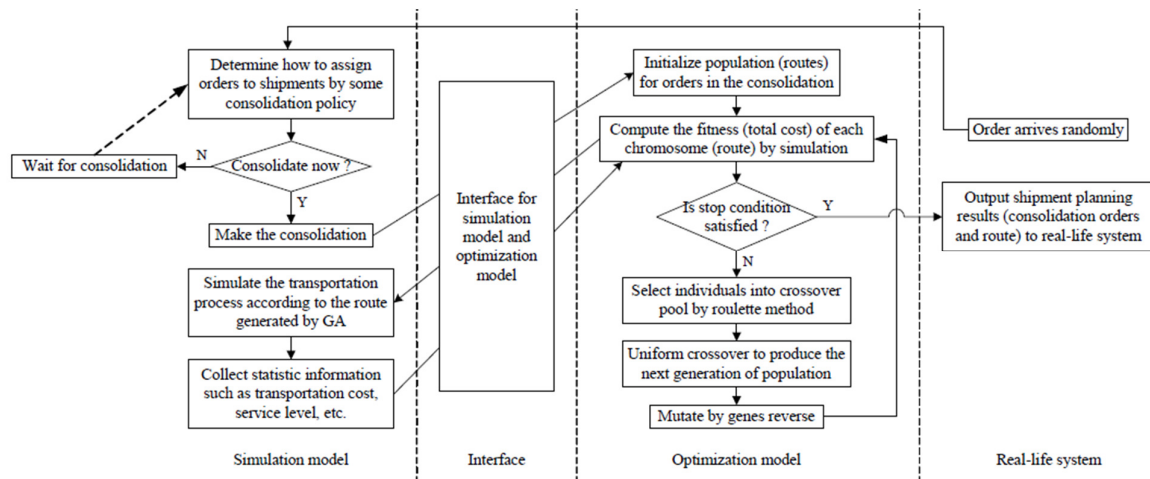


Figure 4 Optimisation Simulation Framework for Pan et al methodology

The results of this particular simulation showed which policy gives the best solution in terms of; cost, arrival time, lead time and order size.

Yugang Yu, Haoxun Chen, Feng Chu (2008) use a 2-step approach to optimise their *Inventory Routing Problem* (IRP), this being the same as DRAI problem mentioned previously. In this approach, the first step is solved by creating an integer programming problem to solve the delivery schedule and the second, using heuristics to construct a set of delivery routes.

The table outlined by Baita, et al (1998) for the CVRP, shows that this type of DRAI problem being reviewed (one-to-many, given number of vehicles, etc.) should consider *Mixed Integer*

Programming (MIP), *Dynamic Programming* and *Heuristic* Techniques as possible solution approaches. This leads to investigate these particular techniques bearing in mind that consolidation and routing needs to be optimised.

In Koskosidis and Powell (1992), the *Capacitated Clustering Problem* (CCP) is used to assign n customer orders into K vehicles. The CCP often tends to form part of a larger problem where vehicle routing is also considered, which in this paper is what we are trying to achieve. The algorithm used to define this problem uses *integer programming* as a base for its formulation, although it is restricted to small scale problems. Therefore for larger scaled problems, an iterative heuristic can be applied.

Figure 5 explains how the iterative heuristic algorithm functions.

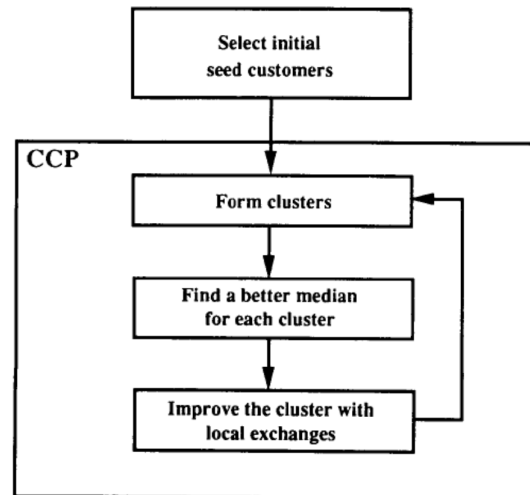


Figure 5 Iterative Heuristic Flow Diagram from Koskosidis and Powell's article on CCP

Finally, Ruiz, R., Maroto, C. and Alcaraz, J. (2004) also use a 2-stage approach to solve a typical VRP. This is achieved by using an enumerative algorithm to determine all feasible routes and from then, an adaptation of an *Integer Program* to select the optimum route. In this problem, a decision support system (DSS) as they call it, is created by developing a software application using Delphi 5.0 and LINGO. The system was tested with a client base of 60 clients, giving results within 60 seconds of solution time. The results also showed that a reduction in distance and costs could be obtained from this model.

2.8 Model Selection

All of these applications use a 2 stage approach to solve the problem of order consolidation and vehicle routing. Therefore in the case of Melbro, 0-1 integer programming models will be used to both optimise the assignment of orders and the routing of each of the vehicles. This will be achieved by creating a 3 stage approach as the consolidation and routing form 2 of the stages where the third stage is created by further splitting consolidation into clustering and assignment where; clustering is the formation of the clusters determined by the nodes' locations and assignment is the process whereby vehicles are assigned to each cluster based on certain conditions. This is further outlined in Chapter 3 and an illustration (Figure 6) of this 3 stage concept is shown below.

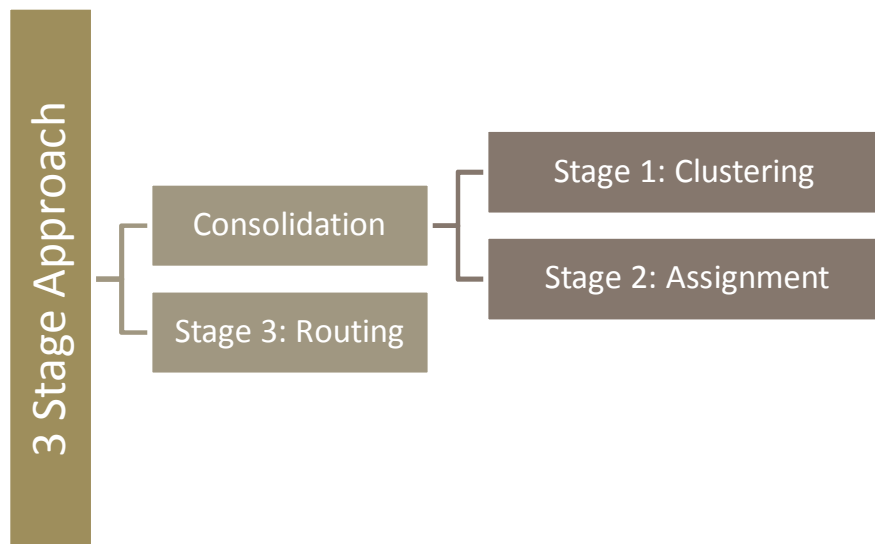


Figure 6 3 Stage Approach

2.9 Computational software

2.9.1 Simulation

Process-Orientated

Arena, mentioned already in paragraph 2.7, is a simulation package that is commonly used for simulating processes. Hence, *Arena* utilises process-oriented simulation. Other packages exist such as *Simul8* although their characteristics are similar to *Arena* and hence, will not be discussed further.

Object-Orientated

SIMIO is an acronym for *Simulation with Intelligent Objects*. This means that SIMIO simulation package utilises object-oriented simulation unlike *Arena*.

2.9.2 Optimisation

For the purpose of computing mathematical programs, optimisation software is usually the best and most practical option as it can be used as a means to solve the given problem. Many different software exist which include LINGO and *Microsoft Excel* including *Excel Solver*. Many other unique *Microsoft Excel Add-ins* have been created by the use of *Excel* capability and VBA technology which will be discussed in the following paragraph 2.9.3.

Downfalls when using optimisation software is that they often tend to have large computational times for larger models. Therefore, the way in which the problem is modelled is crucial.

2.9.3 Excel Solver/VBA

Many *Microsoft Excel* tools, known as “Add-ins”, already exist which justifies that they can be created. Tools such as dynamic programming, VRPs, etc. all have been developed but they come at high price or are complex to use.

A particular Add-in by the name CDXZipStream has been produced by CDX Technologies (Hughes Financial Services, n.d.), at a price, for companies to use in *Microsoft Excel*. The small availability of these Add-ins, show that there is a potential gap to fulfil.

2.9.4 Online Solvers

The same concept of *MS Excel Add-ins* has been found throughout the internet such as *Route Planner* from *MyRoutineOnline*, although these applications only consider the routing of a problem and not the consolidation.

2.10 Data Collection

2.10.1 Google Maps API

When planning routing *Excel* Add-ins and Internet applications both use co-ordinate data to determine the optimal routing. *Google Maps API*, where API stands for Application Programming Interface, is a useful technique that can be used to draw address data. *Google Maps API* Web Services can be accessed through URL interfaces which are determined by specific HTTP requests. URL parameters of the given data can then be drawn or imported as XML data to a specific application. The following data are examples of what can be collected from such requests:

- * Co-ordinates (latitude and longitude) of a given address or vice versa
- * Directions between places
- * Distances between 2 places
- * Distance matrix between multiple places

2.10.2 Google Docs

Google Docs is extremely similar to *MS Office* and *Google Docs Spreadsheet* is the corresponding *Google* version of *MS Excel*. *Google Spreadsheet*, even though similar to *Excel* has some different functionality. Two important points to note of *Google Spreadsheet* are:

- A function, by the name of *ImportXML*, can directly import XML data into a cell.
- *Spreadsheet* solver can only solve linear problems and therefore is very limited.

2.11 Software Selection

The following factors are considered when selecting the proposed solution for Melbo's consolidation and routing problem.

2.11.1 Repeatability/Flexibility

Many simulation and optimisation software packages result in an optimal solution which is often difficult to run on a daily basis. This is either due to the structure of the algorithm, the software used or the size of the model that has been developed.

The aim of the system is to provide Melbro with an optimised delivery system. As the environment is forever changing, a tool needs to be designed so that the solution can be calculated on a daily basis.

2.11.2 Cost

Software is a crucial point to consider as it is expensive and does not present enough value in the eyes of the company owners at Melbro in terms of cost. Currently, they do not have any simulation or optimisation software available for use. This is purely due to the fact that no other work in this avenue is being completed which makes the necessity to purchase software very low.

