ANALYSIS AND OPTIMIZATION OF G4S CASH-IN-TRANSIT TRANSPORT SERVICE OPERATIONS

IR VAN HELSDINGEN [1]

September 30, 2015

Project leader: Dr. Nico de Koker

ABSTRACT

This document details a project in which two types of vehicles were analysed and compared using the Analytical Hierarchy Process, to select the best vehicle for G4S Cash Solutions Cash-In-Transit operations based on operating costs and performance.The project also optimized the vehicle route schedules at G4S Cash Solutions Pretoria branch using a "Capacitated Vehicle Routing Problem", based on the Clarke & Wright algorithm. The report concludes that although the Lancet vehicle has better performance and lower operating costs than a Hino when compared in single units, the large capacity of the Hino make it the superior choice when a fleet operates in built up areas such as Pretoria compared to a fleet of Lancet vehicles. The Lancet vehicle can however be used in rural areas where customer density and demand are not limiting factors.

---

* *Department of Industrial and System Engineering, University of Pretoria*

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 ABBREVIATIONS

Abbreviations used:

CIT - Cash-In-Transit
AHP - Analytical Hierarchy Process
VRP - Vehicle Routing Problem
CVRP - Capacitated Vehicle Routing Problem

2 INTRODUCTION

G4S South Africa, located in Centurion, is one the largest providers of integrated security solutions in South Africa. Offering far more than commodity products and services designed for security, G4S harnesses the power of technology and transformation to offer customers end-to-end security and cash solutions.

G4S Cash Solutions (SA) services more than 22 000 customers daily, with a large portion of these operations being cash-in-transit services. As such a large fleet of armoured vehicles and personnel need to be maintained and managed throughout South Africa to provide these services, with time capacity and fuel consumption being among the major factors determining the success and profitability of these operations. As such the management of G4S believe that considerable savings can be achieved by analysing current as-is operations as well as optimizing and implementing new service methodologies within the cash-in-transit services.

G4S CIT Pretoria(478 van Riebeeck Street, Hermanstad, Pretoria) has roughly 40 vehicles at its disposal to service clients within the Pretoria region. The vehicles used are specialized armoured vehicles with a 2 man crew, made up of a driver and carrier. The current process for servicing clients is widely considered inefficient due to long vehicle idling times during operations as well as various other factors.

Management at G4S is considering the acquisition of a new type of armoured vehicle (Lancet), with the aim of improving performance and reducing costs.To help in the decision making process,substantial research is needed to be able to compare the two vehicles and how choosing either option will impact time capacities and fuel costs.

3 PROBLEM STATEMENT

G4S Management believe that considerable operational cost savings can be obtained by acquiring new Lancet vehicles and replacing older vehicles,considering that existing vehicles consume a large amount of fuel while idling. However, research is needed to assist management in the decision making process to help make an informed and substantiated decision whether new vehicles should be bought or not. Therefore the first part of the identified problem was to analyse and compare the two vehicle models and their operational methodologies, based on certain criteria, and applying them to the G4S Cash Solutions Pretoria Branch to identify potential cost savings of each option compared to the other.

The second part of the problem involved vehicle route optimization of the Pretoria Cash Management branch using whats known as the "Capacitated Vehicle Routing Problem". The Pretoria branch currently has roughly 40 vehicles,each with a crew of 2, and optimization of the route schedule could potentially reduce fuel costs and improve performance.

4 LITERATURE REVIEW

4.1 Choosing between alternatives

Decision making can be broken down into a process where a set of alternatives are weighed up against one another using a certain type of criteria,resulting in the selection of what is considered the best option.This cognitive process can be done via various means and have been studied extensively over the years.Decision making is essentially split into two types: subconscious decisions which are usually influenced by emotion; and logical decision making which is usually based on comparisons between alternatives using some type of empirical data. Seeing as subconscious decisions are usually made based on emotions and other illogical factors, such decisions are very often biased and incorrect in terms of choosing the best course of action.

Logical decision making is considered the preferred method of making decisions within the scientific community as it relies less on emotional or biased opinions and relies more on empirical data and expert opinion. Relying on intuition to make informed decisions is therefore dependant on the experience and knowledge of the decision maker, which in many instances is lacking and can lead to bad business decisions.

One such method that uses logical and mathematical decision making is the "Analytical Hierarchy Process" and is often considered as one of the best decision making processes and has been applied in many industries for various applications throughout the world.[Saaty, 2012]

The decision making process within the scope of this project is to determine the best alternative between two vehicles. A similar problem is addressed by [Sinan Apak, 2012], in which the AHP process is used to select the best alternative between luxury cars, based on given criteria and preferences.This is very similar to what is attempted in this project and goes some way in validating the use of the AHP process in choosing between vehicle alternatives.[Haas, 2012b] demonstrates another instance in which the AHP process is used to select the best option from among a list of family vehicles and is also quite similar to the type of problem addressed in this report.These two sources including that of Saaty(2008) will be used as the chief reference for developing and implementing the AHP process to solve the given decision making problem for this project.

4.2 Optimizing vehicle routes

The problem of optimizing a route, such as those which G4S Cash Solutions are involved in,is what is known as a "Vehicle Routing Problem" or VRP.The Vehicle Routing Problem (VRP) is one of the most challenging combinatorial optimization tasks found in industry due to its complexity. Defined more than 40 years ago, this problem consists of finding and identifying the optimal routes for a finite size fleet of vehicles that service a set of customers within an area.This type of problem closely resembles that which this project aims to address and the problem of optimizing routes for G4S Cash Solutions will be treated as a VRP problem.As there are many different types of VRP problems,each with a different set of constraints and challenges, many methods have been developed over the years to solve these problems with wide ranging approaches to solving the problem.

One of the most well known and trusted methods of solving a capacitated vehicle routing problem is to use what is

known as the "Clarke and Wright Algorithm". This algorithm in essence determines the distance savings between customers when combining two routes into one,which allows the optimal route combinations or "links" to be identified.This method does however require many iterations before an optimal sollution is found.[Haas, 2012a]
Shaw(1998) illustrates the use of integer programming using the Large Neighbourhood Search (LNS)technique to solve typical vehicle routing problems. Of particular interest is the Capacitated Vehicle Routing Problem (CVRP) which in essence is a single depot that services a client base,each with demand, using a constrained fleet of uniform vehicles(as is the case with G4S Cash Solutions).[Shaw, 1998]
Further literature concerning vehicle routing problems include [Ruben Ruiz, 2003], and [E. Scholtz, 2012].Both these articles include typical vehicle routing problems similar to that faced by G4S, however [Shaw, 1998] uses the most applicable approach and the methods used therein (CVRP and the Clarke & Wright Savings Algorithm)will be used as a reference guide during the project.[Louis Caccetta, 2012]

5 RESEARCH DESIGN AND METHODOLOGY

5.1 Determining the Best Vehicle Type

The first deliverable is to determine the best alternative between vehicles, which is the current G4S cash-in-transit vehicle and the new Lancet model.To make an informed decision the AHP process will be applied and a suitable "best option" obtained from the results. The first step involves time studies and data obtained from time sheets at the Pretoria G4S Cash Solutions branch in order to obtain the required metrics and data.The selection criteria for choosing the optimal vehicle and the weight each criteria carries will then be determined through consultation with G4S stakeholders/management.This data will then be used in the Analytical Hierarchy Process (AHP)to select the best alternative.

5.1.1 *The Analytical Hierarchy Process Methodology*

The Analytical Hierarchy Process is a structured way of making decisions using sound judgement,qualitive and quantative data,and various other input data.This process is accomplished using matrix algebra via the use of pairwise comparison matrices and Eigen value vectors. The AHP process is however subject to a certain degree of error due to the uncertain nature of decision making. It is therefore vital to consult with experts who have knowledge in the subject matter,as well as to obtain accurate data and information.[Saaty, 2012]To apply the AHP process a number of steps is required,as well as a certain ammount of matrix algebra.The steps and procedures required are listed bellow:[Saaty, 2012]

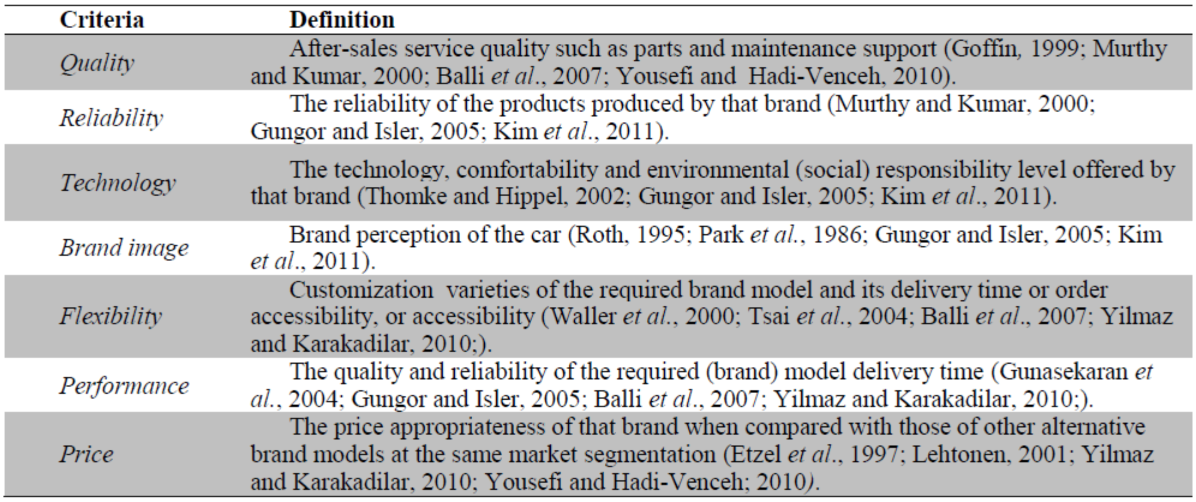
1. Determine the objective and establish what data is required.

2. Construct a decision hierarchy starting with the objective,branching down to the criteria,and finally branching down to the various options(set of alternatives).

3.Set up a pairwise comparison matrix weighing each criteria and alternative to all the other options.

4.Weigh the calculated priorities from the pairwise comparison matrices with the entries in the branch below.Repeat this process for every entry.Next add every entry in the branch bellow with its weighted values to determine its global importance(priority).Repeat this procedure until the final importance/preference of the alternatives in the lowest branch are calculated.

