

EXECUTIVE SUMMARY

The South African Post Office (SAPO) has experienced a major decline in revenues over the past five years, with a recorded net loss of R1.37 billion for the 2015 financial year. The major contributor to these losses was due to the SAPO's inability to conform to the requirements of the ever-changing logistics industry. The parcel industry of the SAPO is regarded as the highest contributor to revenues, amounting to R3.58 billion during the 2015 financial year. The SAPO has however, experienced a major decline in revenue due to their inadequate ability to achieve the required customer service levels, resulting in 1641 recorded complaints over the past 12 months. A lack of trust and reliability between the SAPO and their customers is due to the SAPO's poor delivery services, which ultimately leads to customers changing to alternative options for courier purposes. The entire supply chain of the SAPO is responsible for the poor levels of customer service and an improvement to all the processes of the supply chain is necessary in order for the SAPO to once again record a profit. The most significant constraint that has been identified in the supply chain is through the transportation process and in particular, the routing of vehicles. The transportation costs of the SAPO amounted to R747 million for the 2015 financial year, thus the ability to reduce these expenses would have a major impact on the profitability of the SAPO. In this document, various route optimisation tools and techniques were evaluated and assessed for the transportation of parcels from retail outlets, to mail centres across South Africa. The Emalahleni mail centre was used as the pilot location to solve a sequential insertion heuristic that generated near-optimal transportation routes for the SAPO. The model was validated using various different assessments, which include increasing the number of vehicles used, changing the capacity and demand of vehicles, as well as analyzing the effect of the computational time on the model. The generated solution reduced the distance travelled by the SAPO in the Emalahleni region by 315.65km per day, which amounted to a total cost saving of R1 220 200.80 per annum. This document provides a complete literature review, the background of the problem, the project aim, the problem investigation, the project approach, data analysis, the solution design using a sequential insertion heuristic, validation and verification of the model and finally, the implementation plan and future work of the project.

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List of Abbreviations

API	Application Programming Interface
CVRPTW	Capacitated Vehicle Routing Problem with Time Windows
HCAP	Highway Corridor Analytic Program
OVRP	Open Vehicle Routing Problem
SAPO	South African Post Office
VRP	Vehicle Routing Problem
VRPMT	Vehicle Routing Problem with Multiple Trips
VRPPD	Vehicle Routing Problem with Pickup and Delivery
VRPTW	Vehicle Routing Problem with Time Windows

Chapter 1

Introduction

The SAPO is South Africa's national mail courier service and delivers more than 5 million items of mail on a daily basis to all nine provinces across South Africa. The SAPO offers a variety of delivery options and is divided into various divisions consisting of ordinary mail, freight moving options, savings bank options, money transfer services and a courier service. The courier service of the parcel industry is a division of the SAPO that promises speedy and flexible delivery of parcels to customers across South Africa. The parcel industry is seen as one of the SAPO's major generators of revenue, contributing 63% of total revenue earned, amounting to R3.58 billion for the 2015 financial year. Over the past few years, the SAPO has experienced a major decline in revenues, with a recorded net loss of R1.37 billion for the 2015 financial year. A major contribution to the decline in revenues experienced by the SAPO is caused by the substantial decline in the SAPO's courier service due to factors such as customer dissatisfaction and an increase in the competitive logistics market. The SAPO has restricted access to specified areas around South Africa as a result of certain government policies, however, the large majority of South Africa is freely available for alternative courier companies to offer their services to the public.

Customer complaints have also had a major impact on the SAPO due to the poor quality of service with 1641 recorded complaints over the past 12 months. The driving force behind customer complaints was the high percentage of late or no deliveries as shown in Figure 1, which contributed to the net losses experienced by the Post Office of R100 million per month. The root cause of this problem is the lack of effective operations in the supply chain with regards to the transportation of parcels from retail outlets to mail centres. Transportation costs were the second highest recorded expense experienced by the Post Office, behind labour costs, amounting to R747 million in 2015. Therefore, the SAPO's ability to effectively optimise their supply chain and particularly, optimise the routes travelled between retail outlets and mail centres, will ensure that the costs involved are minimised and customer satisfaction is maximised.

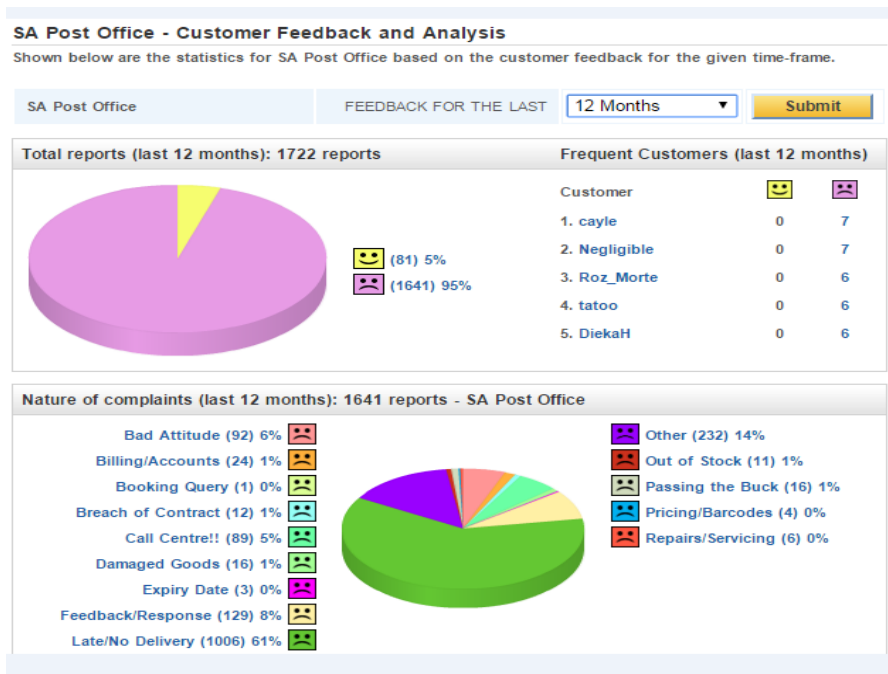


Figure 1: Pie chart showing customer complaints over the past 12 months [1]

The objectives of the project are the following:

- I. To analyse the current 'as-is' supply chain of the SAPO and propose improvement opportunities to the processes involved
- II. To minimise the costs involved in transporting parcels from retail outlets to mail centres
- III. To maximise customer satisfaction by ensuring that parcels effectively reach their respective mail centre within a given time window
- IV. To investigate various route optimisation problems that can be customized to suite the SAPO transportation system

1.1 Project Aim

The aim of the project is to maximise customer satisfaction through a higher precision rate of the SAPO's courier service, while minimising the costs involved in the supply chain. The main factor affecting the costs of the SAPO is the transportation of parcels within the supply chain. The use of various route optimisation techniques will be analysed and assessed to ensure that parcels are effectively delivered to mail centres within a given time window, therefore, ensuring that customer requirements are achieved.

1.2 Project Rationale

The SAPO recorded net figures of R5.69 billion in revenue in their annual financial reports for 2015. The biggest contribution to that revenue is through their private sector, which is made up of registered mail and their parcel industry, which contributed 63% of total revenue, amounting to R3.58 billion. Despite these revenues and over 66 million customers visiting the SAPO throughout the year, the SAPO still recorded losses of close to R100 million per month. With the constant growth in an already competitive market, a decline in the parcel industry could cause the SAPO to decline to unrecoverable levels [2]. Furthermore, the SAPO recorded transportation costs of R747 million for the financial year end, which was their second highest expense behind labour costs [3]. Therefore, the SAPO's parcel industry and in particular their transportation industry, is a vital division and major contributor to ensuring that the SAPO recovers from their previous losses and generates a profit in their future financial reports. The ability of the SAPO to compete amongst other logistics companies is also directly related to the optimisation of their transportation routes, which could potentially reduce costs involved, while increasing customer delivery and satisfaction, thus increasing revenues. The solution generated in this project resulted in cost saving of R1 220 200.80 per annum, which further validated the relevance of this project and the importance of route optimisation.