2.11.3 Simplicity

Ignoring cost being a factor, the desired tool to determine the optimal shipment strategy needs to be simple as the tool will be used by the managers of the dispatch department. Software and techniques that are based on simplicity should be chosen as it is easier for people to understand and use on a daily basis as required.

2.11.4 Accuracy VS Already mentioned factors

According to Melbro's requirements, simplicity, cost and repeatability all override accuracy although this does not allow the model to give a poor optimal solution but rather a "good" one.

2.11.5 Functionality

This refers to the actual functionality of the given model, i.e. what it can and cannot do. Melbro's requirements are very particular and therefore the system needs to be able to function accordingly.

2.11.6 AHP

Due to the many choices, *Analytical Hierarchy Process* (AHP) was used to determine which method should be chosen based on four criteria. These criteria are:

- * Cost
- * Simplicity
- * Accuracy
- * Repeatability
- * Functionality

AHP uses a hierarchy outline, namely an affinity diagram (see Figure 7), and pairwise comparison matrices (see Appendix C) to determine the best software solution. In this case, the software choices that are compared as alternatives are:

- * Simulation
- * MS Excel
- * Google Docs
- * LINGO

The following affinity diagram outlines the criteria and alternative for this problem.

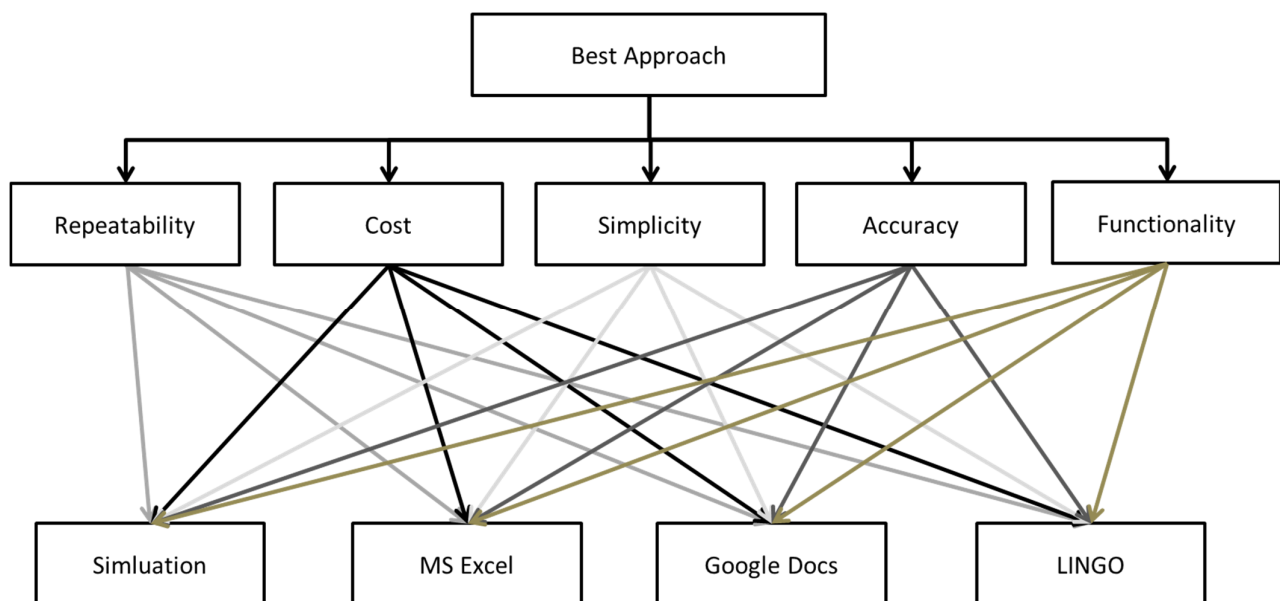


Figure 7 AHP Affinity Diagram

The pairwise comparison matrices use a comparative scale from 1 to 9 (1 being equal importance and 9 being extreme importance). The reciprocal or inverse of this value is used as the opposite element in the matrix. (For example, if i is being compared to j and results in a value of 2, then j is compared to i , the value will be $1/2$). The matrices are given in Appendix C together with the calculations for the given AHP problem.

The results of the AHP show that *MS Excel* is the best software choice (see Table 2). This is proven by having the highest calculated priority weighting. Secondly is *Google Docs*, followed by *LINGO* and finally *Simulation* where *Google Docs* and *LINGO* are extremely close in weight. Therefore *Heuristics* are a strong contender as a methodology to the selected solution.

Table 2 AHP Probability Results

Software	Determined Probability
Simulation	0.113
MS Excel	0.55
Google Docs	0.173
LINGO	0.165

2.11.7 Selected Software

For the above mentioned reasons of repeatability, cost, simplicity, accuracy and functionality, the selected software will be a combination of *Google Docs Spreadsheet* and *MS Excel* with embedded VBA for automation. This also ensures that Melbro will not have to outlay any capital for software. *Google Docs* will be used to collect all data required and *Excel Solver* will be used to perform the mathematical calculations for the various optimisation models discussed. *MS Office* packages are already installed at Melbro. Usually in companies, people are familiar with it, even if only on a surface level unlike other less common software. *Google Docs* follows a very similar principle to *MS Office* although is an online application which allows free access to any user.

Chapter 3

3. Concept Development

3.1 Initial Concept

Similar to what is currently being performed; the dispatch manager will run the *MS Excel* tool to determine the optimal strategy for consolidating loads and vehicle routing. This will replace the existing manual operation. As deliveries start at roughly 6AM, this could be done the day prior to the delivery.

The tool that will be provided will be designed in such a way that the manager will easily follow a progressive cycle to firstly, determine the optimal consolidation of shipments and secondly, to determine the optimal routing for each vehicle. Figure 8 shows the process inputs, transformation and outputs for the described tool.

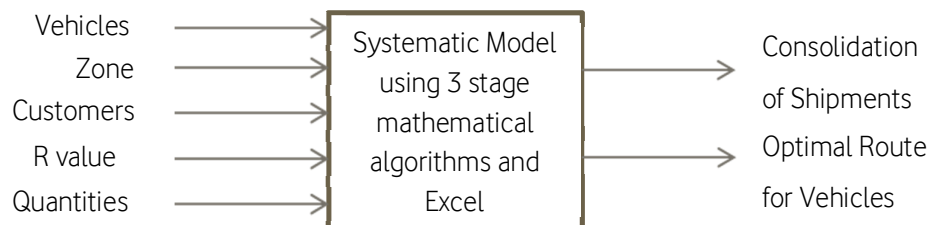


Figure 8 Simple Process Flow

3.2 Implementation Concept Design

The sections to follow all outline the design of the model that is to be implemented. Each section is broken down into the important factors that need to be considered when designing the model and the physical mathematical model that represents the problem of that stage (where applicable).

To summarise, the model is split into four parts. Three of these parts have already been mentioned as “the three stages” within the literature review (See section 2.8). The fourth part originates from the lack of data available. Information about the customer’s addresses needs to be collected as input data for the optimisation models. The three already mentioned stages are namely; Clustering, Assignment and Vehicle Routing.

3.3 Context Data Flow Diagram

“Context Data Flow Diagram: a process model used to document the scope for a system.” (Bentley and Whitten, 2007)

A Context DFD is a DFD where only the communication that is important in the eyes of a system owner is defined. In general, a DFD is a diagram which shows all the interactions between external agents or systems. The model therefore helps to identify the overall purpose of the system. The system shown in the context DFD (Figure 9) on the following page shows the interaction between the consolidation and routing tool, and the; dispatch manager, *Google Docs*, Melbro’s internal system, and Vendors.