When choosing criteria for an AHP process, certain factors need to be considered such as what defines quality or which measures of performance are quantifiable.[Sinan Apak, 2012] suggests the following criteria when selecting between various vehicle alternatives:

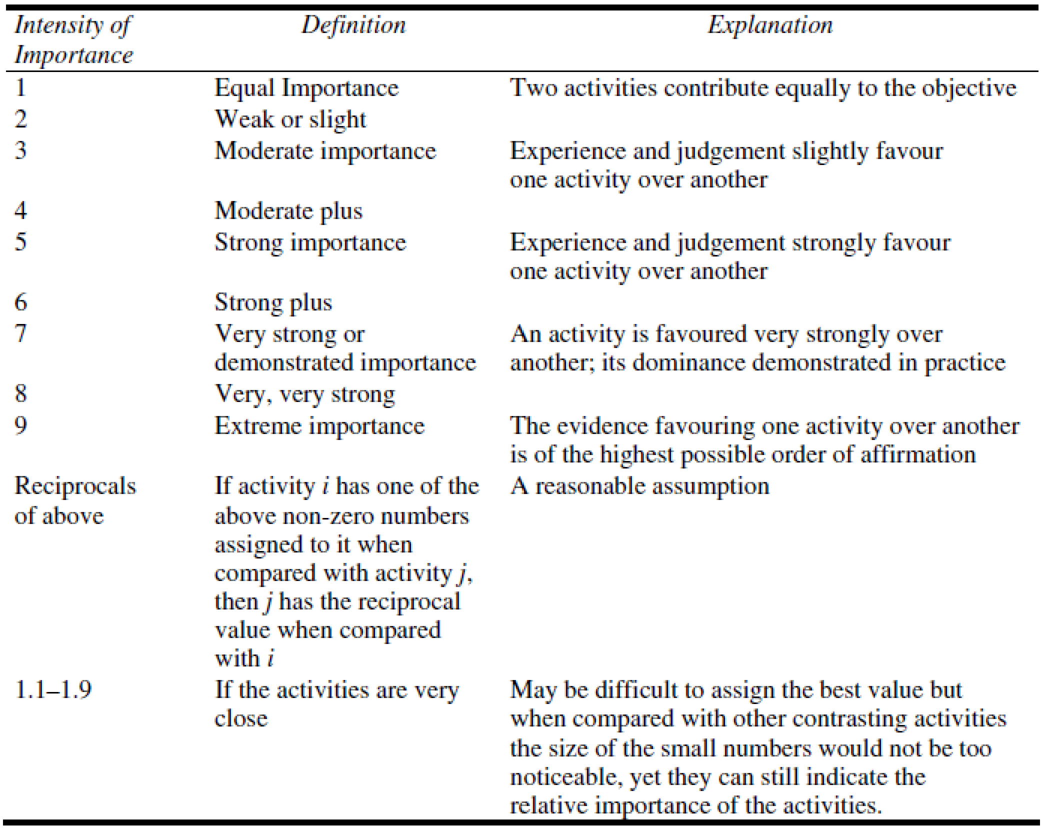


Criteria	Definition
Quality	After-sales service quality such as parts and maintenance support (Goffin, 1999; Murthy and Kumar, 2000; Balli *et al.*, 2007; Yousefi and Hadi-Venceh, 2010).
Reliability	The reliability of the products produced by that brand (Murthy and Kumar, 2000; Gungor and Isler, 2005; Kim *et al.*, 2011).
Technology	The technology, comfortability and environmental (social) responsibility level offered by that brand (Thomke and Hippel, 2002; Gungor and Isler, 2005; Kim *et al.*, 2011).
Brand image	Brand perception of the car (Roth, 1995; Park *et al.*, 1986; Gungor and Isler, 2005; Kim *et al.*, 2011).
Flexibility	Customization varieties of the required brand model and its delivery time or order accessibility, or accessibility (Waller *et al.*, 2000; Tsai *et al.*, 2004; Balli *et al.*, 2007; Yilmaz and Karakadilar, 2010;).
Performance	The quality and reliability of the required (brand) model delivery time (Gunasekaran *et al.*, 2004; Gungor and Isler, 2005; Balli *et al.*, 2007; Yilmaz and Karakadilar, 2010;).
Price	The price appropriateness of that brand when compared with those of other alternative brand models at the same market segmentation (Etzel *et al.*, 1997; Lehtonen, 2001; Yilmaz and Karakadilar, 2010; Yousefi and Hadi-Venceh; 2010*)*.

Figure 1: Decision Criteria Variables [Haas, 2012b]

To make comparisons between criteria, a scale is needed of numbers that indicates the relative importance or dominance of one element over another element with respect to the criteria provided.Figure(2) exhibits such a scale.

Once the objective has been determined,criteria established and alternatives selected,the information can be processed to determine relative preference among the alternative set .Sound judgement needs to be applied(G4S management and personel) to derive weights and priorities.The preference of one criteria over another is then indicated in matrix form. This is known as the pairwise comparison matrix.The pairwise comparison matrix is defined as follows:



Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Figure 2: Scale of Importance table [Haas, 2012b]

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

The next step would be to determine the rankings of preferences from the comparison matrix.Dr. Thomas L. Saaty demonstrated that the eigenvector solution is the optimal method.[Saaty, 2012]The eigenvector is determined as follows:

First the pairwise comparison matrix is normalized:

$$A_1 = \begin{bmatrix} a_{11}' & a_{12}' & \cdots & a_{1n}' \\ a_{21}' & a_{22}' & \cdots & a_{2n}' \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1}' & a_{n2}' & \cdots & a_{nn}' \end{bmatrix},$$

$$\text{and } a_{ij'} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \text{ for } i, j = 1, 2, \ldots, \text{n},$$

The eigenvalue and eigenvector can then be calculated:

$$w = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}, \text{ and } w_i = \frac{\sum_{i=1}^{n} a_{ij}'}{n} \text{ for } i = 1, 2, \ldots, n,$$

$$w' = Aw = \begin{bmatrix} w_1' \\ w_2' \\ \vdots \\ w_n' \end{bmatrix},$$

$$\text{and } \lambda_{\max} = \frac{1}{n}\left(\frac{w_1'}{w_1} + \frac{w_2'}{w_2} + \cdots + \frac{w_n'}{w_n}\right),$$

w =Eigen vector

w_i =Eigen value of criteria I

λ_{max} = Largest Eigen value of comparison matrix

The following calculations are then done to determine consistency: (Table(1) shows a set of recommended RI values presented by [Saaty, 2012])

CI = Consistency index

Table 1: Random Index table

N	2	3	4	5	6	7	8	9	10
RI	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

CR = Consistency ratio

λ_{max} = Largest Eigen value of comparison matrix

n = matrix order

RI = Random index

$$CI = (\lambda_{max} - n)/(n-1)$$

$$CR = CI/RI$$

If the CR values are greater than 0.10 for a matrix larger than 4x4, it indicates inconsistency.In this case the original values in the pairwise matrix should be revised.If CR is satisfactory with a value less than 0.1 then the normalized matrix can be used to make decisions.

The procedure shown above is first used to determine the weighted relevant importance between criteria.The process is then repeated to determine the relative importance of each criterion compared to the alternatives.Once all the Eigen vectors have been determined,the Hierarchical tree can be updated and the best solution determined by multiplying the criteria Eigen vector with the alternative eigen vector matrix to give an nx1 matrix listing the global weighted importance of each alternative.The entry with the highest value is considered the best option.

5.1.2 *Analytical Hierarchy Process model validation*

The following calculations were done to validate the AHP process. The first step is to establish what data is needed as well as criteria etc. This is shown in Figure(3)

Objective: Select a vehicle

Criteria : Style, Reliability, Fuel economy

Choices : 4 Arbitrary vehicles (A...D)

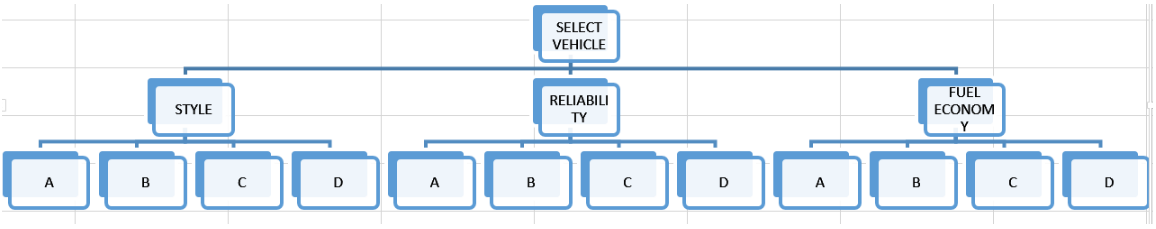


Figure 3: Hierarchy Tree

Next the criteria piecewise comparison matrix is constructed,and its Eigen vector,which is as follows:

$$A_c = \begin{array}{c} \\ \mathtt{Style} \\ \mathtt{Reliability} \\ \mathtt{FuelEconomy} \end{array} \begin{array}{c} \begin{array}{ccc} \mathtt{Style} & \mathtt{Reliability} & \mathtt{FuelEconomy} \end{array} \\ \begin{pmatrix} 1.000 & 0.500 & 3.000 \\ 2.000 & 1.000 & 4.000 \\ 0.333 & 0.250 & 1.000 \end{pmatrix} \end{array}$$

$$w_c = \begin{array}{c} \mathtt{Style} \\ \mathtt{Reliability} \\ \mathtt{FuelEconomy} \end{array} \begin{pmatrix} 0.3196 \\ 0.5584 \\ 0.1220 \end{pmatrix}$$

In terms of Style, the pairwise comparison matrix and Eigen vector is as follows:

$$A_{style} = \begin{array}{c|cccc} & A & B & C & D \\ \hline A & 1.000 & 0.250 & 4 & 0.166 \\ B & 4.000 & 1.000 & 4 & 0.250 \\ C & 0.25 & 0.250 & 1 & 0.200 \\ D & 6.000 & 4 & 5 & 1 \end{array} \quad w_{style} = \begin{array}{c} A \\ B \\ C \\ D \end{array} \begin{pmatrix} 0.1160 \\ 0.2470 \\ 0.0600 \\ 0.5770 \end{pmatrix}$$

In terms of Reliability, the pairwise comparison matrix and Eigen vector is as follows:

$$A_{rel} = \begin{array}{c|cccc} & A & B & C & D \\ \hline A & 1.000 & 2.000 & 5 & 1.000 \\ B & 0.500 & 1.000 & 3 & 2.000 \\ C & 0.200 & 0.333 & 1 & 0.250 \\ D & 1.000 & 0.500 & 4. & 1.000 \end{array} \quad w_{rel} = \begin{array}{c} A \\ B \\ C \\ D \end{array} \begin{pmatrix} 0.3790 \\ 0.2900 \\ 0.0740 \\ 0.2570 \end{pmatrix}$$