1.3 Project Approach

Figure 2 is used to show the approach taken for the completion of the project. The first step in the process was to ensure that the problem had been identified and defined. The SAPO is not satisfying customer demands, particularly in their parcel industry. The parcel industry is seen as the greatest revenue generator for the Post Office, however, is failing to meet the expectations of customers in the highly competitive logistics industry. In addition to defining the problem, a comprehensive literature review was completed to identify the best possible solutions that could potentially be implemented at the SAPO. The SAPO has four main processes for the parcel industry, namely the collection of parcels from retail outlets, the transportation of parcels to two alternative warehouses, where they are sorted and scanned onto the system and lastly, the transportation of parcels to their desired retail outlet. The main expense experienced by the SAPO is in the transportation sector, where expenses of R747 million were recorded for the 2015 financial period. Due to the demands and expenses of the transportation sector, route optimisation was performed with the aim of minimising the transportation costs, while maximising customer satisfaction.

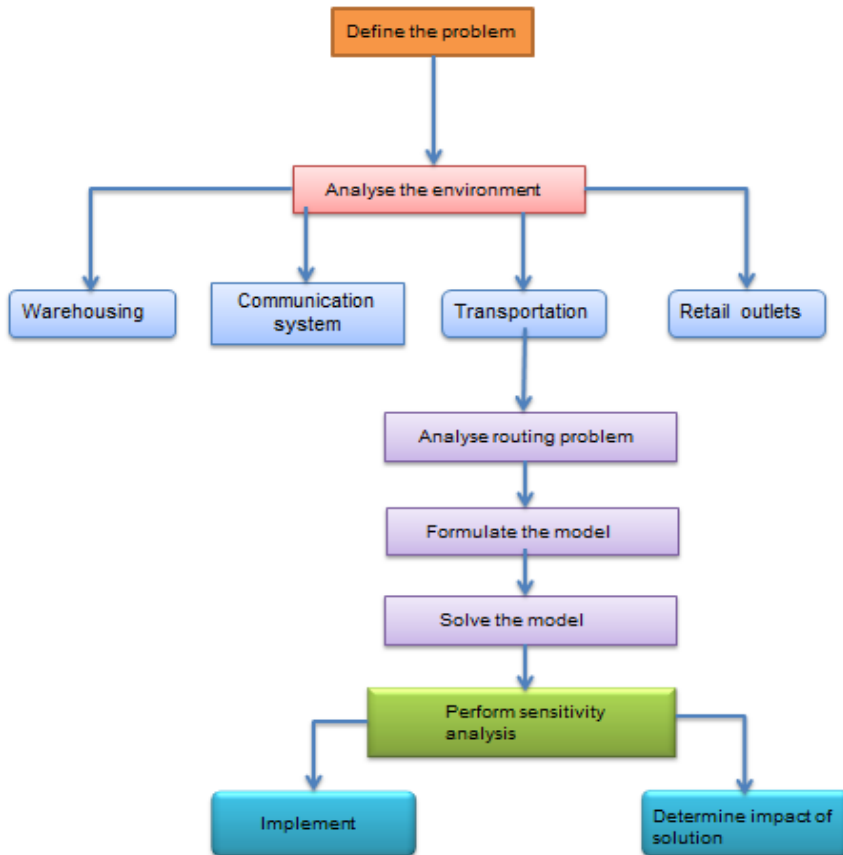


Figure 2: Project approach to effectively fulfilling the project requirements

A mixed integer linear programming model was formulated as an initial step to developing the algorithm in order to acknowledge constraints and objectives that the SAPO needs to adhere to. The following inputs were required to formulate the mathematical model:

- Define the objective function
- Define the constraints
- Determine the decision variables

Once the basic model was formulated, solving the model using a heuristic technique was done using a pilot location that services a reasonable number of retail outlets. The pilot model was based on the Emalahleni mail centre and the retail outlets within the Emalahleni district was analysed. The distances from the mail centre, to each individual retail outlet was done using the latitude and longitude of each retail outlet and these locations were entered into the heuristic. Route formulation was done for the pilot location, followed by various evaluations to ensure that the solution was validated and can accurately be applied to alternative mail centres across South Africa.

A heuristic approach was taken due to the complexity of the problem and to ensure that a satisfactory solution was found within an accessible time frame. Lastly, a sensitivity analysis was done using different input data values to assess the uncertainty in the model and the robustness of the results obtained from the model. Various sensitivity inputs included:

- Petrol prices
- Demand of customers
- Capacity of vehicles
- Number of vehicles

The implementation of the model and the impacts obtained was not evaluated in this project, however, additional studies can be conducted based on the potential improvement opportunities. Furthermore, a heuristic approach was completed first due to time constraints, followed by a simulated annealing metaheuristic, however, for future purposes, a comparison between different metaheuristic approaches could further be analysed by the SAPO.

1.4 Document Structure

The remaining sections of the document is organised as follows: Chapter 2 describes the problem investigation for the SAPO, which includes the problem background, problem definition, the chosen pilot mail centre and global logistic trends. Chapter 3 describes the literature review of different solution methods available, as well as appropriate solution strategies that could potentially be implemented by the SAPO. A solution design is described in Chapter 4 and the baseline model of the solution is evaluated. Chapter 5 validates and verifies the solution in Chapter 4. Lastly, Chapter 6 concludes the project and states the future work and implementation plan for the project.

Chapter 2

Problem Investigation

The Post Office is South Africa's national mail service provider with more than 2500 operating retail outlets and 26 mail centres located across the 9 provinces of South Africa. The SAPO is made up of different divisions within the organisation. The main form of revenue for the SAPO is generated within the courier division, which contributed R3.58 billion during the 2015 financial year. Furthermore, the courier division is made up of parcels and registered mail, however, a decline in revenue experienced within the courier division has resulted in an analysis of the current 'as-is' supply chain processes for the parcel industry.

2.1 Problem Background

The SAPO requires major infrastructure investments in order to keep up with factors such as urbanization, indicative of a nation that is continuously developing. The SAPO is mandated to reach new urban communities that were previously neglected with investments of R3.5 billion expected during the 2014, 2015 and 2016 financial periods. The planning done by the SAPO regarding the delivery routes for parcels have proven to be a problematic factor, partly for the increase in retail outlets and also due to the static planning methods implemented by the SAPO. The current 'as-is' processes implemented by the SAPO is illustrated in Figure 3.