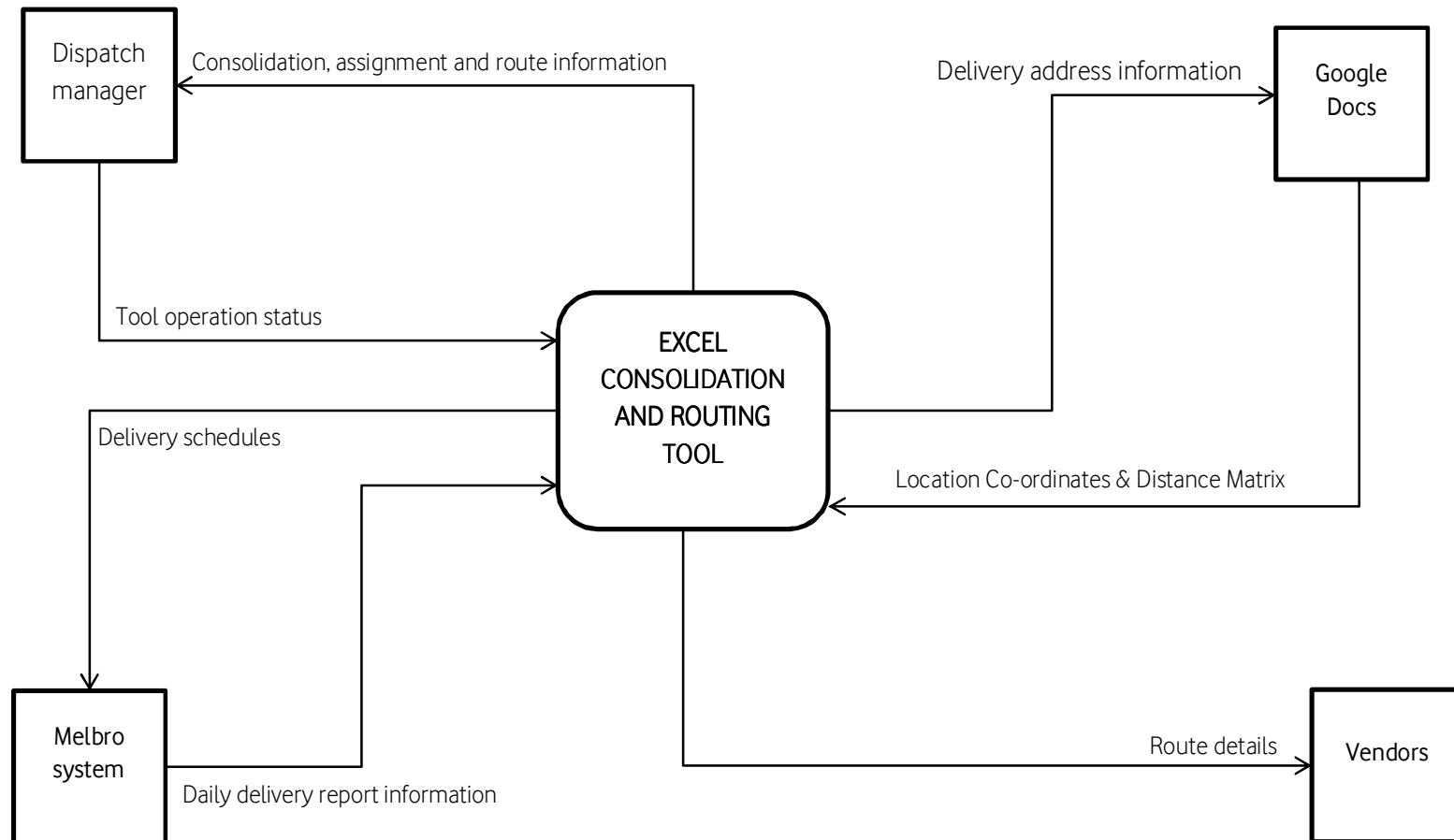


Figure 9 Context Data Flow Diagram

3.4 Functional Decomposition Diagram

A Functional Decomposition Diagram is described by Bentley and Whitten (2007) as “a diagram that partitions the system into logical subsystems and/or functions.” Hence, the diagram is used to break down the system into its various functions by making use of a hierarchical top down structure. In the following functional decomposition diagram (Figure 10), the system that is to be created has been split into 4 separate subsystems as shown numbered from 1 to 4. Below each of these subsystems, are the basic functions for each.

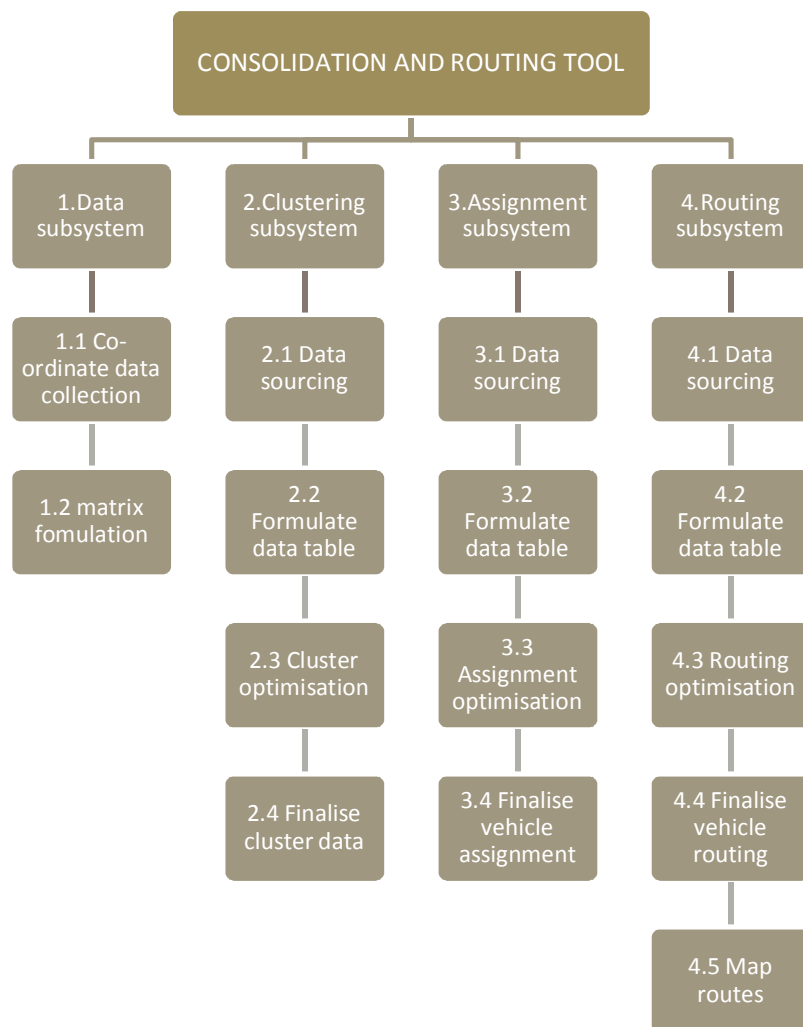


Figure 10 Functional Decomposition Diagram

3.5 Part 1: Data

Part 1 of the model is the “data collection”. Theoretically, Melbro should have a database of this particular customer data readily available for use. For the purpose of exercising the model however, *Google Docs* has been utilized to collect relevant data that is not currently on hand or recorded by Melbro. This however has certain size and corporate limitations when practicing import functions.

As customer information tends to stay unchanged excluding additions, a database is a substantial way in order to refer to this information. This however, will need to be collected by Melbro in some or other form. This could be by; distributing sheets amongst vehicle drivers to capture customer addresses and distances, collecting GPS locations when visiting a customer or customer address forms could be sent to the customers directly for them to complete.

The particular data that is required for the model is broken into two types namely; co-ordinate data and distance data. By using *Google Docs Spreadsheet ImportXML* function together with *Google Maps API Geocoding* and *Distance Matrix*, this data can be exported into *MS Excel* as necessary inputs in part 2 and part 4 of the model. The flow chart (later described in section 3.11) shows exactly how these parts come together and where the information will be carried over to various parts of the tool.

3.6 Part 2: Clustering

Part 2 of the model is used to cluster the various addresses that are detailed in the daily delivery report in order to be used as part of the consolidation process of orders.

3.6.1 Factors to consider

When clustering the addresses, the important things to consider are:

- * Delivery addresses (nodes)
- * Co-ordinates of each node – latitude and longitude
- * Number of nodes
- * Maximum number of nodes per truck = 15
- * Number of clusters to be created

3.6.2 The mathematical model

The objective of the clustering model is to minimize the sum of all the minimum Euclidean distances from the location of each node to the centroids of each cluster. Therefore the model will determine the best position for the centroids of the clusters and hence determine to which cluster a node belongs in. The model is the following;

Let:

$i \in N = \{1, 2, \dots, n\}$ where N is the set of nodes

$j \in K = \{1, 2, \dots, k\}$ where K is the set of cluster centroids

$d_{ij} \triangleq$ the distance between node i and cluster centroid j

$s_{ij} \triangleq \begin{cases} 1 & \text{if } d_{ij} \text{ is the smallest distance between node } i \text{ and cluster centroid } j \\ 0 & \text{otherwise} \end{cases}$

$x_i \triangleq x$ – coordinate of node i

$y_i \triangleq y$ – coordinate of node i

$x_j \triangleq x$ – coordinate of cluster centroid j

$y_j \triangleq y$ – coordinate of cluster centroid j

The objective is:

$$Z = \min \sum_i \sum_j (d_{ij} \times s_{ij})$$

Where,

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

$$\sum_i s_{ij} \leq 15 \quad \forall j \in K$$

$$s_{ij} \in (0,1)$$

3.7 Part 3: Assignment of Vendors

3.7.1 Factors to consider

When assigning vendors or vehicles to clusters there are important things to consider:

- * Cost associated with using a particular vehicle
- * The Rand value of orders and the total Rand value of orders for each cluster
- * The number of cartons for each order and the total for each cluster
- * The capacity volume in cartons of each vehicle
- * The vendor to which the vehicle belongs, the size of the vehicle and the registration

It can be assumed that cartons are considered for capacity rather than weight as the majority of products that are being delivered are generally small and have very little weight. Hence, the dimensions and volume of the orders overrule the factor of weight.

3.7.2 The mathematical model

$i \in V = \{1, 2, \dots, v\}$ where V is the set of vehicles

$j \in K = \{1, 2, \dots, k\}$ where K is the set of clusters

$$x_i \triangleq \begin{cases} 1 & \text{if vehicle } i \text{ is used} \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ij} \triangleq \begin{cases} 1 & \text{if truck } i \text{ is assigned to cluster } j \\ 0 & \text{otherwise} \end{cases}$$

$c_i \triangleq$ the cost associated with using vehicle i

$o_j \triangleq$ the total order value for cluster j

$v_j \triangleq$ the total order volume in terms of cartons for cluster j

$m_i \triangleq$ the maximum capacity in carton volume for vehicle i

The objective is:

$$\min Z = \sum_i \sum_j c_i \times x_i$$

Subject to:

$$\sum_i y_{ij} = 1 \quad \forall j \in K$$

$$\sum_i x_i = K$$

$$\sum_j y_{ij} \times v_j \leq x_i \times m_i \quad \forall i \in T$$

$$x_{ij} \in (0, 1)$$

The constraints explain:

- * For each cluster, only one vehicle must be assigned.
- * The sum of the vehicles used must be equal to the number of clusters that have been developed.
- * The order volume for a cluster must be less than the capacity volume of the truck that is used.

3.8 Part 4: Vehicle Routing Problem

3.8.1 Factors to consider

When optimising the routing for a given vehicle, there are a number of factors to take into consideration, namely:

- * The relevant nodes assigned to the vehicle
- * To/From distances from each node

3.8.2 The mathematical model

The mathematical model for the vehicle routing aims to optimise the total distance travelled by the vehicle by selecting the optimum order in which nodes are visited. Therefore the model is as follows.

Let,

$i, j \in N = \{1, 2, \dots, n\}$ where N is the set of nodes

$d_{ij} \triangleq$ the driving distance from node i to node j

$x_{ij} \triangleq \begin{cases} 1 & \text{if a vehicle travels from node } i \text{ to } j \\ 0 & \text{otherwise} \end{cases}$

The objective is:

$$\min Z = \sum_i \sum_j x_{ij} d_{ij}$$

Subject to,

$$\sum_i x_{ij} \leq 1 \quad \forall j$$

$$\sum_j x_{ij} \leq 1 \quad \forall i$$

$$x_{ij} + x_{ji} \leq 1 \quad \forall i, j \in N$$

$$\sum_i \sum_j x_{ij} = n$$

$$x_{i=j} = 0 \quad \forall i, j \in N$$

$$x_{ij} \in (0,1)$$

3.9 Integration of the system part 1, 2, 3 and 4

3.9.1 Integration of information

The integration of part 1, 2, 3 and 4 is necessary as information flows from a preceding part to the next. A table to follow (Table 3) summarises the inputs and outputs for each part.