Fuel economy information is obtained for each alternative quantatively (this negates the need for a comparison matrix), with the information normalized in an vector as follows:

$$w_{fuel} = \begin{array}{c} A \\ B \\ C \\ D \end{array} \begin{pmatrix} 0.3010 \\ 0.2390 \\ 0.2120 \\ 0.2480 \end{pmatrix}$$

Using this information to update the Hierarchy tree results in Figure(4):

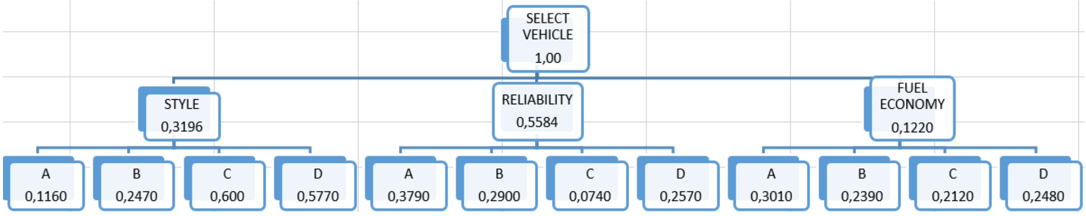


Figure 4: Updated Hierarchy Tree

From this data, the eigen vector values are synthesized into two matrices, with the criteria eigen vector being multiplied by the combined eigenvector values of the choices(A...D) compared to each criteria,as follows:

$$\begin{array}{cccc} & \mathrm{Style} & \mathrm{Reliability} & \mathrm{FuelEconomy} \\ A & 0.1160 & 0.3790 & 0.3010 \\ B & 0.2470 & 0.2900 & 0.2390 \\ C & 0.0600 & 0.0740 & 0.2120 \\ D & 0.5770 & 0.2570 & 0.2480 \end{array}$$

$$\mathbf{X} \begin{array}{cc} & \mathrm{CriteriaRanking} \\ A & 0.3010 \\ B & 0.2390 \\ C & 0.2120 \\ D & 0.2480 \end{array}$$

$$= \begin{array}{cc} A & 0.3060 \\ B & 0.2720 \\ C & 0.0940 \\ D & \mathbf{0.3280} \end{array}$$

As can be seen vehicle D has the highest ranking with 0.3280. This indicates the the best option would be to choose D as based on the AHP process.The process is also validated due to the fact that the input data used was obtained from an article written by Dr. Rainer Haas from the University of Vienna[Haas, 2012b],in which he illustrates the usefulness of the AHP process in making decisions.As the project progresses more accurate data will be obtained and the AHP model refined to give an accurate answer.

5.2 Route Optimization

The second deliverable is to optimize the vehicle routes at the Pretoria CS branch to minimize fuel costs while still meeting time schedule demands.The Cash centre location is fixed as well as the time schedule in which clients must be serviced.The optimal variables to be determined will be the type of vehicle,number of vehicles and the route allocation of each vehicle. Each vehicle type will be used to optimize the given route in order to determine which vehicle type is best suited to which type of route.

5.2.1 *Clarke and Wright Savings Algorithm*

The Clarke and Wright savings algorithm has been identified as the simplest and most accurate method of solving the identified vehicle routing problem.The Clarke and Wright algorithm process is explained below:
[Haas, 2012a]

1.The first step is determining assumptions and constraints.

> **1.1.Assumptions and Constraints:**
> 1.1.1 Each vehicle can only travel a maximum distance.
> 1.1.2 Vehicles in the fleet are homogeneous with fixed capacity.
> 1.1.3 There is a finite,fixed amount of customers each with a known demand and coordinates.
> **1.2.Objective**: To minimize total cost of servicing all customers.
> Given that:
> 1.2.1.The maximum range of each vehicle is not exceeded.
> 1.2.2.Vehicle capacity is not exceeded.
> 1.2.3.The demand of all customers are met.

2.Using the coordinates of the customers,(i,j) as well as the coordinates of the depot,the cost of travelling between each coordinate pair C(i,j) is synthesized into a matrix,with symmetrical coordinates being equal.Such a distance cost matrix is displayed below:

Customer	Location	Demand
1	(22,22)	18
2	(36,26)	26
3	(21,45)	11
4	(45,35)	30
5	(55,20)	21
6	(55,45)	16
7	(26,59)	29
8	(55,65)	37

c_{ij}	0	1	2	3	4	5	6	7	8
0	-	26	15	20	7	25	16	24	29
1		-	15	23	26	33	40	38	54
2			-	24	13	20	27	35	43
3				-	26	42	34	15	39
4					-	18	14	31	32
5						-	25	49	45
6							-	32	20
7								-	30

3.A "Savings list" is then constructed.The savings list is ranked from the largest saving to the lowest saving from top to bottom.The savings of each route is calculated as follows:

$$S_{ij} = C_{i0} + C_{0j} - C_{ij}$$
$$i, j = 1, 2, 3, ..., n$$
$$i \neq j$$

4. The Savings list is then processed as follows:

4.1.Starting with the largest saving, and comparing it to the following entry,links are constructed.If a grouping of savings do not violate any of the constraints,then additional entries are added to the link until a condition is violated with the link kept unbroken.This comprises what is known as an optimized route for the included coordinates.

4.2.The process is then repeated until all coordinates are included in links(routes).[Frank W. Takes, 2012]

The Clarke and Wright method to solve a capacitated vehicle routing problem requires many iterations and is usually solved using computer aided programming. The software that was used to implement this algorithm was mainly be Python,however other software packages such as Google Maps and software developed by Dr. Lawrence V. Snyder from the University of Lehigh, was also utilized.[Janakiraman, 2012]

6 SOLUTION DESIGN

6.1 Analytical Hierarchy Process solution design

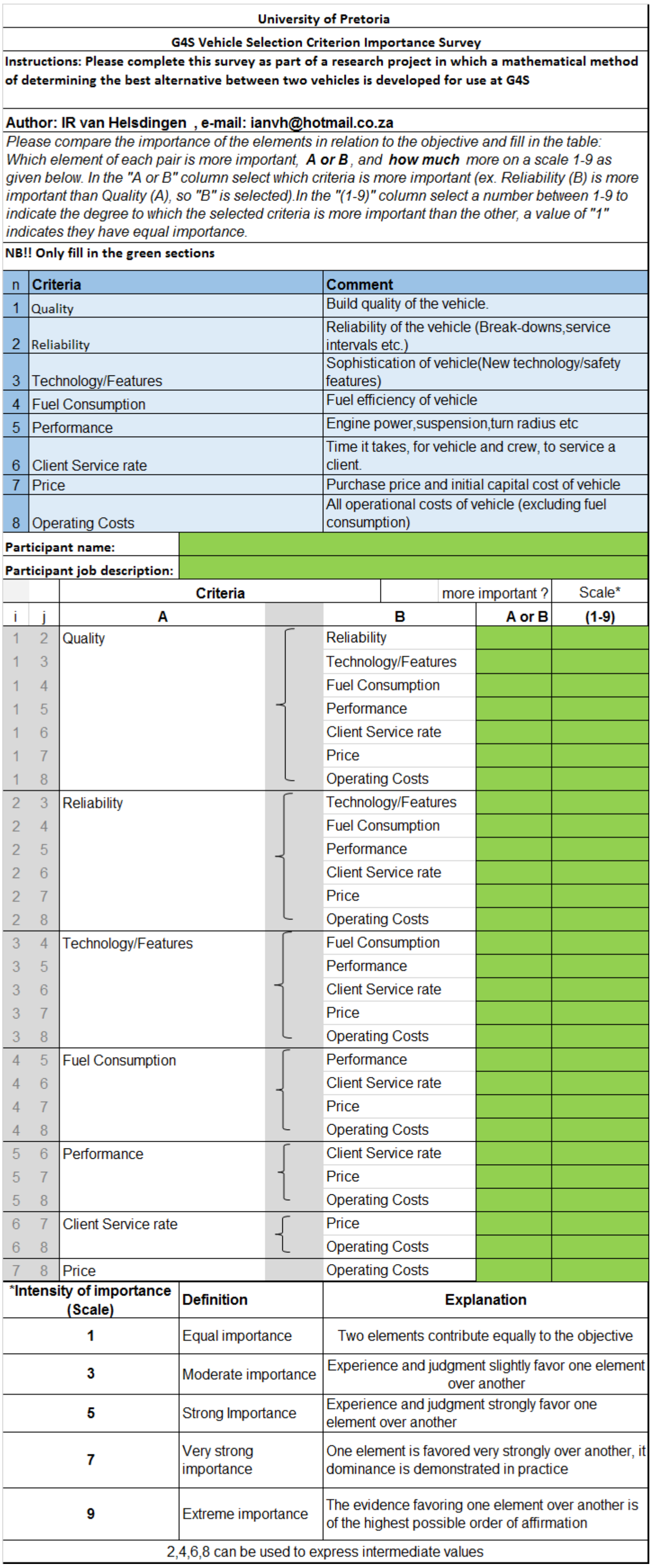
The success of using the AHP process to make a decision relies almost entirely on the accuracy of the input data used. The best way to obtain the relative importance of the criteria within a company structure that has many decision makers,each with a different seniority or "importance", is usually to conduct a survey among the key decision makers and stakeholders. This method is superior as each person is able to give an input based on his/her own knowledge and experience, as well as being assigned an "importance" weight variable.This ensures that all stakeholders' input is taken into account whilst simultaneously factoring in the "chain of command", with top management having a higher "weight" than floor level management.The result is a decision based on the combined knowledge and experience of all stakeholders,resulting in a very accurate answer.

Referring back to the criteria used when selecting vehicles [Sinan Apak, 2012], and adapting it to the specific requirements of G4S, the following criteria was established for selecting the best vehicle:

Table 2: Adjusted Criteria

Criterion	**Comment**
Quality	Build Quality of the vehicle
Reliability	Reliability of the vehicle (Break-downs etc.)
Technology/Features	Technological sophistication of vehicle and safety features
Fuel Consumption	Fuel Efficiency of vehicle
Performance	Engine Power,Torque,max speed etc
Client Service Rate	Time taken to service a customer
Price	Initial capital cost of vehicle
Operating Costs	All operational costs of vehicle(excluding fuel consumption)

Each criteria is then measured based on the specifications of each vehicle to determine a value for each criteria compared to each vehicle.The data for each vehicle is obtained by studying the specifications brochure of each vehicle.The specification sheets contain almost all the technical data of a vehicle,from engine capacity to safety features to fuel consumption. Once the criteria matrix is established, a survey is designed with the aim of distributing it among the management of G4S.The surveys are then reconciled and adjusted to ensure consistency.