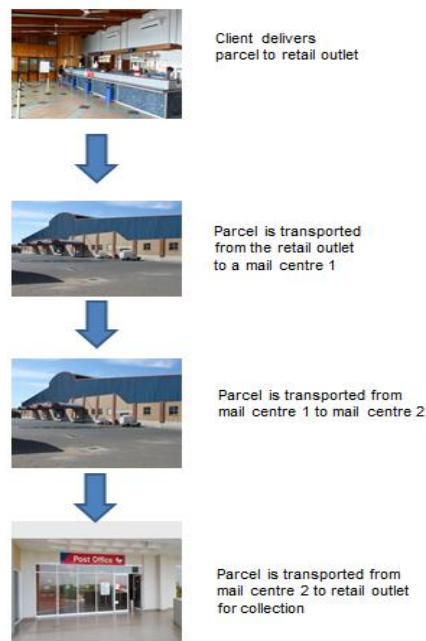


Figure 3: The current 'as-is' supply chain processes of the parcel industry

The process begins with the collection of parcels from specified retail outlets, as indicated by management. The pick-up process follows a specific schedule for each district, where drivers have time constraints that need to be adhered to for each retail outlet. The pick-up times of parcels are specified by the retail outlet and vehicles currently follow a random route based on which retail outlet has the soonest time window. Figure 35 in Appendix A shows an example of the route log used by the SAPO to collect parcels from the Emalahleni district, with all the specified time constraints. The parcels are then transported to one of 26 mail centres located in a certain district on a daily basis. Once the parcels arrive at the mail centre, they are manually sorted using a paper based approach by workers. The parcels are later collected and distributed to one of the alternative mail centres, where an alternative schedule is followed. The routes followed by vehicles from depot-to-depot are scheduled on a daily basis by management and an example of the schedule used is shown in Figure 4.

ROUTE ID	NLH 4A													
ROUTE	CAPEMAIL-GEORGE-PORT ELIZABETH													
NATIONAL TRAFFIC ROUTE	N2													
TRACK & TRACE NO:	S50010													
TYPE VEHICLE	6X4 TRUCK TRACTOR													
CONTRACTOR	CROSS ROADS													
IMPLEMENTATION DATE:	7/1/2015													
	APPROVED						DEPARTURES							
	SCHEDULE	KM	HRS	ETA	STOP	ETD	Km/h	S	M	T	W	T	F	S
S50010	CAPEMAIL					6:00	73			Y	Y	Y	Y	
	GEORGE	440	6.00	12:00	0:30	12:30	74			Y	Y	Y	Y	
	PORT ELIZABETH	350	4.75	17:15										
	790													
	Cml leave one or two spaces open for Gge. Gge connect all work for Peh.													

Figure 4: Example of a depot-to-depot schedule

Lastly, the parcel is delivered from the respective mail centre, to a retail outlet for collection. Once parcels arrive at their destination, they are given a 30 day time-window with which a customer can pick-up the parcel before they are distributed back upstream in the supply chain to their original retail outlet, where the SAPO is responsible for losses incurred. One of the main issues experienced by the SAPO is confusion amongst the mail centres due to human error, as well as uncertainty regarding the required destinations for parcels to be transported. Human error within the mail centres is an extremely costly factor for the Post Office as parcels are sent to incorrect destinations, where they are only notified of this error after the 30 day time lapse. The regular occurrence of human error is a major contributor to customer dissatisfaction and ultimately affects the profitability of the Post Office.

2.2 Problem Definition

The current 'as-is' supply chain of the SAPO is not capturing the true market share for the parcel industry due to the fact that the SAPO is not following the trends of leading logistics organisations. The major driving factor behind the lack of revenues is due to the poor efficiency of the SAPO's supply chain and more specifically, the transportation of parcels within their supply chain. In addition to the transportation process causing significant problems for the SAPO, the mail centres are also having a negative impact on the delivery of parcels. There are 26 mail centres located across South Africa, each playing a vital role in the sorting and distribution of packages to their desired location. Human error, however, has had a negative effect on this process due to the fact that parcels are manually sorted and delivered to dispatch stations on a daily basis, resulting in parcels mistakenly being sent to their incorrect destination. As a result of the SAPO's poor supply chain management and services, customer dissatisfaction is common, with 1641 reported complaints over the past 12 months and 1006 of the reported complaints due to late or no delivery (Figure 1). An increase in customer complaints has resulted in a decrease in customers, contributing to a recorded net loss of R100 million per month for the organisation during 2015. The solution to solving the SAPO's supply chain problems requires analyzing and assessing the transportation problems first, before assessing the 'smaller problems' such as warehouse management and in-house storage. Solving the mail centre problems experienced by the SAPO will not have an effect on the financial statement of the SAPO as significantly as the transportation process will, therefore, solving the greater monetary value process will initially be focused on.

2.3 The Chosen Pilot Mail Centre

The SAPO is an organisation that spreads across the whole of South Africa with over 2500 retail outlets. A pilot depot was chosen for the purpose of the investigation to test and validate the proposed systems in order to first generate a feasible solution before testing the validity of the model on a national scale. The Emalahleni mail centre was chosen as the pilot depot due to the reasonable size of the depot and the number of retail outlets served. The Emalahleni mail centre services seven regional districts, each of those districts having a specific number of retail outlets that need to be serviced on a daily basis. Figure 35 in Appendix A shows the routes travelled by the SAPO from the Emalahleni mail centre to the Middelburg region. Vehicles leave the mail centre at specific times as specified by the schedule and have certain time windows that drivers must adhere to for each retail outlet. The Post Office currently uses five vehicles to cover the seven regional districts from the Emalahleni mail centre, which cover a total of 54 retail outlets on a daily basis. There is, however, a shortage of vehicles used by the Post Office causing the excess retail outlets to be split up between the vehicles.

The main problems experienced by the Emalahleni mail centre are:

- Vehicle maintenance resulting in some vehicles being inoperative for months
- Route duplication where vehicles visit the same retail outlets
- Backlogs in pickup and delivery of parcels as a result of retail outlets not being visited on a daily basis
- Poor conformance to retail outlets time windows
- Customer dissatisfaction due to delays in transportation resulting in delays in delivery

Due to the lack of technology and planning schedules at the SAPO, there is no real time planning systems in place to make the necessary route changes, therefore, a dynamic and flexible real time system is required. The pilot depot was used to evaluate and assess the current transportation methods used by the SAPO and helped determine feasible solutions for the pilot depot before validating the system on a national level.

2.4 Global Logistic Trends

The decline in revenues experienced by the Post Office is not a problem only faced locally. The United States of America's postal service is arguably regarded as the biggest postal service in the world, however, has suffered chronic net losses of \$5.1 billion during the 2015 financial year [4]. The United States of America's Postal Service says the net losses experienced is largely due to the increase of urbanisation and the increase in compensation and transportation costs, amounting to \$52.2 billion and \$6.8 billion during the 2015 financial year respectively [5]. With the problems experienced at the Post Office, the private sector rivals such as Federal Express, Dalsey, Hillblom & Lynn and Deep Submergence Vehicle are continuing to lure customers away from the Post Office, further impacting the future struggles of the Post Office. The key to the success of the U.S Postal Service's competitors is largely due to the dynamic routing systems implemented to improve delivery plans and reduce costs [6]. The dynamic routes allow competitors to alter their routes in response to real time changes in conditions, however, this system is something that the U.S Postal Service is still currently investigating due to the large investments required to implement this system on a national scale. The U.S Postal service has, however, attempted to move towards a dynamic routing system when they recently announced that their attempt to cutting transportation costs was successful, resulting in a decrease of more than \$5 million in transportation costs. The contributing factor to the decrease in transportation costs was the efficiency of the routes travelled by vehicles. A transportation-optimisation system called Highway Corridor Analytic Program (HCAP) was developed as a route optimisation tool, which resulted in a decrease in fuel consumption of 615 000 gallons per year [7]. HCAP aims at using the most cost efficient plans for vehicles to travel by minimising the distances of routes, thus minimising the fuel costs involved.

Locally, the SAPO is mandated by laws that control the prices of delivering packages. These prices are governed by the Independent Communications Authority of South Africa (ICASA) where a notice needs to be given in terms of Section 30 of the Postal Service Act No. 124 of 1998 to increase the rates of sending packages. Competitors such as Deep Submergence Vehicle are therefore able to guarantee customers an express delivery of parcels at a higher price, while still maintaining low costs due to their dynamic routing system. For the SAPO to compete in a highly competitive logistics industry, change is needed within the transportation process to operate with a more dynamic routing system and ultimately improve customer's perceptions of the SAPO.