Table 3 Inputs and Outputs for System Parts

Inputs	Part	Outputs
Daily Delivery Report information: * Customer Number * Customer Name * Customer Address	1: DATA	a. Longitude/Latitude Data b. Distance Matrix
Part 1a: Longitude/Latitude Data	2: CLUSTERING	Clusters: * Number of clusters * Nodes per cluster
Part 2: Clusters & nodes Daily Delivery Report information: * Customer Number * Customer Name * Invoice Value * Number cartons Vendor/Vehicle information: * Vendor * Vehicle Registration * Vehicle Capacity	3: ASSIGNMENT	Vendor/Vehicle Lists: * Nodes per vehicle * Address for each node
Part 3: Vendor/Vehicle Lists Distance Matrix	4: ROUTING	Route & Map: * Sequence of nodes * Distance between nodes * Total distance travelled

These points of input and output are also highlighted in the Basic Flow Diagram (3.11.4).

3.9.2 Computer integration

Computer integration of the 4 parts of the system can be coordinated by linking cells and using *MS Excel Macros* or VBA. One can use the *Macro Recorder* in *MS Excel* to record the simpler *Macros* and use VBA programming techniques for more complex for-loops, etc. *ActiveX Button Controls* found in *MS Excel Developer Tab* can be added, allowing the Dispatch manager to select the process to complete. Finally, all worksheet data that should not be edited by the dispatch manager should be locked and the worksheet should be encrypted to ensure that no information is tampered with that might cause inaccurate results.

Due to time constraints of the project and the nature and complexity of the integrations required, appropriate cells have been linked in order to link certain data although, it is required that Melbro's system and technical experts help to complete these integrations according to given outlines and functionalities of the model before implementing the model.

3.9.3 Role of the dispatch manager

The role of the dispatch manager is highlighted in the flow diagram that is shown under section 3.11.4. This diagram clearly indicates what communication the dispatch manager must have with the tool as well as what activities he must activate, etc.

3.10 Integration with Melbro's current system

Currently all data that is stored at Melbro is through *Mini Computer Business Applications* (MCBA). This data is extracted via *Data Warehouse* or *Qlikview* into *MS Excel* for use in *Excel*.

In order to run the designed *MS Excel* model, the input data needs to be organised in such a way that the parts can be run effectively. The Daily Delivery Report would be used as an input for the model although Melbro need to make sure that their database system is restructured, as many duplicates exist as well as errors which create a large discrepancy in results.

An example of the Daily Delivery Report can be found on the following page (see Figure 11) where, the data that each part of the system would require is the following:

RUN DATE: AUG 25, 2010 - 11:21				MELBRO TRADING (PTY) LTD				USER: dixon				PAGE 0001			
CAPE TOWN				D A I L Y D E L I V E R Y R E P O R T				Report No: 6.11.5							
RANGE: ALL CHARGE ACCOUNTS LOCATIONS WC HS-CAPE TOWN				W1 JMC-CAPETOWN				ALL DELIVERY ACCOUNTS ENDING DELIVERY DATE 30/08/10							
CUST No	CUSTOMER NAME ADDRESS			INV No	INV DATE	INV AMOUNT	DEL DATE	LATEST DATE	COD AMOUNT	CTNS	CASES * if country order	VALUE	WEIGHT	VOLUME COMMENT	STOR LOC
C50112	TRADE SHOW - NON FOOD (CAPE) CAPE			434624	16/07	.00	ASAP			2		.00			
C60374	OLCO HARDWARE UNIT 7 LOSACK FACTORIES 18 LOSACK AVENUE			506341	24/08	1095.06	ASAP			2		1095.06	19.00	2.00	
C60842	THE CRAZY STORE (BF) SHOP 13A PALM GROVE CENTRE CNR MAIN RD & CHURCH STREET			461049	30/07	2809.61	01/08	31/08		4		2809.61	37.00	4.00	
				461742	30/07	2301.67	01/08	31/08		3		2301.67	36.00	3.00	
				480068	11/08	659.49	10/08	10/08		4		659.49	11.00		
				505891	24/08	184.77	ASAP	30/08		1		184.77		FLOWERS & VASES	
C60900	THE CRAZY STORE (BH) SHOP 24 WEST COAST MALL CNR WEST COAST & SANDOWN RDS			499956	20/08	227.82	ASAP	30/08		1		227.82	4.00	FLOWERS + VASES	
C63075	PACKAGING ISSUES I SHENG PLASTICS			440403	20/07	.00	ASAP			1		.00	20.00		
				504722	24/08	.00	ASAP		3		.00				
C66876	PLASTIC MUNDIAL ROODEPOORT			486668	13/08	4256.64	ASAP			3		4256.64	18.00	3.00	

Figure 11 Daily Delivery Report

Other than the data that has already been mentioned, the physical address of the customer is also required. It can be identified that the last column in the daily delivery report - Store Location. Evidently, this particular data is not being pulled through although this would be extremely beneficial for the model. This lack of data constructs the need to search elsewhere and to find alternative sources. After some investigation, it was found that this data is recorded within the customer list.

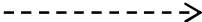
As a future consideration, it would be beneficial to make the most use out of the model results. The results gained, after some manipulation, may act as input data for the current Delivery Schedules that need to be captured on Melbro's system. These schedules currently need to be recorded by the dispatch manager once he has manually consolidated orders. The process is seen as very time consuming and these inefficiencies will be alleviated if this process were to be automatic. An example of this Delivery Schedule is shown on the following page (See Figure 12).

3.11 Flow Diagram of the Tool System

A basic flow diagram of the tool system is shown on the following page (section 3.11.2, Figure 13). A key for this diagram is found under section 3.11.1 (Table 4). This diagram summarises the overall concept of the tool and how the dispatch manager will operate it.

3.11.1 Flow diagram Key

Table 4 Flow Diagram Key

SYMBOL	DESCRIPTION
	System/Subsystem
	Button
	Activity/Operation
	Information flow

3.11.2 Basic Flow Diagram

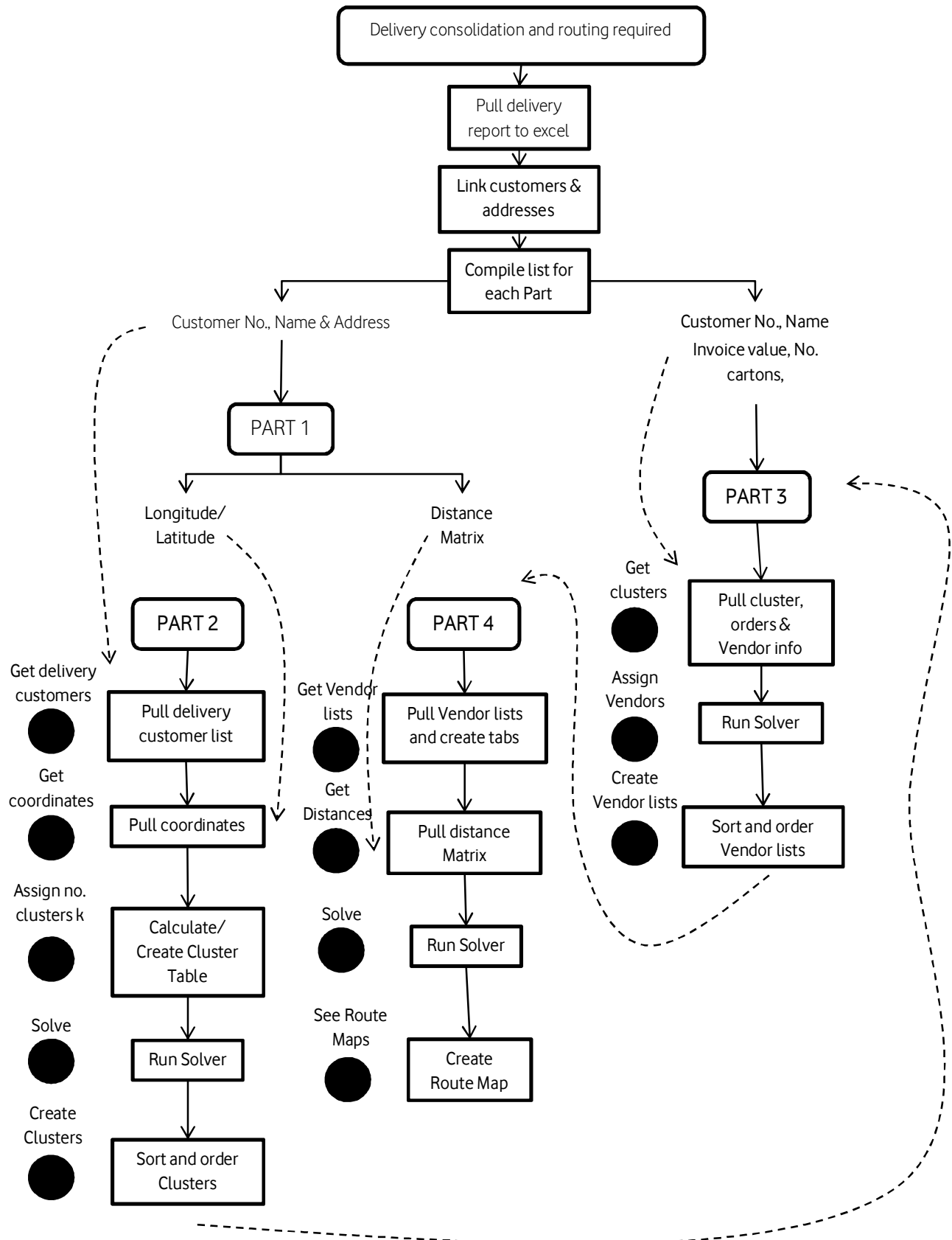


Figure 13 Basic Flow Diagram

Chapter 4

4. Physical Model

Chapter 4 explains the *MS Excel* design. This includes how the mathematical model is formulated and also how all the parts interrelate in order to create an easy and flowing system that can be controlled by the dispatch manager. One *Excel* workbook has been created with multiple tabs for each of the parts and sub-sections. A list of these tabs is outlined in Appendix D. The way in which these tabs have been order illustrates the procedure to which the model would follow. Physical screenshots of these designs are outlined in Appendix E.