University of Pretoria

G4S Vehicle Selection Criterion Importance Survey

Instructions: Please complete this survey as part of a research project in which a mathematical method of determining the best alternative between two vehicles is developed for use at G4S

Author: IR van Helsdingen , e-mail: ianvh@hotmail.co.za

Please compare the importance of the elements in relation to the objective and fill in the table: Which element of each pair is more important, ***A or B****, and* ***how much*** *more on a scale 1-9 as given below. In the "A or B" column select which criteria is more important (ex. Reliability (B) is more important than Quality (A), so "B" is selected).In the "(1-9)" column select a number between 1-9 to indicate the degree to which the selected criteria is more important than the other, a value of "1" indicates they have equal importance.*

NB!! Only fill in the green sections

n	Criteria	Comment
1	Quality	Build quality of the vehicle.
2	Reliability	Reliability of the vehicle (Break-downs,service intervals etc.)
3	Technology/Features	Sophistication of vehicle(New technology/safety features)
4	Fuel Consumption	Fuel efficiency of vehicle
5	Performance	Engine power,suspension,turn radius etc
6	Client Service rate	Time it takes, for vehicle and crew, to service a client.
7	Price	Purchase price and initial capital cost of vehicle
8	Operating Costs	All operational costs of vehicle (excluding fuel consumption)

Participant name:	
Participant job description:	

		Criteria		more important ?	Scale*
i	j	**A**	**B**	**A or B**	**(1-9)**
1	2	Quality	Reliability		
1	3		Technology/Features		
1	4		Fuel Consumption		
1	5		Performance		
1	6		Client Service rate		
1	7		Price		
1	8		Operating Costs		
2	3	Reliability	Technology/Features		
2	4		Fuel Consumption		
2	5		Performance		
2	6		Client Service rate		
2	7		Price		
2	8		Operating Costs		
3	4	Technology/Features	Fuel Consumption		
3	5		Performance		
3	6		Client Service rate		
3	7		Price		
3	8		Operating Costs		
4	5	Fuel Consumption	Performance		
4	6		Client Service rate		
4	7		Price		
4	8		Operating Costs		
5	6	Performance	Client Service rate		
5	7		Price		
5	8		Operating Costs		
6	7	Client Service rate	Price		
6	8		Operating Costs		
7	8	Price	Operating Costs		

*Intensity of importance (Scale)	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

2,4,6,8 can be used to express intermediate values

Figure 5: Survey template

6.2 Capacitated Vehicle Routing Problem solution design

Solving a capacitated vehicle routing problem can be quite difficult if the parameters and constraints of the model aren't correctly specified. This meant that the first step in developing a solution to the CVRP problem was to define the objective and to correctly list the constraints. Following the structure set out in section(5.2.1),these are as follows:

> **1.Objective:**
> Service all customers of G4S Cash-Solutions Pretoria branch using the available vehicles,whilst minimizing total costs.
> **2.Constraints:**
> 2.1 There are only 47 Hino 300(614) vehicles available.
> 2.2 Each vehicle has a maximum capacity of 450 "classified units".
> 2.3 There is a fixed amount of customers, each with a predetermined demand and location.
> 2.4 It is assumed that each vehicle has an infinite range,as it can be argued that vehicles are allowed to re-fuel during a route tour.

The algorithm that will be used to solve the CVRP will be the Clarke & Wright savings algorithm,which has been used for many years and is considered a very stable and reliable algorithm(for more information on the Clarke&Wright algorithm refer to section 5.2.1) Although the basic concept of the algorithm is quite straight forward and simplistic,its real-world implementation is quite complex and requires computer aided programming.This is due to the Clarke & Wright algorithm only conducting one iteration or "pass through" of all the coordinates,his leads to inferior route allocation and generally several iterations of the algorithm are required before an optimal answer is obtained.

6.2.1 *Using Monte-Carlo Techniques to solve CVRP problems*

Many iterations of the Clarke& Wright algorithm is required to find an accurate answer.This raises the question of how to do this in a structured logical way, as there are millions of possible combinations for a CVRP with several hundred customers. Monte-Carlo techniques offer a novel approach to this problem,as these techniques use a probability distribution to select which points should be included in a route.

```
Require: $current$, $r$
Ensure: $solutionQuality$
while !isLeaf($current$) do
    $bestSolution \leftarrow +\infty$;
    $bestChild \leftarrow -1$;
    $n \leftarrow$numberOfChildren($current$);
    for $i = 0$ to $n - 1$ do
        $sum \leftarrow 0$;
        for $k = 1$ to $r$ do
            $sum \leftarrow sum +$ RANDOM SAMPLING($current$.child($i$));
            if $sum/r < bestSolution$ then
                $bestSolution \leftarrow sum/r$;
                $bestChild \leftarrow i$;
            end if
        end for
    end for
    $current = current$.child($bestChild$);
end while
```

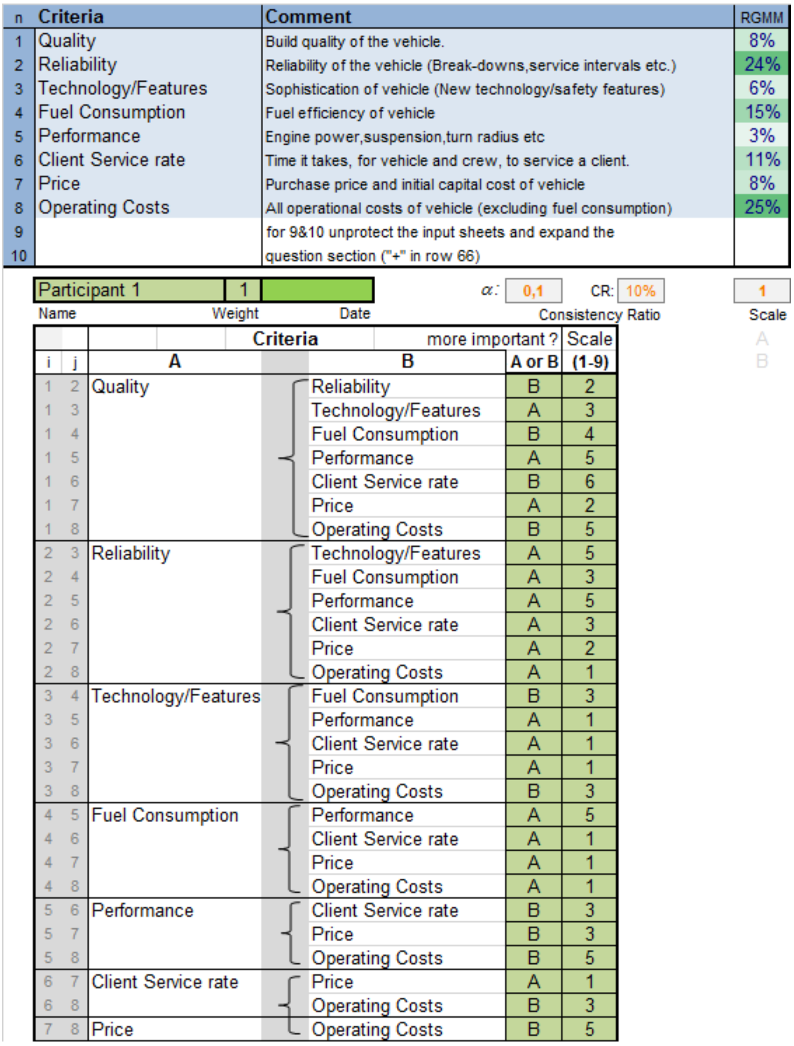
Figure 6: Generic Monte-Carlo simulation algorithm

Frank Takes [Takes, 2010] illustrates a way to use Monte-Carlo Techniques to solve a CVRP problem using a a method called the "Binary-CWS" method. In each simulation of the algorithm, the savings list, sorted in descending order by the size of the savings, is processed linearly from top to bottom. However, in the simulation of the Binary-CWS a savings pair is only processed with a certain probability p $(0 < p < 1)$,with the result that a savings pair is sometimes skipped. Through experimentation, the ideal probability interval was determined to be between $0.05 < p < 0.4$. The "Binary-CWS" method has been found to reduce the deviation from the optimal solution from 6.14% to just 2.28%. This method was chosen to be the basis of the development for the Python program.

7 DATA ANALYSIS

7.1 Analytical Hierarchy Process Data Analysis

The survey mentioned above was circulated among management at G4S, and the results received back shortly after. Some of the surveys indicated inconsistencies ranging between 11% and 23%,which necessitated adjustments having to be made.A final CR ratio of 11.2% was obtained which is acceptable for current purposes(although 10% is ideal).The results were then reconciled and an average determined for all the surveys.



n	Criteria	Comment	RGMM
1	Quality	Build quality of the vehicle.	8%
2	Reliability	Reliability of the vehicle (Break-downs,service intervals etc.)	24%
3	Technology/Features	Sophistication of vehicle (New technology/safety features)	6%
4	Fuel Consumption	Fuel efficiency of vehicle	15%
5	Performance	Engine power,suspension,turn radius etc	3%
6	Client Service rate	Time it takes, for vehicle and crew, to service a client.	11%
7	Price	Purchase price and initial capital cost of vehicle	8%
8	Operating Costs	All operational costs of vehicle (excluding fuel consumption)	25%
9		for 9&10 unprotect the input sheets and expand the	
10		question section ("+" in row 66)	

Name	Weight	Date	α:	CR: Consistency Ratio	Scale
Participant 1	1		0,1	10%	1

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Quality	Reliability	B	2
1	3		Technology/Features	A	3
1	4		Fuel Consumption	B	4
1	5		Performance	A	5
1	6		Client Service rate	B	6
1	7		Price	A	2
1	8		Operating Costs	B	5
2	3	Reliability	Technology/Features	A	5
2	4		Fuel Consumption	A	3
2	5		Performance	A	5
2	6		Client Service rate	A	3
2	7		Price	A	2
2	8		Operating Costs	A	1
3	4	Technology/Features	Fuel Consumption	B	3
3	5		Performance	A	1
3	6		Client Service rate	A	1
3	7		Price	A	1
3	8		Operating Costs	B	3
4	5	Fuel Consumption	Performance	A	5
4	6		Client Service rate	A	1
4	7		Price	A	1
4	8		Operating Costs	A	1
5	6	Performance	Client Service rate	B	3
5	7		Price	B	3
5	8		Operating Costs	B	5
6	7	Client Service rate	Price	A	1
6	8		Operating Costs	B	3
7	8	Price	Operating Costs	B	5