Chapter 3

Literature Review

A literature review was conducted to analyse various techniques previously used in the supply chain and logistics industry with regard to the transportation and in-house storage of parcels as they move across depots around the country. The objectives of the literature review are to analyse and determine the different methods currently used in industry, where route optimisation and supply chain design is the main priority.

3.1 Supply Chain Management

The Institute for Supply Chain Management defines supply chain management as “The design and management of seamless, value-added processes across organisational boundaries to meet the real needs of the end customers” [8] and plays a vital part to ensuring customer requirements are met. Managing the flow of products and services within the supply chain, therefore, becomes an integral part of the SAPO’s plan of maximising revenue within their parcel industry. Supply chain management covers all aspects of the Post Office’s parcel industry, which include the movement and storage of parcels, the in-house storage of parcels at different warehouses and the final delivery of parcels to customers at the end of the supply chain. A crucial element to supply chain management is also related to the ease and efficiency of which information is distributed throughout the supply chain, where different organisations throughout the supply chain are able to conform to certain customer requirements. The ability for a supply chain to operate efficiently and mitigate any possible risk will ensure that customer satisfaction is achieved, as well as ensure that the organisations downstream are able to minimise any losses in products and ultimately, reduce losses [9].

3.2 Supply Chain Design

Determining the optimal supply chain structure for supplier to customer delivery forms a major part of the effectiveness of an organisations supply chain in terms of their profitability. The performance of an organisation is therefore greatly affected by the robustness of their supply chain [10]. The design of the SAPO’s supply chain forms a vital part of the Post Office’s aim of achieving maximum revenue, due to their current underperforming processes. A wider approach, therefore, needs to be taken first in order to identify the major problems within the SAPO’s supply chain before the optimisation of critical aspects within the supply chain can be addressed.

3.3 Customer Relationship Management

The success of a business is directly influenced by their ability to conform to customer requirements, thus ensuring that customer needs and expectations

are met forms a pivotal part of customer relationships. The ability of an organisation to evaluate and assess customer feedback differentiates effective organisations from their competitors, therefore, allowing for high quality products and processes. Customer expectations should continuously be examined due to the ever-changing demands of customers and is a management tool that can have a direct influence on the financial performance of an organisation.

3.4 Parcel Pickup and Delivery

The SAPO currently has 26 mail centres located in 9 different provinces around the country. The mail centres serve as a 'stop and go' point for parcels before being dispatched to their next destination. The processes involved in delivering parcels include two stops at different mail centres, regardless of where in the country the parcels are being delivered, which is a costly and time consuming activity for the SAPO. A common technique used in industry for a process similar to the SAPO's is called arc routing, where the best path for a specific route is selected in a network. When a Post Office vehicle collects parcels from a specified number of retail offices in a district, there are certain constraints and factors that need to be taken into account when the parcel is collected, which includes the order at which parcels are collected, the routes taken to collect these parcels and the routes taken to deliver these parcels to the specified mail centre. Arc routing is a technique that aims to minimise the lost mileage of vehicles, which would ultimately increase profits. Various other projects focusing on mail routing problems specifically have previously been done for the parcel industry. The U.S Postal Service used a Highway Corridor Analytic Program (HCAP) in an attempt to reduce their expenses, which resulting in a total decrease in transportation costs of \$5 million per year. A previous study called "Optimisation mail delivery system by routing" has also been done, which focused on the delivery of mail to depots [11]. In terms of the SAPO, a study was completed last year for the organisation called "Route optimisation for the South African Post Office SoC LTD" that investigated the delivery of mail from depots to houses around the country.

3.5 Arc Routing Problems

There are many different problems associated with arc routing which includes:

- The undirected rural postman problem
- The undirected capacitated arc routing problem [12]

3.5.1 The Undirected Rural Postman Problem or Chinese Postman Problem

This method of arc routing applies to the fact that the postman may deliver parcels in any order chosen, while aiming to minimise the total costs

involved to deliver the mail. The SAPO needs to minimise the transportation costs for all routes travelled from the point when parcels are collected by the postmen at retail outlets, to when the parcel is delivered to its desired retail outlet, which would ultimately generate greater profits. Improvement opportunities for rural postman problems are described in [13]. The main objective of the arc routing problem is to ensure that all sections of a district is covered with regard to deliveries, however, all edges of the district do not need to be travelled to in order to deliver mail, thus reducing transportation costs, as can be depicted by Figure 5.

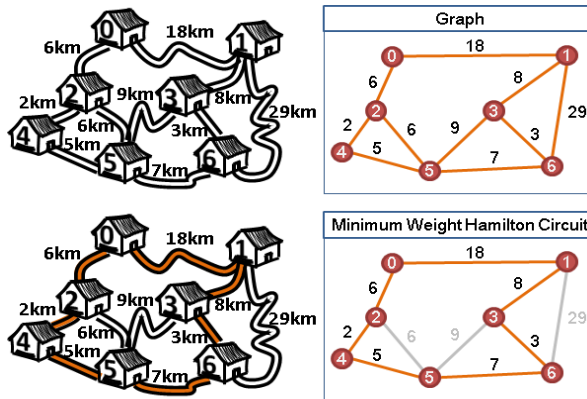


Figure 5: Example of an undirected rural postmen problem [14]

3.5.2 The Undirected Capacitated Arc Routing Problem

This problem allows for more than one vehicle to travel along the boundaries of the specified route in the network [15]. The vehicle may also travel in any direction as there is no limiting factor and the term undirected implies that the routes travelled are two way roads. The routes travelled in an undirected capacitated arc routing problem may require two vehicles to travel the same route, for example, the Post Office may require two vehicles to use the same road when collecting mail. However, the vehicles used to collect mail have a limited capacity with regard to the amount of mail that can be collected [15].

3.6 Vehicle Routing Problem (VRP)

Vehicle routing algorithms aim to find the optimal routes for a number of vehicles to deliver customer products to various specified locations. Figure 6 shows a common example of a VRP, where the nodes would be a representation of the SAPO's different retail outlets and the depot represents the given mail centre that the parcels are taken to. The VRP forms a major part of supply chain management with regards to the physical delivery of goods and services. The main defining question that distinguishes the VRP is; what are the optimal set of routes that a combination of vehicles should travel in order to achieve customer delivery, while minimising the total route costs involved? A common example of a VRP is defined by [16] where the

following occurs: Let $G = (V, A)$ represent a directed graph, which means that directions are already determined and no route has any loops. Let $V = \{0, \dots, n\}$ represent the vertex set, where vertex 0 is used to represent the mail centre and the remaining vertices in relation to the project, represent the various retail offices. $A = \{(i, j): i, j \in V, i \neq j\}$ represents the arc set, which represent the roads travelled by the Post Office's vehicles.