4.1 Part 1 Data Design

As previously mentioned, data collection is completed by utilising *Google Docs Spreadsheet* together with *Google Maps API*. Within the *MS Excel* workbook, 2 tabs have been designed and created, which are:

1. Latitude/Longitude Tab
2. Distance Matrix Tab

These tabs were then imported into *Google Docs Spreadsheet* in order to capture the relevant information and the data was exported back into *MS Excel* for use in the model.

4.1.2 Design of data collection

Latitude/Longitude Data

In order to obtain or collect latitude and longitude coordinate data for each given address (also referred to as node within this section), the *Google Maps API* HTTP/URL address or “Geocode” is required as a source for each individual node. Using the *importXML* function within *Google Docs*, the design of the actual data collection is simple. The latitude and longitude data worksheet therefore looks like the following:

Table 5 Latitude/Longitude Data Collection

Node	Customer no.	Customer address	URL address	Latitude	Longitude

The *Google Maps API* HTTP, used to obtain parameters about a specific node or address uses *Geocoding*. When providing a HTTP in a given format, a URL can be created which returns specific details about the address given in XML code. The *Geocode* HTTP address format is as follows:

<http://maps.googleapis.com/maps/api/geocode/xml?address=address&sensor=false>

Where, the underlined address will be variable address that is obtained from the “Customer address” column cells.

The function in *Google Docs*, ImportXML, is used in the latitude and longitude columns to pull the latitude and longitude parameter data from the described XML for each address. Therefore, for each column, the ImportXML function is the following:

- * Latitude = ImportXML(API URL Address, “//location/lat”)
- * Longitude = ImportXML(API URL Address, “//location/lng”)

1. Distance Calculation/Matrix

To obtain information about the travelling distances between nodes, one can either use the *Directions API* or the *DistanceMatrix API*. The first of the two is namely for a start and end address and returns the described route with directions, as well as the latitude/longitude coordinates of the start and end point and finally the distance to travel between each direction instruction . This therefore is limited to two addresses, a start and an end whereas the *DistanceMatrix API* does not return the physical route directions but rather allows us to input multiple origins and multiple destinations with the distances between each origin and destination as an output.

In order to complete the routing problem, a distance or from/to matrix is required between each of the nodes. This is described later as d_{ij} in Part 4 of the model in section 3.8.2. *DistanceMatrix API* uses the same method as mentioned in the latitude/longitude data. A HTTP

address is created by means of using a standard format which then in result, returns a URL of XML data that contains different parameters including each of the necessary distances for the required matrix. The format of the HTTP address is the following:

`http://maps.googleapis.com/maps/api/distancematrix/xml?origins=origin_address&destinations=destination_address1|destination_address2|destination_address3&mode=driving&language=en&units=metric&sensor=false`

Therefore, to obtain the distances that are required, a table (Table 6) of the following format is set up.

Table 6 FROM/TO Distance Matrix

	TO					
	Node	1	2	...	n	
FROM		Node 1 Address	Node 2 Address	...	Node n Address	HTTP Address
	Node 1 Address					
	Node 2 Address					
	...					
	Node n Address					

Table 6 shows that for each “From” address, a HTTP request is determined. From this HTTP, using the ImportXML function in *Google Docs SpreadSheet*, each of the distances for the matrix can be calculated. As there are many output parameters in the URL XML file that is created by HTTP, only the most relevant data needs to be drawn. This output contains information about time (seconds and in minutes) and distance (metres and in kilometres). Km would be the best option although this output is defined as text which does not help facilitate the tool when calculations are required to be completed. Hence, the distance in metres, which

is defined as a value, will be selected as an input into the table as shown above. The table is extracted back into the *MS Excel* worksheet. As the distances contained in this table are in metres, the data is simply be divided by 1000 into a replica tab to convert the value from *m* into *Km* for further use.

Each of the blank cells that are for data input will therefore contain the following *Google* formula:

=ImportXML (ROW HTTP ADDRESS, “//element[#]/distance/value”)

Element number helps to link the node number to the desired distance value. *Google DistanceMatrix API* uses the order of the nodes in the HTTP description to systematically number the output parameters. Hence, node 1 will be the same as element 1.

4.2 Part 2 Clustering Design

The Clustering Template *MS Excel workbook* is formulated by using the 4 functions mentioned in the Functional Decomposition Diagram (section 3.4). Tabs by the names of; Clusters, Map Data, Map Cluster Data and Cluster Sets are formulated in order to follow out these 4 functions that are described.

The first sheet in the workbook contains the variable data/inputs. In this, the number of clusters that are required is shown which is determined by the following calculation:

$$k = \frac{\sum \text{nodes}}{\text{Max number of nodes allowed per truck}}$$

Where, *k* is the number of clusters which is to be rounded up to the next whole number and the maximum number of nodes allowed by truck is currently determined as 15.

4.2.1 Clusters

The Clusters tab is self-explanatory in its function. Depending on the value of *k* in the variable sheet, depends on how many cluster centres there should be and hence, the number of Euclidean distances are to be calculated as there are more clusters and hence centroids. Table 7 below shows the how main data table is set up in the cluster development tab. This clearly shows that the distances to centroids (denoted by “D to C”) are from 1 to *k*. The minimum

distance is calculated by the *MS Excel* formula $=\min(D \text{ to } C1:D \text{ to } Ck)$ and the Cluster is determined by an if statement (i.e. if $D \text{ to } C1 = \text{minimum distance}$, then “Cluster1” is the cluster that the node belongs in).

Table 7 Cluster Development Data Table

Node	Latitude	Longitude	D to C1	D to C...	D to Ck	Cluster	Min Distance
Sum of Minimum Distances							

In order to optimise the clusters, *MS Excel Solver* is run. *Solver* allows one to complete mathematical programming within a *MS Excel* worksheet according to given parameters placed in cells. The solver uses the already described mathematic algorithm in section 3.6.2 to optimise the centroid coordinates based on minimizing the total sum of the minimum distances. The conditions for the mathematical algorithm are expressed in the *Solver* tool according to the cells that the objective has been set within (sum of minimum distances) and the cells that are required to be changed (i.e. variable cluster centres) to obtain the minimum objective. The outcome of this optimisation is a list of cluster centres together with various nodes that have been assigned.

4.2.2 Map Data and Map

Map data exists in order to restructure data. This is done in such a way to ensure that the data's continued used throughout the model exists. The data in this tab is also used to insert the scatter graph found in the map tab. This graph shows the node and centroid coordinates and helps to give a visual representation of the cluster centroids in relation to each of the nodes (See Figure 14). A static representation from Google Maps is also used to illustrate this fact.

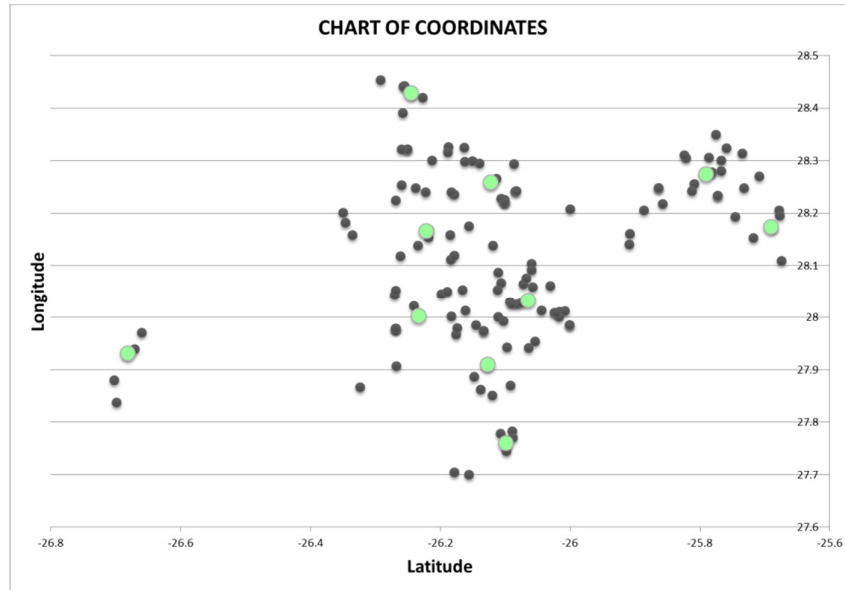


Figure 14 Graph showing node and centroid coordinates

4.2.3 Cluster Data and Sets

These two tabs; cluster data and sets, help to define the clusters explicitly. As an output from the cluster tab, certain clusters may contain too many nodes as they were grouped based on the closest distance. Therefore, cluster data helps to outline exactly what data was gained from the output of the optimisation model and cluster sets helps to explicitly define the clusters by splitting clusters into two or more groups dependent on the amount of nodes.

Therefore, the cluster data will define the clusters by means of the following table:

Table 8 Clusters

Cluster	No. Nodes Assigned	Min Trucks Required

The Cluster Sets tab defines each cluster by listing the nodes within that cluster, the Rand value of the orders for each node, and the number of cartons associated with that order. If a node has more than the desired amount (i.e. + 16 nodes), the clusters need to be split. The sharing of nodes is done by means of using the solver once more. Typical principles of sharing are used as a basis for the solution. This is such as the total amount of nodes per shared cluster must be less than or equal to the total nodes divided by two. The rand value as well as the number of cartons also following this same principle of sharing.

Some orders were found to be extremely high in Rand value which caused errors within results. An assumption was made that if a particular order is greater than or equal to R30000, the order should be excluded from the cluster and should be assigned its own vehicle. This is shown by a description: "1xoutlier". In terms of the business environment, this assumption can be seen as valid. An order with such a large Rand value should be noted as a priority order, therefore making it utterly important to deliver at the best possible service and in a timely manner. A Large Rand values also ensures that an order is large in its capacity making a single truck useful for this operation.

4.3 Part 3 Assignment Design

Using the information gathered from the Cluster Set tab, vehicle assignment can be conducted. The assignment optimisation model is detailed in the Assignment tab although certain information is also required about the specific vehicles. Therefore, a Vehicles tab is also set up in order to define the various specifications for each vehicle.

4.3.1 Vehicles

Like clusters, information relating to the cost of vendors is recorded in the Variables tab. This is to allow for variable changes over time when executing the model without having to update each vehicle independently.

The vehicle tab contains information such as; vehicle number, vendor name (i.e. Kargo), vehicle registration number, capacity of the vehicle in terms of tonnes, cubic metres and cartons,

whether or not the vehicle has insulation and finally, the cost associated with using a particular vehicle for delivery.