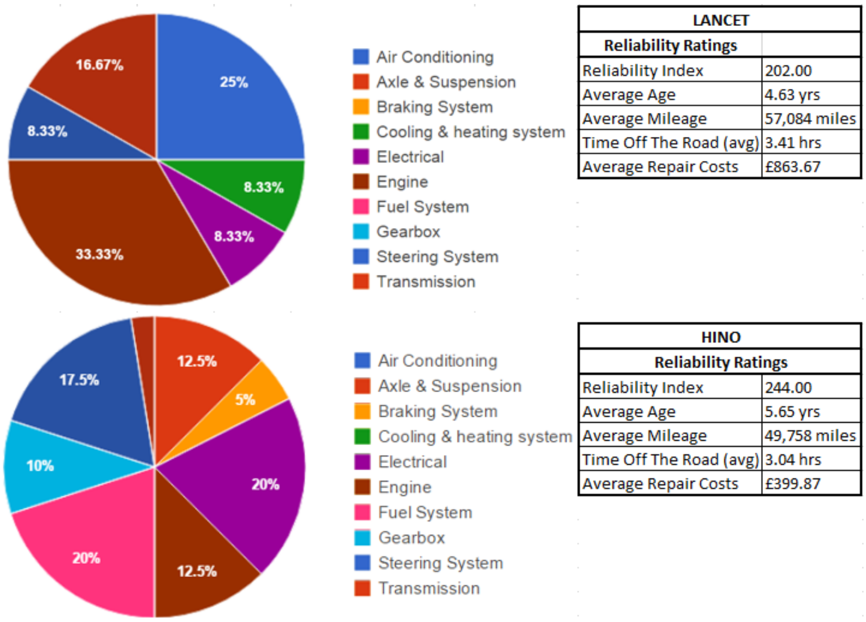
Figure 7: G4S CS Pretoria Branch Manager Survey results

The specification sheets of the Hino 300 and Hilux 2.5L vehicles were then used to obtain the following relative scores:

Table 3

Criteria	**Hino 300 (614)**	**Hilux 2.5 Hi-Rider(Lancet)**
Quality	0.66	1.5
Reliability	0.82	1.2
Technology/Features	0.5	2
Fuel Consumption	0.55	1.79
Performance	0.83	1.2
Client Service Rate	2	0.5
Price	0.75	1.32
Operating Costs	0.76	1.3

The reliability index seen in Table(3) gives a good indication of the overall performance of each vehicle(the pie charts in Figure(8) indicate the frequency of failure of parts of the vehicle)(reliabilityindex.com,2015).



LANCET	
Reliability Ratings	
Reliability Index	202.00
Average Age	4.63 yrs
Average Mileage	57,084 miles
Time Off The Road (avg)	3.41 hrs
Average Repair Costs	£863.67

HINO	
Reliability Ratings	
Reliability Index	244.00
Average Age	5.65 yrs
Average Mileage	49,758 miles
Time Off The Road (avg)	3.04 hrs
Average Repair Costs	£399.87

Figure 8: Reliability of each vehicle, (reliabilityindex.com)

7.2 Capacitated Vehicle Routing Problem Data Analysis

The data analysis for the CVRP problem consisted of consulting with various members of senior management at G4S, as well as the manufacturer of the armoured vehicles, and finally with the data manager for G4S Cash-Solutions. The initial data obtained was in a "chaotic" format and had to be mined and sifted to obtain the required data.Python was once again used to write a program that searches through the raw data and retrieves the required data,after which the data is sorted and stored in a structured manner.The code from this Python program can be found in the appendix.

Of the 2000+ customers at G4S Pretoria, a sample of 50 customers was chosen to determine an initial solution.The remaining customers will eventually also be included in the solution, however the CVRP problem is NP hard which severely increases the processing time if the number of customers is very large.The information* obtained from processing the data was as follows:

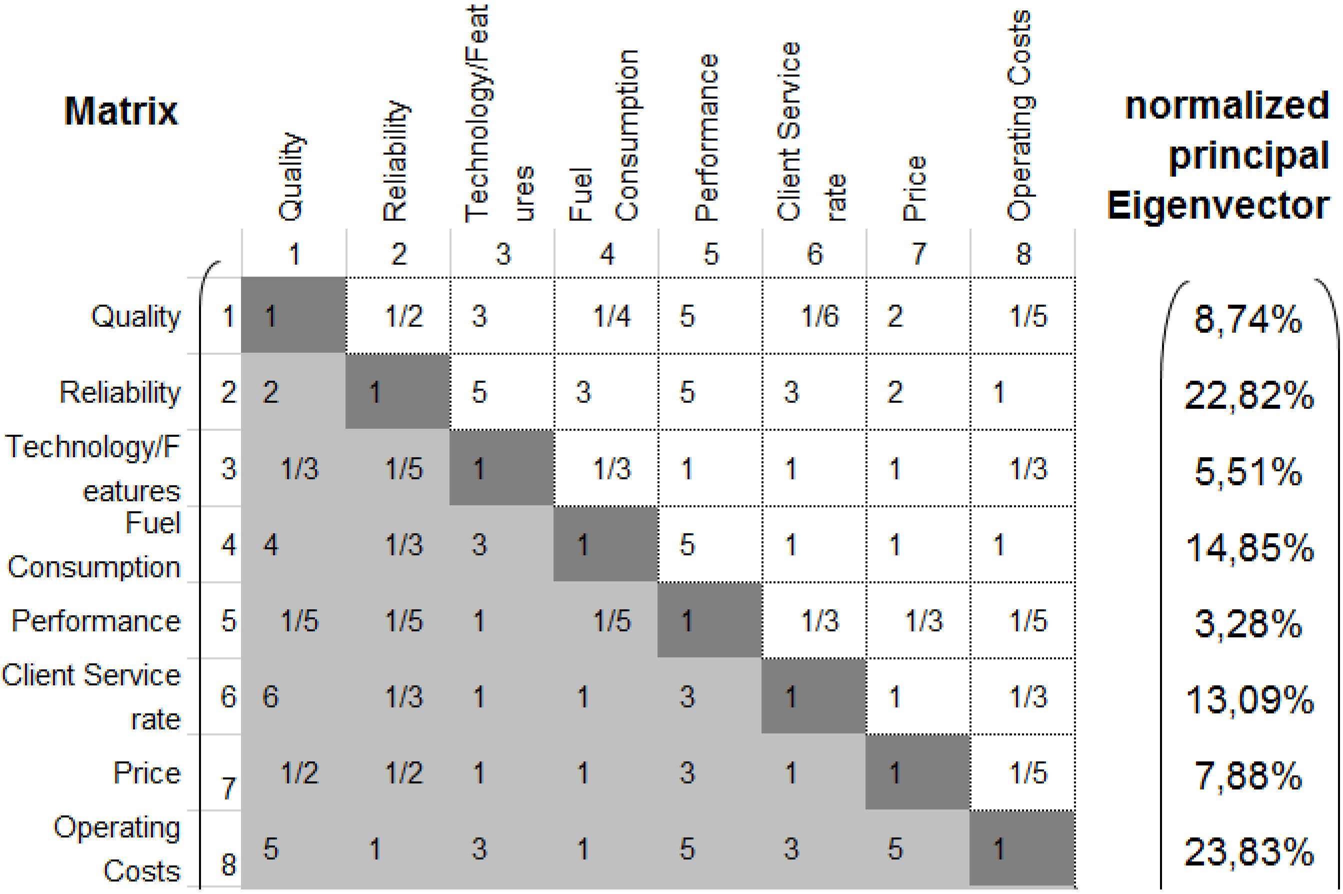
1.Depot Location(GPS Longitude and Latitude).
2.Customer Locations(GPS Longitude and Latitude).
3.The demand of each customer.
4.Maximum Capacity of each vehicle.
5.Vehicle range (was found to be infinite and therefore negligible).
6.Cost per km (not yet determined)
7.Cost per hour(Labour etc.).This will be used in the final iteration to determine whether minimizing time or distance travelled gives the highest savings.

Fully detailed data used can be found in the appendix

8 IMPLEMENTATION

8.1 Analytical Hierarchy Process Implementation at G4S

Following the data gathering,and data analysis phases, which included conducting a survey among G4S management as well as analysis of each vehicles' specifications data sheets,the AHP process was ready to be implemented.This was done following the steps listed in the AHP process methodology section (5.1.1). As the first and second steps were already implemented during the solution design and data analysis,the next step was to use the obtained data to calculate the normalized comparison matrices with the accompanying Eigen Vector.



Matrix		Quality 1	Reliability 2	Technology/Features 3	Fuel Consumption 4	Performance 5	Client Service rate 6	Price 7	Operating Costs 8	normalized principal Eigenvector
Quality	1	1	1/2	3	1/4	5	1/6	2	1/5	8,74%
Reliability	2	2	1	5	3	5	3	2	1	22,82%
Technology/Features	3	1/3	1/5	1	1/3	1	1	1	1/3	5,51%
Fuel Consumption	4	4	1/3	3	1	5	1	1	1	14,85%
Performance	5	1/5	1/5	1	1/5	1	1/3	1/3	1/5	3,28%
Client Service rate	6	6	1/3	1	1	3	1	1	1/3	13,09%
Price	7	1/2	1/2	1	1	3	1	1	1/5	7,88%
Operating Costs	8	5	1	3	1	5	3	5	1	23,83%

Figure 9: Criteria Matrix with normalized Eigenvector

The initial survey results contained several inconsistencies and had to be adjusted accordingly.The lowest CR ratio that could be found however was 11.2%,which although not the recommended consistency ratio,is more than adequate for practical purposes.The calculated relative weights and their corresponding "rank" are listed in figure 9. The updated hierarchy tree can be seen in figure 10.