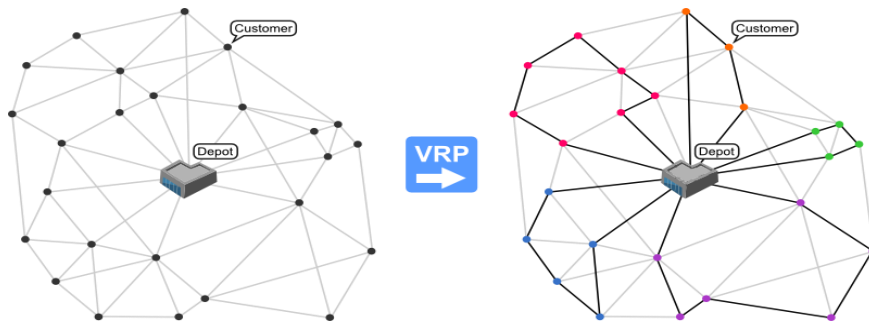


Figure 6: Example of a vehicle routing problem [17]

There are different possible objectives that a VRP can aim to achieve. These objectives depend entirely on the organisation involved and can include the following:

- To minimise the total transportation costs involved by minimising the total distances travelled by a fixed number of vehicles
- To minimise the total number of vehicles used to serve customers parcel delivery
- To minimise the penalties involved for low service quality

Due to the sheer number of trips travelled by the SAPO, the ability to minimise the total distance travelled by the SAPO through route optimisation is one of their main objectives, due to the fact that transportation costs is the SAPO's second highest expense. A comprehensive approach to VRP's is given in literature [16], where certain variations and specialisations exist in solving a VRP that are based on the different types of goods transported, the quality that must be adhered to for the service and the overall characteristics of customers and vehicles involved.

3.6.1 Vehicle Routing Problem Variants

The different variants to vehicle route problems can be categorised into various alternatives, each having different specifications for the different problems that exist.

Vehicle Routing Problem with Pickup and Delivery (VRPPD): When numerous goods need to be collected from a specified pickup location and moved to an alternative delivery location.

Vehicle Routing Problem with Last in First Out: Uses a similar approach to VRPPD, however, the product being delivered to a specified location is the product that was picked up most recently.

Vehicle Routing Problem with Time Windows (VRPTW): Where the products being delivered to a specified location has to be delivered within a certain time window to complete the delivery.

Capacitated Vehicle Routing Problem (CVRP): Where the vehicles used in transportation have a limited carrying capacity when delivering products.

Vehicle Routing Problem with Multiple Trips (VRPMT): Where the vehicles used to transport products can be assigned more than one route at a time.

Open Vehicle Routing Problem (OVRP): Where vehicles do not have to return to a depot.

The SAPO has various time windows that need to be adhered to when collecting and delivering parcels to retail outlets. A schedule is given to drivers, as shown in Figure 35 in Appendix A that provides the specific time windows for drivers to complete delivery to the different retail outlets. The vehicles used by the SAPO also have capacities that need to be taken into consideration when collecting and delivering parcels to retail outlets. Based on these factors, the SAPO's problem can be modelled as a Capacitated Vehicle Routing Problem with Time Windows (CVRPTW).

The CVRPTW is a common problem in logistics and operations research that has received a great amount of attention in recent times with an increased amount of published papers and theories. A number of authors have already solved a CVRPTW and some notable examples include: Dantzig and Ramser [38] used an algorithm based on the two-index formulation, where the two best multi-commodity flow formulations were used. A branch-and-bound algorithm was used by C Archetti [39] to solve a CVRPTW, a branch and price based algorithm was used by N Dellaert to solve a multi-depot CVRPTW [40]. S Karakatic and V Podgorelec used a genetic algorithm to solve a CVRPTW [41] and lastly, S Jawarneh and S Abdullah used a sequential insertion heuristic to solve a CVRPTW.

3.7 Selecting an Appropriate Solution Strategy

The reduction of transportation costs requires the optimisation of routes travelled from a mail centre, to designated retail outlets in a particular district. The design of an appropriate algorithm for the routing problem requires the analysis and identification of an existing solution strategy that has already been effectively employed in a transportation environment.

3.7.1 An Overview of Search Methodologies and Existing Strategies

Figure 7 shows the classification of common methodologies that have been applied in solving popular optimisation problems. For the purpose of the SAPO's route optimisation problem, a combinatorial strategy is more

appropriate for solving the problem. A differentiation between approximate methods and exact methods is then made, where the approximate methods are further categorised into metaheuristic and heuristic methods. This section assesses the suitability of the various methodologies that may be used in solving the route optimisation problem, as well as analyses how the different strategies can be adapted to solving the existing problem.

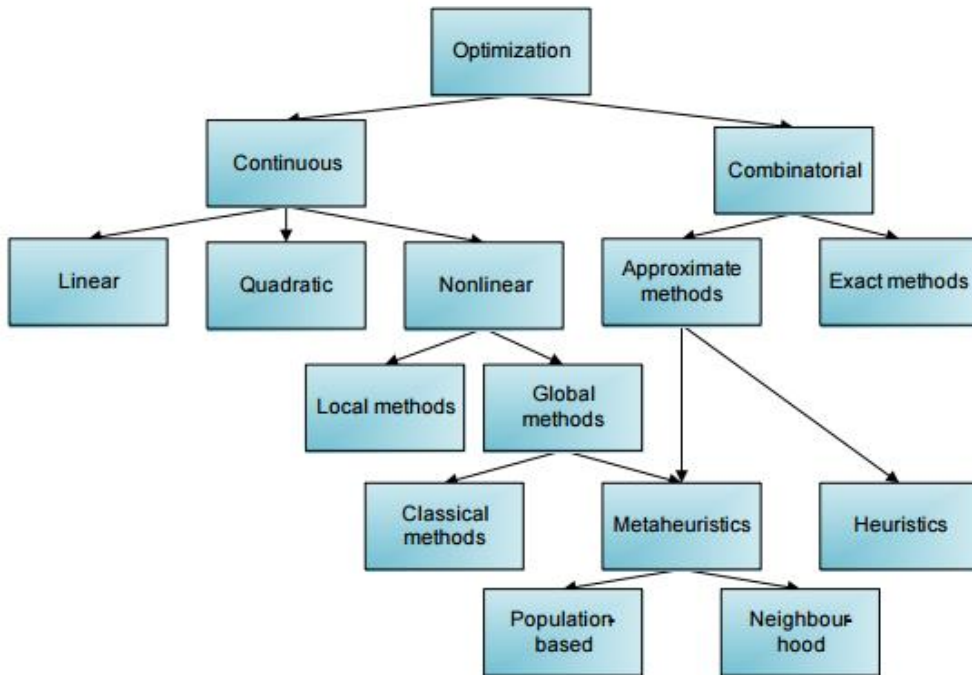


Figure 7: A breakdown of various search methodologies [18]

3.7.2 Exact Solution Method

An exact method is a strategy that aims at determining the exact solution to a specific problem through sophisticated and elaborative mathematical constructs [18]. The branch-and-bound algorithm is seen as the most commonly used enumerative strategy for combinatorial optimisation problems that involves an indirect search of the given tree structure, which is used to represent the solution space of the problem [19]. The aim of this method is to find the optimal solution for a problem and is generally associated with discrete problems. In order to incorporate the optimal solution strategy into the solving of this problem, excessive computational requirements are necessary and the suitability of the strategy is also influenced by the complexity of the problem. Apart from the before mentioned factors, the optimal solution strategy is also problem dependant and would not be suitable for the SAPO due to the sensitivity of the initial upper and lower bound values [18]. Therefore, approximation methods are seen as a suitable alternative. Although solutions to problems do not

guarantee optimality, this method is adequate in solving large scale problems efficiently.

3.7.2 A Heuristic Technique

A heuristic problem solving approach is an approach where the generated solution is not necessarily optimal, however, the heuristic problem solving method ensures that a satisfactory solution is found within an acceptable time period. Literature [20] explains how various algorithms have been used to solve route optimisation problems considering a large number of vehicles. In general, a heuristic technique is a simple search algorithm that determines a “good enough” solution [18] to solving a problem and is regarded as a good first step in moving towards a metaheuristic technique. In relation to the SAPO, a heuristic technique would be a suitable approach to implement due to the number of vehicles the Post Office has and the limited time available to achieve a satisfactory solution. The savings heuristic, a time-oriented nearest neighbour heuristic, the insertion heuristic and the swap city heuristic are often applied to vehicle routing problems.