4.3.2 Assignment

As for the Assignment tab, this is based on the mathematical model set out in section 3.7.2. A matrix is defined as to whether or not a given vehicle is assigned to a particular cluster set. The minimizing function is set at achieving the lowest possible cost but the model also ensures that the capacity considerations of the orders and the vehicles are considered. A total of 28 vehicles are available for use with 2 being 4 ton vehicles and the rest 1 ton.

The results from this tab are the following:

- Whether or not a particular vehicle was used
- The cluster to which the vehicle was assigned
- The number of cartons that is associated with the particular cluster

4.4 Part 4 Routing Design

Part 4 of the model consists of the following components; Individual Distance Matrices, Routes, and finally, Vehicle Maps.

4.4.1 Individual Distance Matrices

After gathering information about the cluster sets and the assignment of vehicles, the individual distance matrices were set up. These matrices contain the same information as the distance matrix described previously, although on a much smaller scale. Only relative values for a given set of nodes are described. I.e. if a vehicle needs to visits 5 nodes, namely; 48, 49, 98, 104, 117, and 134, then the distance matrix for that particular vehicle will constitute a 5 by 5 matrix.

4.4.2 Route

The Route tab uses the mathematical modelling principle outlined in section 3.8.2. Matrices similar to that of the distance matrices are set up although these matrices contain binary variables rather than set values. Solver helps to optimise this model by minimizing the total distance travelled as an objective function. The sequence of how vehicles should travel to nodes for delivery is outlined by this binary output.

4.4.3 Vehicle Maps

Although the sequence has been outlined by the Route tab, it is often difficult to comprehend or recognise the route that should be taken. Therefore, individual maps for each vehicle's delivery schedule are outlined in this tab. This uses the list of nodes described, the customer address associated and the URL address for the desired static Google Map.

5. Results

5.1 Validation and Testing

Testing and validating a model can help to determine whether it physically works and is feasible. Testing therefore helps to determine whether or not the results obtained from the tool are feasible and optimal (i.e. the consolidated vehicles and the route in which a vehicle should follow).

5.1.1 Comparison

The factors considered when testing were:

- * Cost
- * Distance
- * Vehicle Utilisation

The results obtained from the model output should give a “better” result than the current, manual operation. Therefore, cost of vehicles should decrease, the distance that vehicles travel should decrease (which may in turn allow vehicles to increase their maximum stops per day after some investigation and sampling) and finally vehicle utilisation should increase which also in turn decreases the total number of vehicles used for a daily delivery schedule. As distances of the actual deliveries were not recorded, we cannot compare this calculation directly.

From these mentioned factors, it is clear that a comparison needs to be executed. Hence, a case study of the manual operation and the model will be compared. July the 16th was chosen for this purpose of comparing results as the deliveries were seen as “normal” on and around that period (i.e. No public holidays, seasonality, etc.).

5.1.2 Computation

Another method is to test whether or not the model is feasible by means of analysing the computational parameters. This may include the time that it takes to run the tool and to obtain a result from start to finish. (This may also be compared to the time that it currently takes the dispatch manager to manually complete). With this said, this method of validation will only be appropriate for use once the model has been automated by Melbro's programming team. This will be discussed in more detail in the future recommendations of the model.

5.2 Case Study Comparison

As mentioned in the above section 5.2.1, a comparison was done for July the 16th. The results showed that every intention was fulfilled. I.e. Cost of vehicles decreased and utilisation levels increased. Table 9 highlights the total savings that could be made with respect to a decrease in the number of vehicles used for delivery.

Table 9 Vehicle Related Savings

SAVINGS	
Per day	R 12 000
Per week (5 days/week)	R 60 000
Per year (52 weeks/year)	R 3 120 000

Utilisation levels increased by 17%: from an average of 49% to 66%. This however could be higher although this is expected as from the model, the number of nodes to be assigned to a vehicle can be increased which will increase the utilisation for each vehicle. The following page outlines these utilisation levels and cost differences between the "actual" scheduled deliveries on the 16th of July and the "model" output according to the daily delivery report of the 16th.

Table 10 Actual VS Model Results

ACTUAL

Number of Vehicles Used: 23
Cost of Vehicles Used: 36000
Average % Utilisation of Vehicles: 49%

Registration	Capacity (ctns)	Ctns	Utilisation
JRM 398 GP	30	12	40%
JXH 492 GP	30	15	50%
NFZ 949 GP	30	13	43%
NKL 873 GP	30	14	47%
PVX 648 GP	30	19	63%
RJX 618 GP	30	39	130%
TGW 564 GP	30	17	57%
TKJ 834 GP	30	4	13%
TWT 927 GP	30	21	70%
VJK 228 GP	30	12	40%
VLP 606 GP	30	13	43%
VTR 920 GP	30	22	73%
VVW 975 GP	60	5	8%
VWS 586 GP	60	18	30%
WDV 717 GP	30	6	20%
WZL 604 GP	30	18	60%
XGW 698 GP	30	8	27%
XNW 909 GP	30	9	30%
XSF 296 GP	30	10	33%
XZH 441 GP	30	17	57%
YYT 887 GP	30	21	70%
YYT 925 GP	30	23	77%

MODEL

Number of Vehicles Used: 15
Cost of Vehicles Used: 24000
% Utilisation of Vehicles: 66%

Vehicle No	Registration	Capacity (ctns)	Ctns	Utilisation
1	TGW 564 GP	30	24	80%
2	VVW 975 GP	60	39	65%
3	VWS 586 GP	60	31	52%
4	YYT 887 GP	30	15	50%
5	YYT 925 GP	30	15	50%
8	RJX 618 GP	30	23	77%
10	WDV 717 GP	30	10	33%
17	VJK 228 GP	30	21	70%
18	VLP 616 GP	30	21	70%
19	WYP 063 GP	30	18	60%
20	CRN 403 GP	30	19	63%
21	NKL 873 GP	30	29	97%
22	NNB 650 GP	30	24	80%
25	XSF 296 GP	30	17	57%
26	JXH 492 GP	30	24	80%

5.3 Implementation Benefits

Therefore the model has the following potential benefits if in place with the required automation enhancement:

- * Dispatch managers will save time as the process will no longer be manual and the decision will be made by the tool rather than the manager
- * Human error as well as bias decisions will be eliminated from the shipment planning strategy
- * Hence, managers can focus on other areas for the dispatch process which may lead to potential improvements in other fields
- * The number of vehicles could be reduced given the optimal strategy
- * Money will be saved on delivery costs due to a possible reduction in vehicles used as well as more effective utilisation of vehicles
- * The solution may give rise to possible outcomes which have not yet been considered

6. Future Recommendations

As already mentioned, the model requires automation that can only be provided by the skill set of a computer programmer. By outlining the functionalities and method of how the system should run automatically, a computer programming can simply write the code according to the desired functions.

Another future recommendation is to link the model with Melbro's current data system. This will eliminate additional procedures that the dispatch manager usually should complete within a normal working day thus giving him even more time to work on more important tasks and procedures.

Melbro should consistently check the results of the model as trends may become noticeable after some period of time i.e. the number of nodes per vehicle may be increased. This will help lead to continuous improvement in the workplace relative to this particular field.

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Appendices

Appendix A: Table of JMC Brands

JMC Brands
Wrigley
Mars Africa
USN
Act II Microwave Popcorn
Katjes
Hipp Organic
Finn Crisp
Campbells
Evian
Cape Kingdom
Bebivita

Appendix B: Vendors

VENDOR	REGISTRATION	SIZE
KARGO	VWS 586	4 TON
	VVW 975	4 TON
	TGW 564	1 TON
	YYT 887	1 TON
	YYT 925	1 TON
CCI	RJX 618	1 TON
	YGV 684	1 TON
	NFZ 949	1 TON
	VTR 920	1 TON
	JRM 398	1 TON
	XZH 441	1 TON
	WDV 717	1 TON
	WZL 604	1 TON
MXC	VJK 228	1 TON
	WYP 063	1 TON
	NZK 027	1 TON
	PVX 684	1 TON
	TKJ 834	1 TON
	VLP 616	1 TON
JM. OEL	XGW 698	1 TON
	NNB 650	1 TON
	CRN 403	1 TON
	NKL 873	1 TON
	XSF 296	1 TON
	VNR 134	1 TON
GROLINK	JXH 492	1 TON
	TWT 927	1 TON
	XNW 909	1 TON

Appendix C: AHP Pairwise Comparison Matrices

Repeatability	Sim	Excel	Google	LINGO						AVE
Sim	1.00	0.17	0.50	3.00	0.107	0.103	0.105	0.176		0.123
Excel	6.00	1.00	3.00	9.00	0.643	0.621	0.632	0.529		0.606
Google	2.00	0.33	1.00	4.00	0.214	0.207	0.211	0.235		0.217
LINGO	0.33	0.11	0.25	1.00	0.036	0.069	0.053	0.059		0.054
Sum	9.33	1.61	4.75	17.00						1
Simplicity	Sim	Excel	Google	LINGO						AVE
Sim	1.00	0.13	0.25	2.00	0.074	0.072	0.071	0.125		0.086
Excel	8.00	1.00	2.00	9.00	0.593	0.576	0.571	0.563		0.576
Google	4.00	0.50	1.00	4.00	0.296	0.288	0.286	0.25		0.28
LINGO	0.50	0.11	0.25	1.00	0.037	0.064	0.071	0.063		0.059
Sum	13.50	1.74	3.50	16.00						1
Functionality	Sim	Excel	Google	LINGO						AVE
Sim	1.00	0.17	3.00	0.25	0.09	0.11	0.188	0.046		0.11
Excel	6.00	1.00	7.00	4.00	0.53	0.64	0.438	0.734		0.59
Google	0.33	0.14	1.00	0.20	0.03	0.09	0.063	0.037		0.06
LINGO	4.00	0.25	5.00	1.00	0.35	0.16	0.313	0.183		0.25
Sum	11.33	1.56	16.00	5.45						1