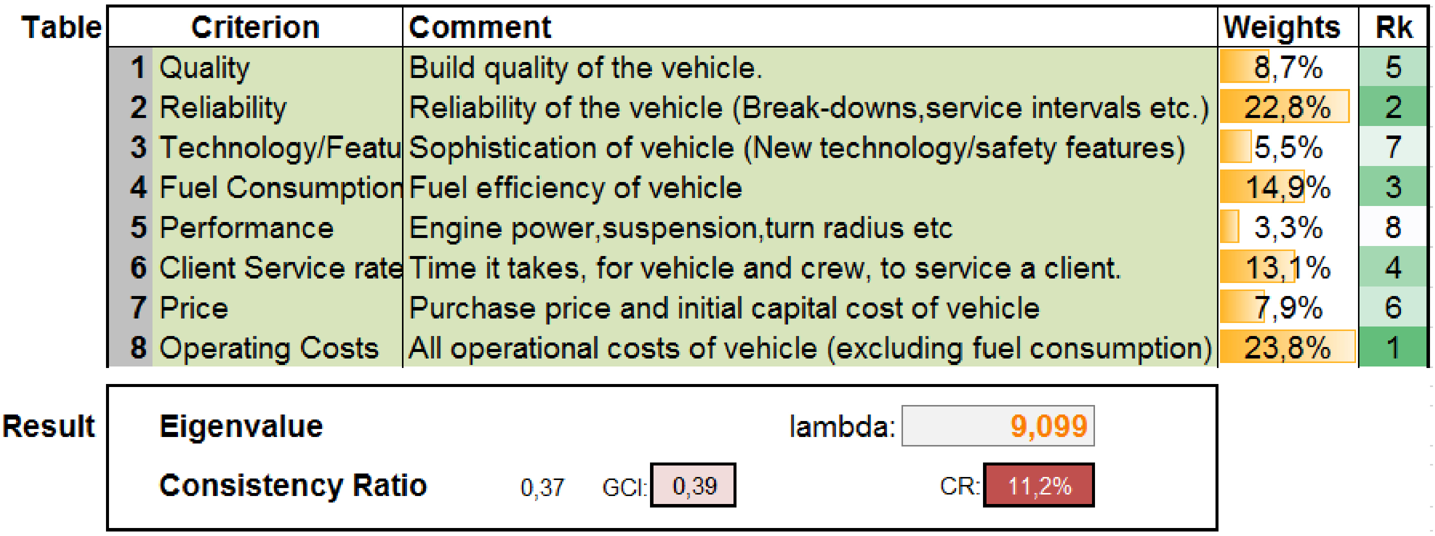


Table	Criterion	Comment	Weights	Rk
1	Quality	Build quality of the vehicle.	8,7%	5
2	Reliability	Reliability of the vehicle (Break-downs,service intervals etc.)	22,8%	2
3	Technology/Featu	Sophistication of vehicle (New technology/safety features)	5,5%	7
4	Fuel Consumption	Fuel efficiency of vehicle	14,9%	3
5	Performance	Engine power,suspension,turn radius etc	3,3%	8
6	Client Service rate	Time it takes, for vehicle and crew, to service a client.	13,1%	4
7	Price	Purchase price and initial capital cost of vehicle	7,9%	6
8	Operating Costs	All operational costs of vehicle (excluding fuel consumption)	23,8%	1

Result

Eigenvalue lambda: 9,099

Consistency Ratio 0,37 GCI: 0,39 CR: 11,2%

Figure 10: Criteria Matrix with normalized Eigenvector

The final answer to the AHP process is then found by determining the matrix product between the criteria Eigenvector and the alternative matrix. This is essentially multiplication between an mxn and nx1 matrix resulting in a mx1 matrix, in this case a 2x1 matrix.

AHP Process Result:

The best alternative,based on the Analytical Hierarchy Process, using the input data provided by G4S management, is the Lancet(Hilux 2.5L)vehicle with a score of **55.1%**,followed closely by the Hino 300(614) vehicle with **44.9%**.

$$\begin{pmatrix} \textbf{QUAL.} & \textbf{REL.} & \textbf{TECH} & \textbf{FUEL} & \textbf{PER.} & \textbf{CSR} & \textbf{PRICE} & \textbf{OPCost.} \\ 0,601 & 0,547 & 0,666 & 0,643 & 0,545 & 0,333 & 0,570 & 0,566 \\ 0,398 & 0,452 & 0,333 & 0,356 & 0,454 & 0,6667 & 0,429 & 0,433 \end{pmatrix} \times \begin{pmatrix} \textbf{Criteria} \\ 0.0874 \\ 0.2282 \\ 0.0551 \\ 0.1485 \\ 0.0328 \\ 0.1309 \\ 0.0788 \\ 0.2383 \end{pmatrix} = \begin{pmatrix} \mathrm{LCT} & \mathbf{0.551} \\ \mathrm{HNO} & 0.449 \end{pmatrix}$$

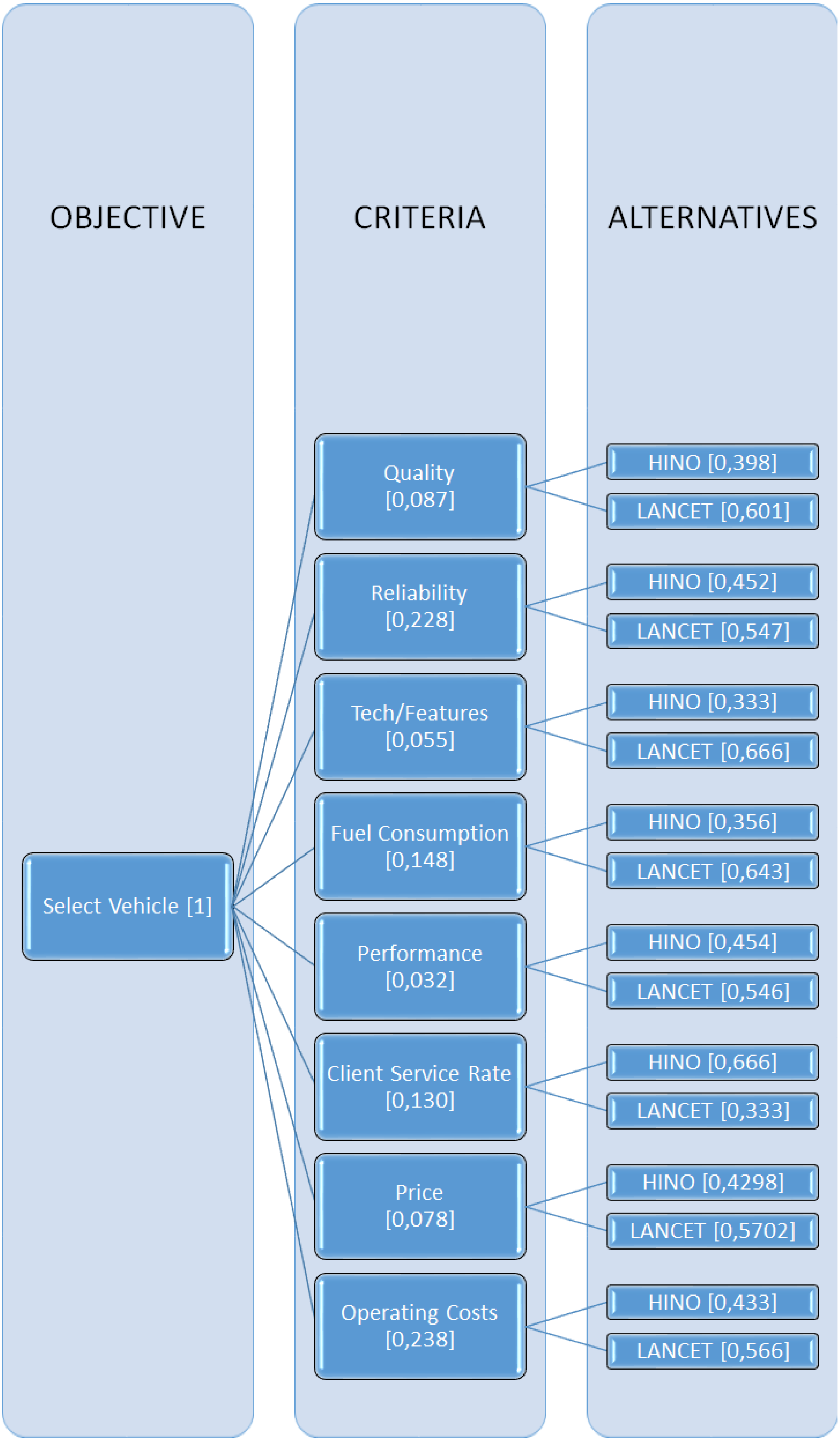


Figure 11: Updated Hierarchy Tree

8.2 Capacitated Vehicle Routing Problem Implementation at G4S

8.2.1 *Clarke & Wright Monte-Carlo "Binary-CWS" algorithm validation*

The "Binary-CWS" algorithm was implemented using Python programming to write and develop a program that receives the input data listed in section(7.2),performs the necessary steps and operations associated with both the Clarke&Wright algorithm as well as implementing the "Binary-CWS" monte-carlo method, after which the result is stored in a text document and the optimal routes plotted on a graph to illustrate the answer.Software and literature developed by Dr. Lawrence V. Snyder from Lehigh University was also used extensively to validate and improve accuracy.
Once the Python program had been developed and tested,it had to benchmarked to validate the accuracy of the program in solving a CVRP problem.The benchmark selected was the "CMT1",which is very similar to the typical distribution of customers for cash-in-transit type operations.The input data for this problem can be seen in table(4)(detailed input data can be found in the appendix) :

Table 4

Name:	CMT1
Type:	CVRP
Known optimal:	524.61
Customers:	50
Capacity:	160
Vehicles:	5
Distance format:	Euclidean

The resulting routes were then obtained as can be seen in table (7). As can be seen an error of 26.8% was recorded which means a deviation from the known optimal by 0.26.The accepted norm for conformity is usually 10%,however the deviation is most likely due to errors in the python code.