3.7.3 The Savings Heuristic

In 1964 Clarke and Wright proposed the savings method as a well-known example of a constructive heuristic [21]. The objective of the algorithm is to minimise the total transportation costs involved and is based on the savings concept. The procedure to solving this algorithm involves determining the allocation of customers to specific routes, the sequence of routes and customers and determining which route will be covered by a specific vehicle. The measure of costs saved by the savings heuristic is given by [22]:

$$Sav_{ij} = d_{i0} + d_{0j} - \mu d_{ij} , \quad \mu \geq 0$$

Where Sav_{ij} denotes the savings from serving customers i and j on one route instead of serving them separately from the depot, d_{i0} denotes the distance from node i to the depot, represented by 0, d_{0j} denotes the distance from the depot represented by 0, to node j , d_{ij} denotes the distance from node i to node j , μ denotes whether the two routes are combined or not. For example, $\mu = 1$ will service customers i and j together on one route. Figure 8 is used to describe the savings equation, where point 0 is used to represent the depot and the savings equation describes how the algorithm merges two routes into one route. Figure 8(a) illustrates how customers are visited from a specific depot on separate routes. Figure 8(b) shows an alternative to this method, where customers i and j are visited on the same route, minimising the distances travelled and maximising the total savings for each trip, as shown by the equation above. High savings values indicate an attractive alternative to the existing route and various different combinations of routes can be determined to find the best possible solution. Opinions regarding the savings heuristic seem to conflict in relation to solving complex vehicle routing problems, however, the savings concept has already been

used to solve vehicle routing problems with time windows. Additionally, the savings concept's main objective of minimising transportation costs aligns with the SAPO's objectives. The negatives associated with the savings heuristic relate to the analysis of the savings as given by the formula above. The savings heuristic is deemed to be attractive when Sav_{ij} is relatively large, however, there are no guidelines or values that indicate when a solution is attractive and the savings for one organisation may not have the same influence on another organisation. The savings heuristic is also dependent on the way the algorithm is implemented and may involve high computational costs when managing different routes at the same time.

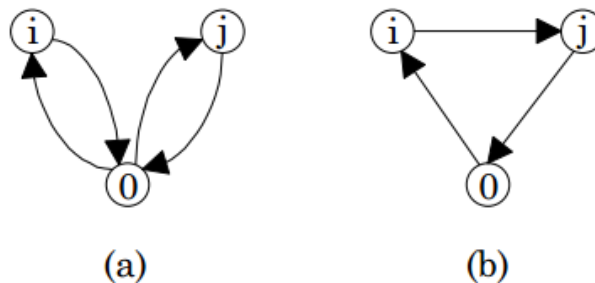


Figure 8: The Savings Concept [23]

3.7.3 A Time-oriented Nearest Neighbour Heuristic

The time-oriented nearest neighbour heuristic is a sequential algorithm that initiates every route from the closest customer to the depot [22]. Thereafter, the heuristic searches for the subsequent customer that is closest to the current customer and generates the next route. Figure 9 provides a visual representation of how the heuristic generates routes, for example a vehicle starting at depot A will travel to customer E instead of customer B due to the shorter distances. The heuristic repeats the process for all feasible customers that abide by the given constraints (capacity constraints, allocated time windows and arrival and departure times from depots) and generates the nearest possible neighbours route. The time-oriented nearest neighbour heuristic is regarded as one of the more common heuristics used for practical problems due the ease of implementation, as well as fast executions. However, the heuristic is often termed “greedy” because of its nature to miss shorter routes that are easily noticeable with human insight. Previous results have also shown that the algorithm has generated routes that are much longer than the optimal route.

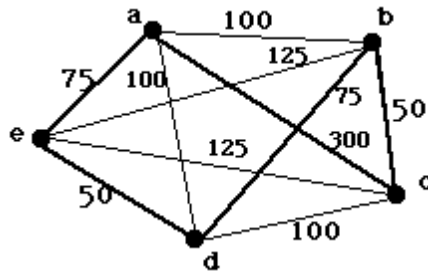


Figure 9: Nearest Neighbour Heuristic [24]

Route of nearest neighbour path: AEDBCA

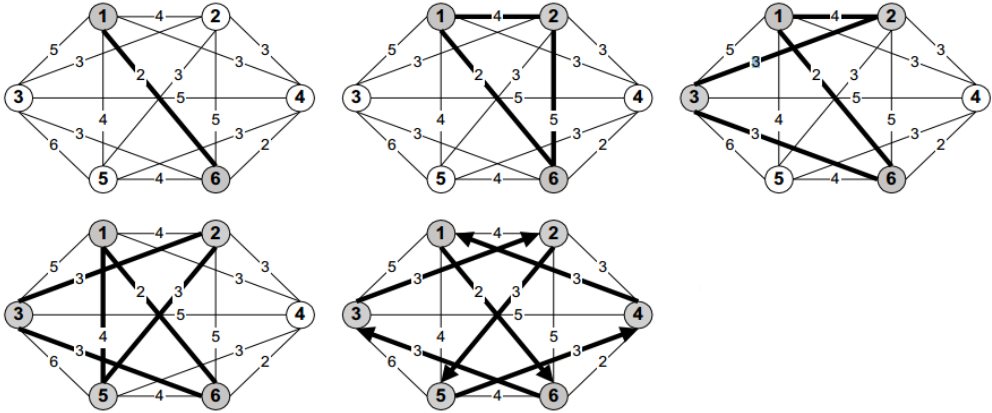
Cost of nearest neighbour path: $75+50+75+50+300 = 550$

3.7.4 The Insertion Heuristic

Algorithms for vehicle routing problems may be broken up into two different types of algorithms: sequential or parallel methods. Sequential methods construct one route at a time, as opposed to parallel methods where more than one route is constructed simultaneously. From all the initial solution heuristics that have previously been evaluated, Solomon concluded that the sequential insertion heuristic proved to be extremely successful in terms of the computational time needed to generate a solution, as well as the quality of the solution [25]. One city or point that is denoted by i , is first inserted into the route. The first customer inserted into the route is known as the seed customer. A common criterion previously used to select the initial customer is based on the farthest un-routed customer and the customer that has the earliest deadline. Once the seed customer has been selected, city j is chosen as the city that minimises the weighted average of the distances and times when inserting customers into the route. The current route is not initialised and a new city called k is inserted into the current route. Literature [22] gives a practical example of the insertion method where values of k are based on the following equation:

$$k = \text{minimum weighted average}(c_{ik} + c_{kj} - c_{ij}) \quad [26]$$

Where k denotes the city that is inserted into the route, c_{ik} denotes the minimum cost or distance from node i to node k , c_{kj} denotes the minimum cost or distance from node k to node j , c_{ij} denotes the minimum cost or distance from node i to node j .