Cost	Sim	Excel	Google	LINGO						AVE
Sim	1.00	0.13	0.20	2.00	0.07	0.07	0.059	0.143		0.09
Excel	8.00	1.00	2.00	6.00	0.55	0.56	0.588	0.429		0.53
Google	5.00	0.50	1.00	5.00	0.34	0.28	0.294	0.357		0.32
LINGO	0.50	0.17	0.20	1.00	0.03	0.09	0.059	0.071		0.06
Sum	14.50	1.79	3.40	14.00						1
Accuracy	Sim	Excel	Google	LINGO						AVE
Sim	1.00	3.00	5.00	0.33	0.22	0.32	0.313	0.201		0.26
Excel	0.33	1.00	2.00	0.20	0.07	0.11	0.125	0.121		0.11
Google	0.20	0.50	1.00	0.13	0.04	0.05	0.063	0.075		0.06
LINGO	3.00	5.00	8.00	1.00	0.66	0.53	0.5	0.603		0.57
Sum	4.53	9.50	16.00	1.66						1

CRITERIA	Repeat	Cost	Simplicity	Accuracy	Functionality							AVE
Repeat	1.00	2.00	0.50	5.00	0.50	0.175439	0.240096	0.117647	0.3125	0.193548	0.207846	
Cost	0.50	1.00	0.50	3.00	0.25	0.087719	0.120048	0.117647	0.1875	0.096774	0.121938	
Simplicity	2.00	1.00	1.00	4.00	0.50	0.350877	0.120048	0.235294	0.25	0.193548	0.229954	
Accuracy	0.20	0.33	0.25	1.00	0.33	0.035088	0.039616	0.058824	0.0625	0.129032	0.065012	
Functionality	2.00	4.00	2.00	3.00	1.00	0.350877	0.480192	0.470588	0.1875	0.387097	0.375251	
Sum	5.70	8.33	4.25	16.00	2.58						1	

Sim	0.113		
Excel	0.55		
Google	0.173		
LINGO	0.165		

Appendix D: MS Excel Model Tabs

Tab Name	Description
Variables	Includes Cluster and Vehicle Variable Data
Lat&Long	Table of latitude and longitude coordinates for customers given their particular address
Distance Matrix (m)	Matrix of to/from distances for all nodes measured in metres
Distance Matrix (km)	Matrix of to/from distances for all nodes measured in kilometres
Vehicles	List of vehicles and related information such as cost, capacity, and registration
Invoices	List of invoices required to be delivered
Clusters	Cluster optimisation model used to cluster nodes according to their geographical location
Map Data	Cluster output data that is also used to create a charted map of coordinates
Map	Map of node coordinates as well as cluster centre points & Google Map representation of data
Cluster Data	Summary of cluster model output
Cluster Sets	Model used to split clusters if number of nodes per cluster is too large
Assignment	Assignment optimisation model used to assign vehicles to clusters
Individual Distances Matrices	The relative distance matrices for each of the vehicles
Route	Route optimisation model used to determine the optimal sequence or routing for vehicles
Vehicle Maps	A geographical representation of the route for each vehicle
Improvements	Summary of the actual data VS the model output and the improvements and cost savings thereof

CLUSTERS						VEHICLES					
Determination of No. of Clusters											
No. of nodes =		140				KARGO 1t		1000			
						KARGO 4t		3000			
Max no. of nodes per truck =		15				CCI COURIERS		1500			
						MXC COURIERS		1500			
Min No. of trucks required =		10				JM OELSON		1500			
						GROLINK COURIERS		1500			

Lat&Long

Node	Cust No	Customer Name	Address Line 1	Address Line 2	Combined Address	Postal Code	Geocode	Latitude	Longitude
1	T08254	BINUNS - MENLYN	Cnr Atterbury Rd + Lois Ave	MENLYN	Cnr Atterbury Rd + Lois Ave MENLYN	63	http://maps.googleapis.com/maps/api/geocode/xml?address=Cnr+Atterbury+Rd+Lois+Ave,MENLYN&sensor=false	-25.7817141	28.2778057
2	Z09809	BP BROADACRES	CNR CEDAR RD + VALLEY RD	BROADACRES	CNR CEDAR RD + VALLEY RD BROADACRES	2146	http://maps.googleapis.com/maps/api/geocode/xml?address=CNR+CEDAR+RD+VALLEY+RD,BROADACRES&sensor=false	-26.0008231	27.9850682
3	Z95693	BP FOURWAYS	CNR SUNRISE BLVD + WILLIAM NICOL DR	WITKOPPEN	CNR SUNRISE BLVD + WILLIAM NICOL DR WITKOPPEN	2068	http://maps.googleapis.com/maps/api/geocode/xml?address=CNR+SUNRISE+BLVD+WILLIAM+NICOL+DR,WITKOPPEN&sensor=false	-26.0161472	28.010195
4	Z45356	BP MONTECASINO	WILLIAM NICOL ROAD	FOURWAYS	WILLIAM NICOL ROAD FOURWAYS	2055	http://maps.googleapis.com/maps/api/geocode/xml?address=WILLIAM+NICOL+ROAD,FOURWAYS&sensor=false	-26.0240528	28.0088936
5	Z75569	BP RUSLOO S/STATION	3132 MC Botha Dr	VOSLOORUS	3132 MC Botha Dr VOSLOORUS	1475	http://maps.googleapis.com/maps/api/geocode/xml?address=3132+MC+Botha+Dr,VOSLOORUS&sensor=false	-26.3495584	28.2001464
6	Z21786	BREDELL SPAR 2	169 3rd Ave	KEMPTON PARK	169 3rd Ave KEMPTON PARK	1619	http://maps.googleapis.com/maps/api/geocode/xml?address=169+3rd+Ave,KEMPTON+PARK&sensor=false	-26.08594	28.29388
7	Z10330	BROADACRES S'SPAR	CNR CEDAR RD + VALLEY RD	BROADACRES	CNR CEDAR RD + VALLEY RD BROADACRES	2021	http://maps.googleapis.com/maps/api/geocode/xml?address=CNR+CEDAR+RD+VALLEY+RD,BROADACRES&sensor=false	-26.0008231	27.9850682
8	X10569	BUCCLEUCH KWIKSPAR	10 Gibson Dr	BUCCLEUCH	10 Gibson Dr BUCCLEUCH	1406	http://maps.googleapis.com/maps/api/geocode/xml?address=10+Gibson+Dr,BUCCLEUCH&sensor=false	-26.0592849	28.1038615
9	T10662	BUILDING IMPROVEMENT & GAS	232 COMMISSIONER ST	KRUGERSDORP	232 COMMISSIONER ST KRUGERSDORP	1739	http://maps.googleapis.com/maps/api/geocode/xml?address=232+COMMISSIONER+ST,KRUGERSDORP&sensor=false	-26.0978831	27.7542588
10	Z11411	CALTEx CEDAR ROAD	10 CEDAR ROAD	FOURWAYS	10 CEDAR ROAD FOURWAYS	2090	http://maps.googleapis.com/maps/api/geocode/xml?address=10+CEDAR+ROAD,FOURWAYS&sensor=false	-26.0164511	28.0004395

Distance Matrix

FROM/TO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	48.16	43.56	45.09	78.31	37.19	48.16	40.95	69.62	44.75	61.66	50.57	57.62	41.44	51.1	40.97	0	71.29	64.66	51.17
2	48.74	0	3.498	4.751	54.65	51.37	0	17.38	34.86	2.343	67.81	48.84	47.46	45.02	33.22	31.72	48.74	27.35	20.76	41.35
3	48.6	4.596	0	1.53	52.79	49.5	4.596	15.52	39.42	2.951	65.94	46.97	45.6	43.15	31.35	29.86	48.6	26	19.42	39.49
4	48.14	3.798	0.909	0	52.32	49.04	3.798	15.06	38.62	2.153	65.48	46.51	45.14	42.69	30.89	29.39	48.14	25.21	18.62	39.02
5	79.16	54.42	52.31	51.4	0	50.28	54.42	44.63	65.28	52.77	29.46	25.05	17.19	43.93	32.13	42.66	79.16	53.37	52.61	23.96
6	38.43	49.1	46.99	46.08	47.54	0	49.1	31.88	70.4	47.45	25.04	13.95	23.76	7.579	17.24	9.984	38.43	58.49	64.02	17.31
7	48.74	0	3.498	4.751	54.65	51.37	0	17.38	34.86	2.343	67.81	48.84	47.46	45.02	33.22	31.72	48.74	27.35	20.76	41.35
8	41.6	16.58	13.83	14.01	46.03	42.75	16.58	0	51.4	14.94	59.19	40.22	38.84	36.39	24.59	21.39	41.6	35.78	29.25	32.73
9	68.94	34.2	37.66	38.91	65.94	92.56	34.2	54.31	0	36.5	76.02	69.95	59.29	66.12	54.32	68.65	68.94	12.53	23.12	62.46
10	48.12	2.999	1.154	2.408	52.31	49.03	2.999	15.04	37.86	0	65.47	46.5	45.12	42.67	30.87	29.38	48.12	25.01	18.42	39.01

Vehicles

LIST OF AVAILABLE VEHICLES							
Vehicle	Vendor	Registration	Capacity (tons)	Capacity (m ³)	Capacity (Ctns)	Insulation?	Cost (R)
1	KARGO	TGW 564 GP	1	20	30	TRUE	1000
2	KARGO	VVW 975 GP	4	50	60	TRUE	3000
3	KARGO	VWS 586 GP	4	50	60	TRUE	3000
4	KARGO	YYT 887 GP	1	20	30	TRUE	1000
5	KARGO	YYT 925 GP	1	20	30	TRUE	1000
6	CCI	JRM 398 GP	1	20	30	TRUE	1500
7	CCI	NFZ 949 GP	1	20	30	TRUE	1500
8	CCI	RJX 618 GP	1	20	30	TRUE	1500
9	CCI	VTR 920 GP	1	20	30	TRUE	1500
10	CCI	WDV 717 GP	1	20	30	TRUE	1500

Invoices

INVOICE SUMMARY					
		DATE	No Invoices →	144	
		16-Jul-12	Total R Value →	R 435,446.34	
Invoice	Node	Customer No	Customer Name	R Value	Cartons
946824	1	T08254	BINUNS - MENLYN	10458.63	8
947444	2	Z09809	BP BROADACRES COD	1026.85	1
947498	3	Z95693	BP FOURWAYS COD	1901.46	1
947195	4	Z45356	BP MONTECASINO COD	1321.91	1
946250	5	Z75569	BP RUSLOO S/STATION COD	727.67	1
947816	6	Z21786	BREDELL SPAR 2	833.92	2
946331	7	Z10330	BROADACRES SUPERSPAR 21211	2045.79	7
947547	8	X10569	BUCCLEUGH KWIKSPAR 21503	2147.65	2
946268	9	T10662	BUILDING IMPROVEMENT & GAS COD	1498.21	1
947869	10	Z11411	CALTEX CEDAR ROAD COD	898.04	1