ROUTE 1		
Stop	Weight	Distance
1	0	2,24
47	5	10,20
12	19	10,00
17	15	8,00
10	11	6,40
50	18	7,62
39	15	7,07
6	21	9,22
13	29	6,00
48	25	9,43
Total:	158,00	76,18

ROUTE 2		
Stop	Weight	Distance
1	0	10,00
33	12	11,70
23	8	15,03
21	17	6,08
37	6	20,10
29	14	6,32
32	11	10,05
27	7	7,21
9	23	9,22
49	17	8,60
28	15	8,00
Total:	158,00	119,40

ROUTE 3		
Stop	Weight	Distance
1	0	29,12
30	6	7,21
22	8	7,81
51	10	6,40
35	26	6,71
31	19	9,22
11	5	10,00
40	14	13,93
34	23	7,00
46	10	6,71
16	10	6,08
45	16	7,28
38	9	18,11
Total:	156,00	135,58

ROUTE 4		
Stop	Weight	Distance
1	0	14,76
19	41	14,42
14	23	13,15
26	28	6,40
15	21	10,77
25	10	9,43
24	16	11,18
7	15	11,40
Total:	154,00	91,53

ROUTE 5		
Stop	Weight	Distance
1	0	26,42
8	19	12,04
44	11	43,68
2	7	19,21
4	16	15,30
3	30	37,01
5	9	32,02
41	7	12,08
42	27	5,00
20	9	8,54
43	13	14,32
18	3	17,26
Total:	151,00	242,89

Total Distance	665.29
Known Optimal	524.61
% Error	26.8 %

Table 5: CMT1 Benchmark Results

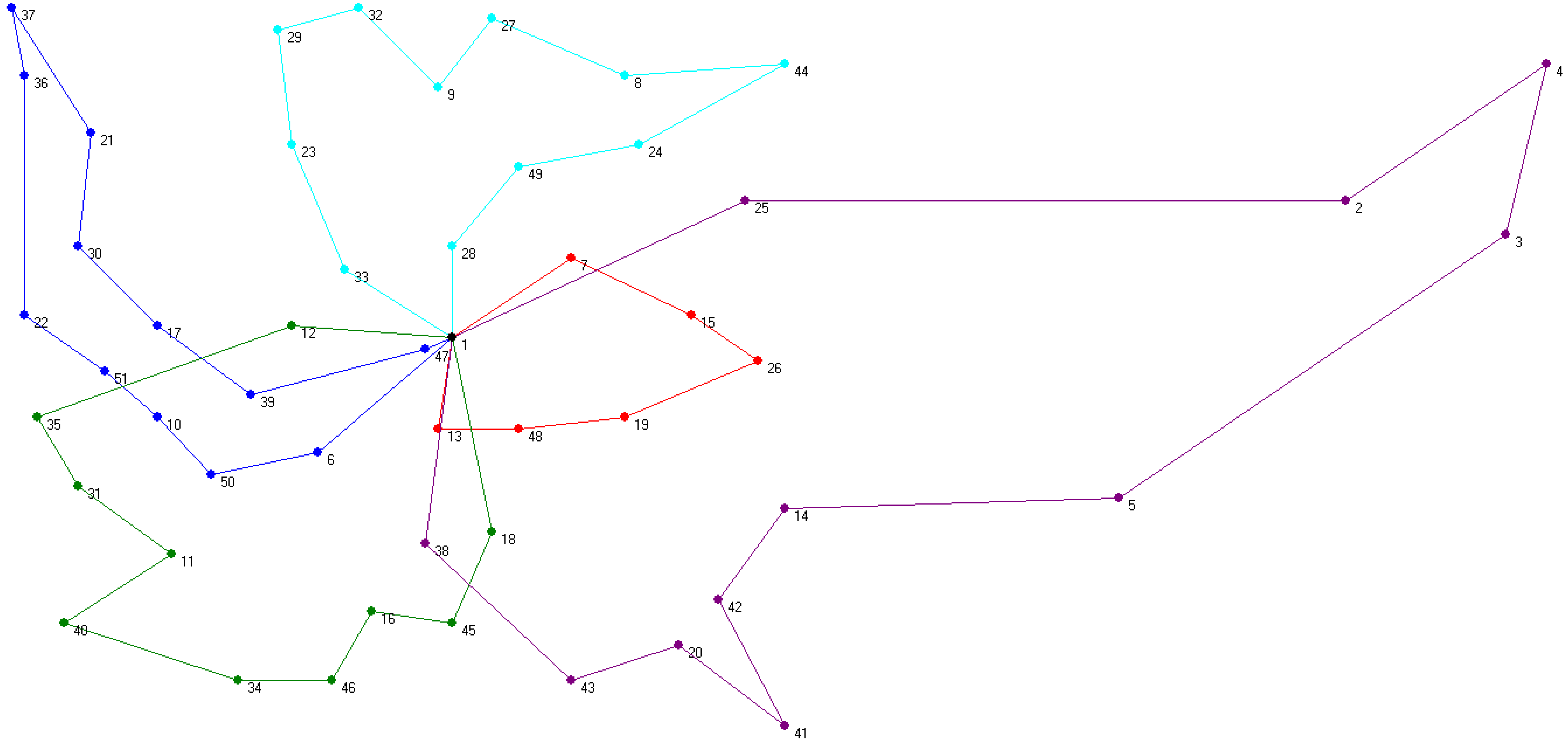


Figure 12: Optimized routes from centralized depot

8.2.2 *Clarke & Wright Monte-Carlo Python program implementation*

The first iteration in implementing the CVRP solution program included taking a sample size of 50 customers from the 2000+ customer database and determining the optimal routes for these 50 customers. The instance shown uses the input data of the Toyota "Lancet" vehicle. Due to the size of data the other 4 instances have not been included but can be found in the appendix. This includes solutions for the Toyota "Lancet" vehicle for 100 and 500 customers, as well as the Hino 300 vehicle with 500 customers.

An additional python program had to be written to convert the given GPS co-ordinates(longitude and latitude) into Cartesian X-Y co-ordinates.The basic formulae for the conversion is as follows (The code for this program can be found in the appendix).

Latitude-Longitude Cartesian Conversion Formulae:

lat =latitude of co-ordinate (ex. -25.714904)
$long$ =Longitude of co-ordinate(ex. 28.155929)
$R = 6371km$(Approximate Radius of Earth)

$x = R \times \cos(lat) \times \cos(long)$
$y = R \times \cos(lat) \times \sin(long)$

Table 6

Name:	G4S
Type:	CVRP
Known optimal:	–
Customers:	50
Capacity:	150
Vehicles:	47
Distance format:	GPS co-ordinates

ROUTE 1		
Stop	Weight	Distance
1	0	0,14
51	30	0,25
32	59	0,40
36	86	0,26
34	68	0,00
35	139	0,01
10	53	0,03
2	44	0,22
Total:	479	–

ROUTE 2		
Stop	Weight	Distance
1	0	0,36
33	20	0,20
47	244	0,00
6	4	0,20
39	165	0,00
Total:	433	–

ROUTE 3		
Stop	Weight	Distance
1	0	0,00
9	127	0,00
11	57	0,00
7	139	0,00
8	59	0,00
Total:	382	–

ROUTE 4		
Stop	Weight	Distance
1	0	0,03
13	7	0,09
21	44	0,04
22	31	0,05
46	68	0,01
41	38	0,00
45	271	0,03
43	10	0,03
40	2	0,04
50	26	0,10
Total:	497	–

ROUTE 5		
Stop	Weight	Distance
1	0	0,03
18	46	0,01
29	166	0,00
28	133	0,04
Total:	345	–

ROUTE 6		
Stop	Weight	Distance
1	0	0,14
30	123	0,00
19	48	0,01
3	10	0,01
42	127	0,02
16	7	0,02
37	46	0,10
14	105	0,16
26	33	0,10
Total:	499	–

ROUTE 7		
Stop	Weight	Distance
1	0	0,03
23	43	0,04
44	48	0,01
38	124	0,00
12	7	0,01
17	48	0,01
48	127	0,05
Total:	397	–

ROUTE 8		
Stop	Weight	Distance
1	0	0,01
5	20	0,02
27	29	0,06
25	47	0,03
24	46	0,02
20	37	0,00
4	82	0,00
15	38	0,03
49	9	0,01
31	188	0,06
Total:	496	–

Table 7: G4S CVRP First iteration

8.3 Results Analysis (Lancet Vs. Hino 300)

The main differences between the two vehicles are that the capacaties of the two vehicles vary greatly,with the Hino having a capacity 3.3 times larger than that of the Lancet vehicle.This impacts greatly on the total distance travelled by a fleet of vehicles. In an attempt to compare the two vehicles performance when used in conjunction with the CVRP algorithm, two instances of the 500 customer sample were solved, with the Lancet sample having a capacity of 150 and the Hino 300 a capacity of 500. The results are tabled below.

Table 8: Lancet vs. Hino with 500 customers each

	Hino	Lancet
Customers	500	500
Capacity(clasified units)	500	150
Total Distance (km)	**1529**	**4305.58**
Routes(vehicles)	**57**	**188**

As can be seen from Table 8, the distance travelled by the fleet of Lancet vehicles is considerably more than the fleet of Hino vehicles, this is due to its reduced capacity.This, coupled with the fact that the fleet size requirements are almost double that of the Hino fleet, would mean that operating costs would be much greater than the Hino. The only possible mitigating factor for this would be that the Lancet vehicle has 1/3 the crew requirements of the Hino vehicle, which could potentially even the costs. Thus the only economic justification of selecting the Lancet vehicle over the Hino would be if labour costs are a greater influencing factor than fuel costs(the Lancet would have to save labour costs by a factor of 2.8 to break even with the Hino vehicle).However given the fact that 3 Lancet vehicles are required for every route one Hino vehicle completes, the savings in labour costs seem unrealistic. Thus the results of the CVRP solution indicates that the Hino 300 is a better option than the Lancet Vehicle.