Total length of the tour: 17

Figure 10: The insertion heuristic [26]

As shown in Figure 10, the seed customer is represented by city 1. City 6 is selected next due to the fact that the distance from city 1 to city 6 is the shortest. City 2 is selected as the initial k city (based on the furthest un-routed customer criterion), however, does not form part of the partial route and instead, assists the algorithm to generate routes thereafter. City 2 is based on specific criteria the organisation wants to adhere to, for example, the furthest un-routed customer. City 3, 4 and 5 could have all been chosen in step 3 due to their equal distances from city 2. City 5 was linked to city 2 and city 4 due to the fact that the distances travelled would be shorter than travelling from city 1 to city 5, hence why the route in step 4 was discarded. The insertion heuristic requires vehicles to return to the seed customer, therefore, city 4 has a final leg linking back to city 1. The algorithm tests many different combinations before the final route is obtained, which has the minimum total distance. In terms of the SAPO scenario, the cities would be replaced by retail outlets and the starting and ending point (represented by city 1 in Figure 10) would be the mail centre. Insertion heuristics are relatively straight forward and easy to understand with insertions occurring based on the shortest possible distances from the current location. The shortcomings associated with the sequential insertion heuristic is the fact that all un-routed nodes are considered when determining the selection and insertion criteria, which can result in a computationally expensive heuristic.

3.7.5 Swap Cities Heuristic

The swap cities heuristic forms part of the tour improvement approach, where a combination of construction and improvement is made to the routes. The heuristic is relatively simple and follows one main rule: if the total length of the route after the swap has been made is reduced, keep the new route, otherwise, the swap is unsuccessful and an alternative must be considered

[27]. Figure 11 illustrates the concept of the algorithm where A' and B' represent the changes made to the algorithm based on the formula:

Denote: $A, B \in \{0,1,2,3, \dots, K\}$ where K is the total number of cities prior to the swap city heuristic being implemented

Denote: $A', B' \in \{0,1,2,3, \dots, N\}$ where N is the total number of cities after the swap city heuristic has been implemented

$$Total\ Distance(A' + B') < Total\ Distance(A + B)$$

The process is repeated for every city until no more improvements can be made to minimizing the distances, thus resulting in the final route for the system. Although the swap city heuristic is easy to implement with a computational burden that is low, swap city heuristics do not take into account the distances between cities and primarily work on a trial and error basis, which could be extremely time consuming.

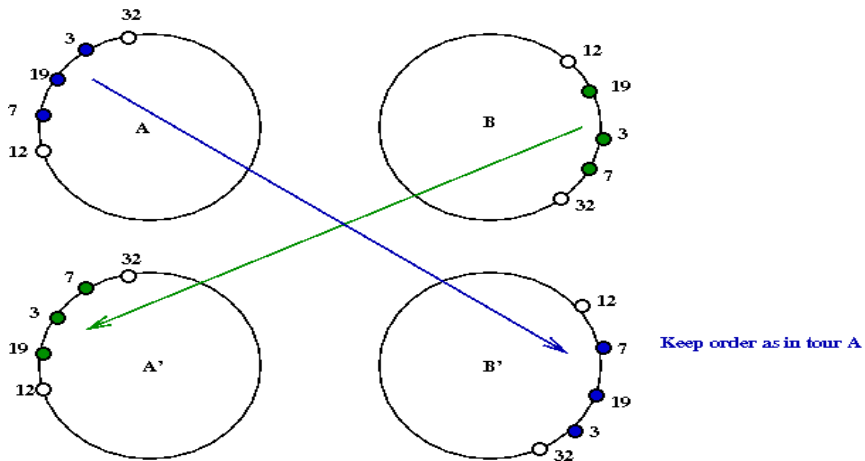


Figure 11: Swap cities heuristic [34]

3.7.6 Metaheuristics

A metaheuristic is defined as an iterative generation process that guides a subordinate heuristic by combining various concepts for exploiting and exploring the search space in order to find efficiently near-optimal solutions. [37]. Metaheuristics are a result of a heuristic technique's inability to escape local optima [18]. The results generated by metaheuristics do not, however, guarantee an optimal solution will be found, but do assist in guiding the search processes, where solutions close to the optimal solution are found [21]. An optimisation problem may contain incomplete or imperfect information. The benefits of using a metaheuristic technique are that few assumptions regarding the problem are made and the algorithm developed can then be used for a large variety of problems. The main disadvantages associated with using metaheuristics are the long computational times required, slow convergence speed, difficult encoding scheme and the tuning

of many parameters [28]. Metaheuristics is a non-deterministic approach that efficiently assists in the search towards the optimal solution, while minimising the range of optimal solutions and may be used as an advanced method to solving the problem once a heuristic technique has been used [29].

3.7.7 Simulated Annealing

Figure 12 shows some of the common metaheuristics used. However, due to time restrictions, simulated annealing was chosen as the only metaheuristic to further analyse due to the following advantages [40]:

- Can deal with cost functions and arbitrary systems
- Statistically guarantees an optimal solution will be found
- Is relatively easy to code
- Generally provides a ‘good’ solution

Simulated annealing is an optimisation process based on the cooling process of solids and liquids [18]. Simulated annealing models the physical process of heating a material and then gradually decreasing the temperature to reduce defects, therefore, minimising the systems energy. As the substance cools down, molecules align in a crystalline structure that is associated with the minimum energy state of the system. This is similar to the algorithm converging to the optimal solution for a specific optimisation problem. As the metals temperature decreases, the alignment of atoms continuously changes, where an alignment that results in a lower energy state, similarly results in an improved solution [18]. The disadvantage of using a simulated annealing algorithm is the excessive computational time required to achieve ‘good’ solutions.

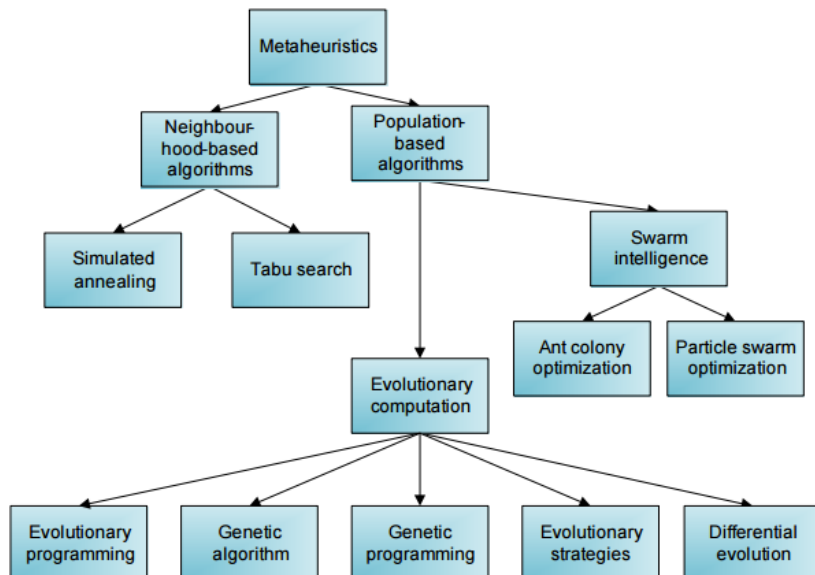


Figure 12: Common metaheuristics [18]

3.8 Conclusion

Based on the above analysis, a heuristic was chosen for further investigation. The heuristic provides a suitable solution that will continuously progress towards a more suitable solution within an acceptable time frame. Apart from the fact that a heuristic is a good first step before implementing a metaheuristic, there are also many distinct advantages that are associated with using an approximation based algorithm for optimising the transportation of parcels. Since the Post Office has a high number of retail outlets to collect from with a limited time available, the complexity of the problem would require a metaheuristic to generate a satisfactory solution. However, due to the limited time available to complete the project, a simulated annealing metaheuristic was the only metaheuristic technique further analysed to address the issue of heuristics getting stuck in local minima. Of all the heuristic techniques available, the sequential insertion heuristic appeared to be the most suitable heuristic for the complex transportation problem. The computational time needed to generate a solution, as well as the quality of the solution [25] using a sequential insertion heuristic was a suitable strategy for the SAPO. The objectives of a sequential insertion heuristic is to minimise the total distance travelled by vehicles, thus minimising the costs involved, which aligns with the objectives of the SAPO.