Clusters

Euclidean Distance

Node	Latitude	Longitude	Dist to C1	Dist to C2	Dist to C3	Dist to C4	Dist to C5	Dist to C6	Dist to C7	Dist to C8	Dist to C9	Dist to C10	Cluster	Min Distance
1	-25.7817141	28.2778057	0.5043	0.6078	0.5291	0.3743	0.4529	0.4858	0.9640	0.3401	0.0092	0.1401	9	0.0092
2	-26.0008231	27.9850682	0.1464	0.2463	0.2325	0.0788	0.2838	0.5046	0.6822	0.2983	0.3572	0.3635	4	0.0788
3	-26.0161472	28.010195	0.1492	0.2644	0.2168	0.0527	0.2562	0.4752	0.6695	0.2692	0.3470	0.3648	4	0.0527
4	-26.0240528	28.0088936	0.1425	0.2608	0.2088	0.0462	0.2508	0.4727	0.6615	0.2674	0.3532	0.3725	4	0.0462
5	-26.3495584	28.2001464	0.3668	0.5078	0.2308	0.3313	0.1339	0.2505	0.4273	0.2356	0.5647	0.6608	5	0.1339
6	-26.08594	28.29388	0.3866	0.5351	0.3275	0.2627	0.1862	0.2068	0.6972	0.0503	0.2971	0.4147	8	0.0503
7	-26.0008231	27.9850682	0.1464	0.2463	0.2325	0.0788	0.2838	0.5046	0.6822	0.2983	0.3572	0.3635	4	0.0788
8	-26.0592849	28.1038615	0.2057	0.3472	0.2016	0.0720	0.1722	0.3724	0.6453	0.1661	0.3184	0.3762	4	0.0720
9	-26.0978831	27.7542588	0.1576	0.0046	0.2813	0.2798	0.4286	0.6887	0.6090	0.5043	0.6035	0.5846	2	0.0046
10	-26.0164511	28.0004395	0.1425	0.2550	0.2163	0.0572	0.2620	0.4837	0.6681	0.2780	0.3547	0.3696	4	0.0572

Cluster Centres

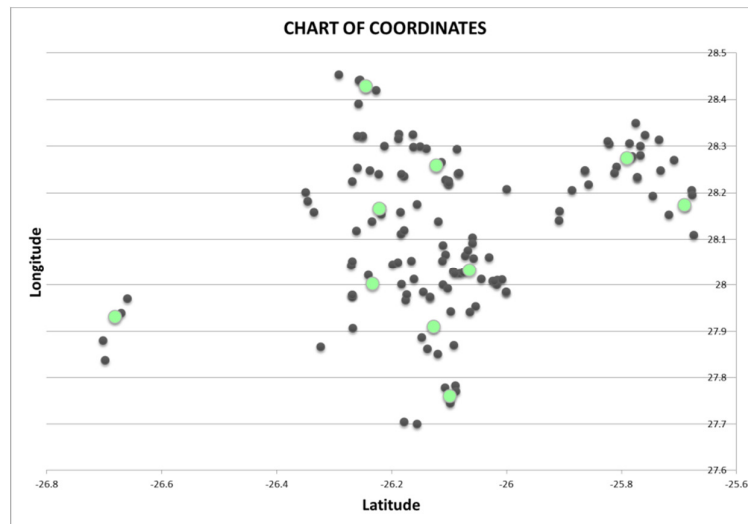
CENTRES		
Cluster Centre	Latitude	Longitude
1	-26.13	27.91
2	-26.10	27.76
3	-26.23	28.00
4	-26.06	28.03
5	-26.22	28.16
6	-26.24	28.43
7	-26.68	27.93
8	-26.12	28.26
9	-25.79	28.27
10	-25.69	28.17

Map Data

CLUSTER RESULTS			
Node	Latitude	Longitude	Cluster
1	-25.7817	28.277806	9
2	-26.0008	27.985068	4
3	-26.0161	28.010195	4
4	-26.0241	28.008894	4
5	-26.3496	28.200146	5
6	-26.0859	28.29388	8
7	-26.0008	27.985068	4
8	-26.0593	28.103862	4
9	-26.0979	27.754259	2
10	-26.0165	28.00044	4

CLUSTER RESULTS			
Node	Latitude	Longitude	Cluster
18	-26.1374	27.861899	1
19	-26.1279	27.909081	1
20	-26.1261	27.909279	1
26	-26.1452	27.984542	1
76	-26.1328	27.973638	1
89	-26.0915	27.869621	1
96	-26.1472	27.88637	1
121	-26.1328	27.973638	1
129	-26.0636	27.941573	1
137	-26.1195	27.85039	1
139	-26.0974	27.942091	1

Map



Cluster Sets

CLUSTER	NODES WITHIN EACH IN CLUSTER																CTNS
1	18	19	20	26	76	89	96	121	129	137	139						29
2	9	28	42	43	54	85	128	136									15
3	23	31	52	59	62	71	91	93	94	108	110	111	114	115	116	133	31
4.1	2	3	4	7	8	10	21	25	39	40	58	125					24
4.2	46	61	66	74	80	86	88	95	101	103	132						24
4.3	63																15
5.1	5	13	15	41	75	78	83	87	92	102	107	113	123	126	138		23
5.2	70																39
6	11	29	32	33	34	35	37	45	73	118	120	140					19
7	47	55	60	64	131												10
8.1	6	12	24	36	50	51	57	65	72	122							17
8.2	14	16	38	44	56	79	109	124	130	135							18
9.1	1	84	90	97	99	100	105	106	112	119	127						21
9.2	17	22	27	30	53	67	68	69	77	81	82						21
10	48	49	98	104	117	134											24

CLUSTER	4	Nodes		24												
Node	R value	Ctns			1	2	= 1									
2	1026.85	1	# Vehicles	2	2	1	0	1	1026.85	0			1	0		
3	1901.46	1	R value	58570.96	3	1	0	1	1901.46	0			1	0		
4	1321.91	1	Ctns	48	4	1	0	1	1321.91	0			1	0		
7	2045.79	7			7	1	0	1	2045.79	0			7	0		
8	2147.65	2	Rvalue/vehicle	29285.48	8	1	0	1	2147.65	0			2	0		
10	898.04	1	R value rounded	20000	10	1	0	1	898.04	0			1	0		
21	613	1	Ctns/vehicle	24	21	1	0	1	613	0			1	0		
25	4200.8	2			25	1	0	1	4200.8	0			2	0		
39	435.07	1	1xoutlier		39	1	0	1	435.07	0			1	0		
40	679.76	1			40	1	0	1	679.76	0			1	0		
46	1262.89	1			46	0	1	1	0	1262.89			0	1		
58	11396.12	4			58	1	0	1	11396.12	0			4	0		
61	1238.39	1			61	0	1	1	0	1238.39			0	1		
66	2795.83	1			66	0	1	1	0	2795.83			0	1		
74	4540.42	2			74	0	1	1	0	4540.42			0	2		
80	95.76	1			80	0	1	1	0	95.76			0	1		
86	9598.22	6			86	0	1	1	0	9598.22			0	6		
88	670.97	2			88	0	1	1	0	670.97			0	2		
95	4609.47	4			95	0	1	1	0	4609.47			0	4		
101	773.5	1			101	0	1	1	0	773.5			0	1		
103	554.86	1			103	0	1	1	0	554.86			0	1		
125	1253.08	2			125	1	0	1	1253.08	0			2	0		
132	4511.12	4			132	0	1	1	0	4511.12			0	4		
63	44569.77	15														
					≤ nodes/2 →	12	11		≥ Rounded R value→	26666.45	24811.95		≥ Ctns/2→	24	24	

Assignment

[illegible]

Individual Distance Matrices

DISTANCE													
21	18	19	20	26	76	89	96	121	129	137	139		
18	0	8.5	51	15	15	7.4	3	15	16	2.9	14		
19	8.3	0	57	14	12	6.8	5.7	12	9.1	8.4	6.6		
20	51	56	0	39	41	62	49	41	47	55	50		
26	15	11	40	0	1.9	16	13	1.9	11	19	7		
76	14	8.9	42	1.8	0	15	11	0	9.4	17	5.1		
89	8	7.4	57	16	15	0	12	15	11	4.5	11		
96	3	5.7	50	12	12	11	0	12	14	6	11		
121	14	8.9	42	1.8	0	15	11	0	9.4	17	5.1		
129	16	9.6	46	11	9.3	14	14	9.3	0	16	4.3		
137	3.5	8.9	54	18	19	4.5	5.7	19	16	0	14		
139	14	7.1	50	7	5.1	11	11	5.1	4.3	14	0		

DISTANCE															
8	5	13	15	41	75	78	83	87	92	102	107	113	123	126	138
5	0	17	32	24	2.4	12	28	27	15	19	26	5.9	28	32	17
13	16	0	17	15	16	4.5	25	14	3.2	3.1	11	19	25	29	17
15	33	19	0	13	30	23	8.7	5.7	22	16	9.8	28	9.5	7.5	17
41	24	15	14	0	21	12	10	5.6	14	9.6	1.7	19	9.2	14	8.2
75	2.4	17	30	22	0	11	26	25	15	19	23	3.5	25	30	14
78	12	5.5	21	11	11	0	23	14	3.3	6.9	10	16	23	27	15
83	30	23	8.5	10	27	24	0	6.9	26	20	12	25	1.4	8.5	14
87	29	14	5.7	5.4	27	14	6.9	0	17	12	4.1	25	8.3	13	14
92	15	4.2	20	14	15	3.3	25	17	0	5.6	15	19	24	29	16
102	19	2.4	14	9.6	19	6.9	20	11	5.5	0	8	21	20	23	19
107	26	10	10	1.7	23	10	12	4.6	13	8	0	21	11	15	9.9
113	5.6	21	28	15	3.1	15	24	23	19	23	15	0	23	28	12
123	28	23	8.4	8.5	26	22	1.1	6.7	24	20	10	24	0	8.4	12
126	33	25	11	13	30	26	8.9	13	29	23	15	28	9.6	0	17
138	18	19	17	9.5	16	16	14	13	18	20	11	12	13	17	0

[illegible]