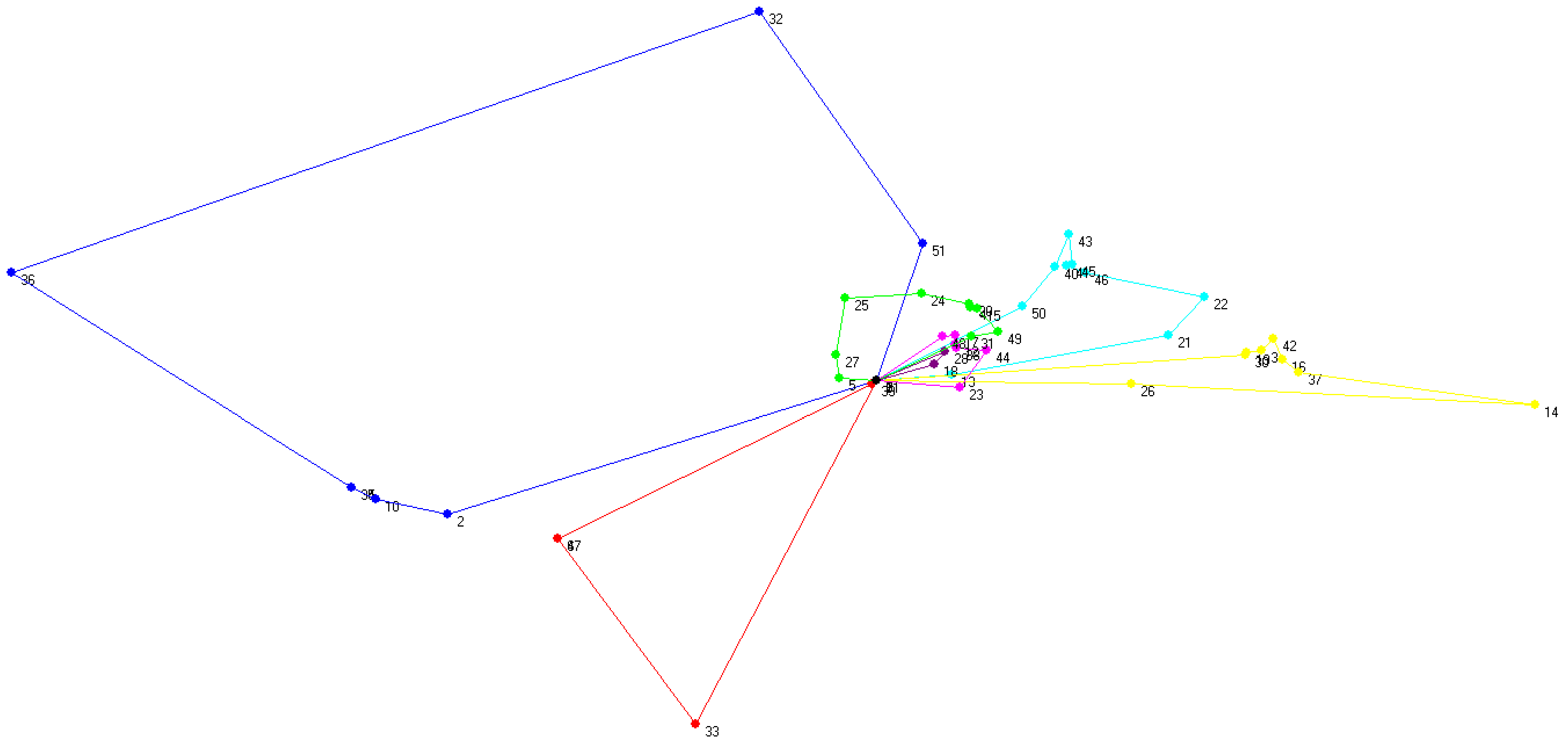


Figure 13: Optimized routes from centralized depot for G4S

8.4 Scalability and effects of NP-hardness of the CVRP Algorithm

Through experimentation of the CVRP algorithm, the scalability and effect that increasing the sample size had on the solution time, was determined. As expected the results indicate that the heuristics used and the problem solved is in fact NP-Hard(Non-Deterministic Polynomial Time-Hard). By gradually increasing the sample size and measuring the time it took to solve each problem, it was noted that the time taken to solve a problem as sample size increases also increases greatly. This was verified by plotting the measured sample solution times and fitting an exponential trend line to it. The maximum sample size the algorithm could solve was found to be around 500 customers, however a vertical asymptote of the graph would indicate 600 customers is still feasible. 500 Customers was the maximum sample size the algorithm could process due to RAM constraints of the computer used.

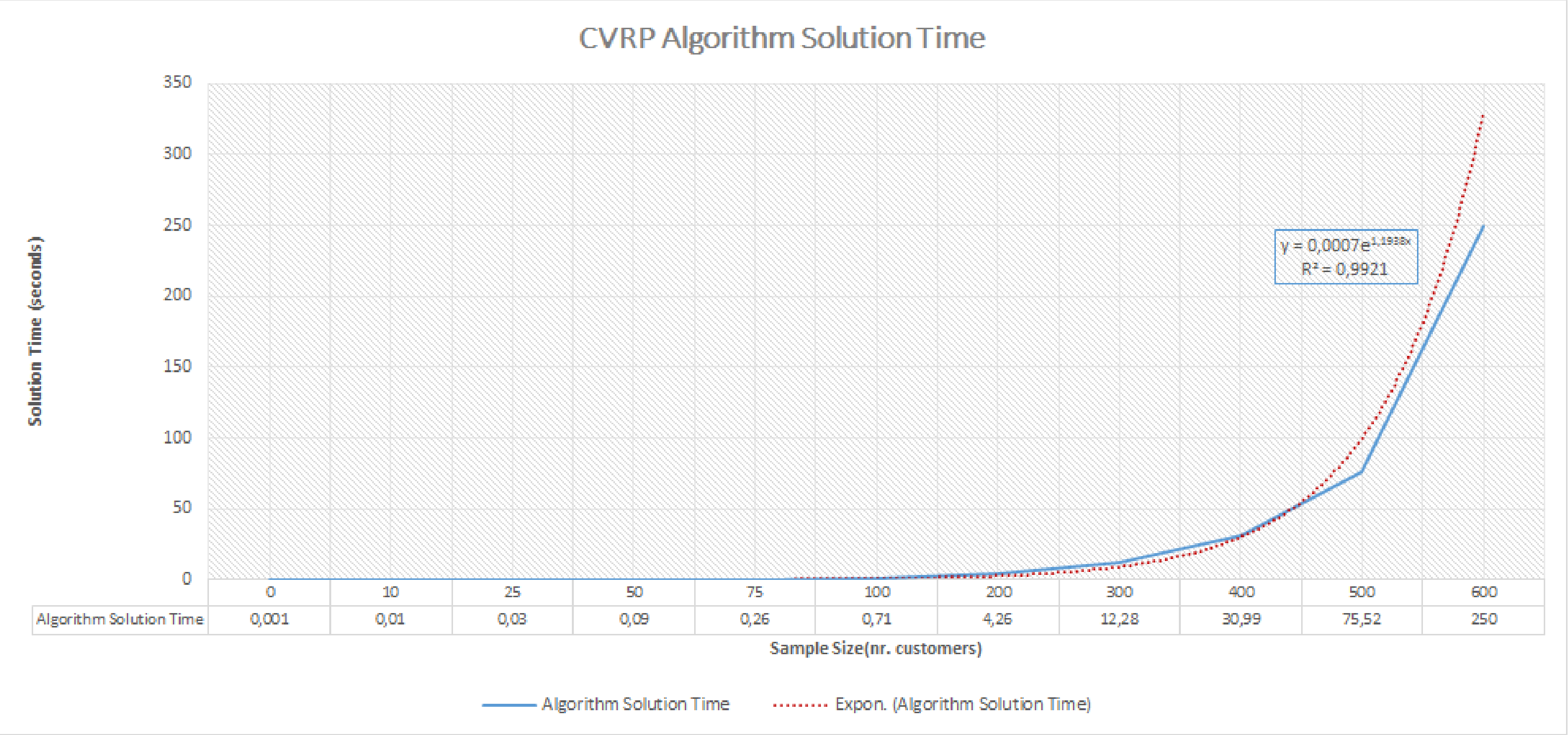


Figure 14: Solution time of samples with gradual increases in customer size

9 CONCLUSION

The results of the AHP and CVRP problem analysis offer conflicting answers as to which vehicle would be better suited to use in a fleet of cash-in-transit vehicles. The AHP results indicate that the Lancet vehicle is a better option due its high quality and low purchase price, as well as very efficient fuel consumption compared to the Hino 300. However what the AHP process fails to take into account is the total distance a fleet of Lancet vehicles would have to travel compared to a fleet of Hino vehicles, not to mention that the Lancet fleet would have to be nearly triple the size of the Hino fleet to be able to service the same ammount of customers in a given time.

The CVRP results show the overwhelming impact that vehicle capacity has on a vehicle fleets' ability to service customers.When comparing a single Lancet vehicle to a single Hino 300 truck it is cheaper to buy and operate a Lancet vehicle, however once these vehicles operate in a fleet environment economy of scale soon become evident. Thus the cost savings that a Lancet vehicle gains over a Hino is lost due to the fleet size requirements and distance travelled.

These costs can however be mitigated by the low labour costs of the Lancet vehicle, however such an analysis is outside the scope of this report. It can therefore be concluded that in a built up area such as Pretoria, where customer density and proximity is very close to one another,as well as high customer demand in a limited time window, that the Hino 300 vehicle is more suited to be used in a cash-in-transit role than the Lancet vehicles. However, in an environment with limited customers and low customer density, necessitating long distance travel for low volume customers, the Lancet vehicle would be the superior choice as capacity would no longer be a limiting factor and the low running costs,combined with greater fuel efficiency and crew costs would shift the cost-efficiency in favour of the Lancet vehicle. It is recommended that future research be conducted to establish the effect of labour(crew) cost savings of the Lancet vehicle compared to the Hino 300, as this will validate whether labour costs can in fact mitigate fuel consumption or not.

REFERENCES

[E. Scholtz, 2012] E. Scholtz, J. Bekker, D. d. T. (8 November, 2012). Multi-objective optimization with stochastic discrete-event simulation in retail banking.

[Frank W. Takes, 2012] Frank W. Takes, W. A. K. (2012). Applying monte carlo techniques to the capacitated vehicle routing problem,leiden institute of advanced computer science, leiden university, the netherlands.

[Haas, 2012a] Haas, D. R. (2012a). Scheduling of vehicles from a central depot to a number of delivery points,college of science and technology, university of manchester, england,1997.

[Haas, 2012b] Haas, D. R. (2012b). The analytic hierarchy process,university of natural resources and applied life sciences,vienna.

[Janakiraman, 2012] Janakiraman, S. (2012). Truck routing problem in distribution of gasoline to gas stations,the pennsylvania state university the graduate school college of engineering,2010.

[Louis Caccetta, 2012] Louis Caccetta, M. A. (2012). An improved clarke and wright algorithm to solve the capacitated vehicle routing problem,etasr,vol3,no.2,2013.

[Ruben Ruiz, 2003] Ruben Ruiz, Concepcion Maroto, J. A. (30 January 2003). A decision support system for a real vehicle routing problem.

[Saaty, 2012] Saaty, T. L. (2012). Int. j. services sciences, vol. 1, no. 1, 2008.

[Shaw, 1998] Shaw, P. (1998). Using constraint programming and local search methods to solve vehicle routing problems.

[Sinan Apak, 2012] Sinan Apak, Gizem Gogus, I. K. (2012). An analytic hierarchy process approach with a novel framework for luxury car selection.

[Takes, 2010] Takes, F. (2010). Applying monte carlo techniques to the capacitated vehicle routing problem.

10 APPENDIX

10.1 G4S First iteration input data

10.2 CMT1 Benchmark Input Data

10.3 Lancet 50 customers

10.4 Lancet 100 customers

10.5 Lancet 500 customers

10.6 Hino 500 customers

10.7 CVRP "BINARY-CWS" Python Code

10.8 Data mining Python Code

10.9 Vehicle data sheets

10.10 GPS Cartesian Conversion Python Program Code

10.11 G4S AHP Surveys