Chapter 4

Solution Design

This chapter is used to describe the chosen solution method in more detail. A model is first formulated, followed by the algorithm implementation, which analyses the difference between the sequential insertion heuristic, the nearest neighbour heuristic and the simulated annealing metaheuristic to determine the most suitable model for the SAPO. In addition, various off the shelf software is analysed to determine the best toolkit to implement the algorithm.

4.1 Mixed Integer Programming Model

There are two different ways the SAPO's problem can be formulated:

1. Optimising the fuel usage
2. Optimising the time spent travelling

For the purpose of the SAPO, optimizing the fuel usage would be the most suitable option due to the fact that transportation costs amounted to R747 million for the 2015 financial year. Vehicles need to travel from the mail centre, to the specific retail outlets in each district, while minimising the fuel that the vehicles use. There are certain constraints that need to be taken into account such as:

- The demand from customers
- The capacity of each vehicle (depending on the weight and size of the items)
- The time window for each retail outlet (trucks may arrive earlier at a retail outlet, however, would have to wait until the time window opens)
- The service time at each customer

The mixed integer programming model as presented by Tompkins et al. (2010) was identified as a suitable mathematical model for the SAPO. The model allows for decision variables and parameters to be examined before the heuristic is developed, as well as examines certain constraints that need to be adhered to in order to satisfy the SAPO's restrictions, while minimising the total transportation costs. For the purpose of the model, an arc represents the connection between two nodes, as well as the direction travelled. Vertex 0 is used to represent the depot and the remaining vertices are used to represent the retail outlets of the SAPO.

Denote: $i \neq j; i, j \in \{0, 1, 2, 3, \dots, N\}$ where N is the total number of retail outlets
Denote: $k \in \{0, 1, 2, 3, \dots, K\}$ where K is the total number of vehicles used by the SAPO

The decision variables include:

$$X_{ijk} \in \begin{cases} 0, & \text{if vehicle } k \text{ travels from node } i \text{ to node } j \\ 1, & \text{otherwise} \end{cases}$$

The model parameters include:

$T_i \triangleq$ The arrival time at node i

$C_{ij} \triangleq$ Total cost incurred from node i to node j for the arc

$t_{ij} \triangleq$ The travel time between node i and node j

$m_i \triangleq$ Demand at node i

$q_k \triangleq$ Carrying capacity of vehicle k

$f_i \triangleq$ Service time at node i

$e_i \triangleq$ The earliest arrival time at node i

$l_i \triangleq$ The latest arrival time at node i

$r_k \triangleq$ Maximum route time allowed for vehicle k

$$\text{Objective function} = \min \sum_{i=0}^N \sum_{j=0}^N \sum_{j \neq i, k=1}^K C_{ij} X_{ijk} \quad (1)$$

S.T

$$\sum_{k=1}^K \sum_{j=1}^N X_{ijk} \leq K \quad \forall i = 0 \quad (2)$$

$$\sum_{j=1}^N X_{ijk} = 1 \quad \forall i = 0, k \in \{1, \dots, K\} \quad (3)$$

$$\sum_{k=1}^K \sum_{j=0, j \neq i}^N X_{ijk} = 1 \quad \forall i \in \{1, \dots, N\} \quad (4)$$

$$\sum_{k=1}^K \sum_{i=0, i \neq j}^N X_{ijk} = 1 \quad \forall j \in \{1, \dots, N\} \quad (5)$$

$$\sum_{i=1}^N m_i \sum_{j=0, j \neq i}^N X_{ijk} \leq q_k \quad \forall k \in \{1, \dots, K\} \quad (6)$$

$$\sum_{i=0}^N \sum_{j=0, j \neq i}^N X_{ijk} (t_{ij} + f_i) \leq r_k \quad \forall k \in \{1, \dots, K\} \quad (7)$$

$$\sum_{k=1}^K \sum_{i=0, i \neq j}^N X_{ijk} (t_{ij} + f_i) \leq T_j \quad \forall i \in \{1, \dots, K\} \quad (8)$$

$$e_i \leq (T_i + f_i) \leq l_i \quad \forall i \in \{1, \dots, N\} \quad (9)$$

$$X_{ijk} \in \{0, 1\} \quad \forall i, j \in \{1, \dots, N\}; \quad \forall k \in \{1, \dots, K\} \quad (10)$$

The objective function indicated by equation 1 minimises the total costs involved in transporting parcels between nodes for all vehicles of the SAPO. Constraint 2 indicates that the total number of trips made is represented by the number of vehicles, K and at most, there are K outbound arcs from the mail centre. Constraint 3 ensures that exactly one arc from the mail centre is represented for each vehicle and that the trip between nodes is complete. Constraint 4 ensures that there is only one arc per vehicle for each node i . Similarly, Constraint 5 ensures that each node represented by j has only one particular node per vehicle that enters. Constraint 6 ensures that the total demand is less than or equal to the carrying capacity of each vehicle. Constraint 7 is used to ensure that the time of travel for each vehicle does not exceed the maximum time allocated to a specific route, which is currently

specified by the SAPO by a daily schedule represented by pickup and delivery time constraints. Constraint 8 ensures that the arrival time of each vehicle at a specific node is less than or equal to the arrival time at that specific node. Constraint 9 guarantees the arrival time and service time for each vehicle at node i is greater than or equal to the earliest arrival time and less than or equal to the latest arrival time as specified by node i . Lastly, Constraint 10 defines the binary variable [16].

4.2 Off the Shelf Software

Based on the analysis of the literature, a heuristic technique was selected due to the complexity of the problem and limited time available to generate a satisfactory solution. A comparison between different toolboxes currently available for solving the SAPO problem was performed:

QuintIQ: QuintIQ is a company that specializes in the development of planning, scheduling and supply chain optimisation software [30]. Route optimisation for the Postal Service parcel industry contributes significantly to the business of QuintIQ in countries such as the Czech Republic, however, would require a large investment to implement and the SAPO does not have the funds available for such an investment.

RouteXL: RouteXL finds the fastest routes with multiple trips and takes into account live traffic data to help avoid any delays. RouteXL focuses on travelling salesman problems to find the optimal routes and solving time is lengthy [31].

JSpirit Algorithm: JSpirit is also referred to as the Walkthrough algorithm and is a toolkit for solving vehicle routing problems to minimise transport costs [32]. JSpirit is a flexible, lightweight and easy to use open source toolkit, however, only focuses on solving metaheuristic problems.

OptaPlanner: OptaPlanner is an embeddable, lightweight planning engine used to optimise planning problems. OptaPlanner can be used for a range of different problems including vehicle routing problems, job shop scheduling and employee shift rostering. The toolbox contains many different heuristic and metaheuristic algorithms including insertion heuristics, simulated annealing metaheuristics and genetic algorithms [33].

OptaPlanner was chosen as the preferred toolkit due to the fact that OptaPlanner has built in algorithms for vehicle routing problems, as well as insertion heuristics. The toolkit is user-friendly, with a free user guide and has many online tutorials for further knowledge enhancement. Lastly, the toolkit can be used for different comparisons to analyse results and determine the best possible solution. Comparisons include optimizing the fuel usage and optimizing the time spent travelling by vehicles.

4.3 The Insertion Heuristic

The problem was solved on a smaller scale using the Emalaheni mail centre as the initial location. In future, the model can be expanded to a national

level taking into account all the various retail outlets around the country. Algorithm 1 shows the overall steps of applying the sequential insertion heuristic to the vehicle routing problem as described in the literature review.

Algorithm 1: Sequential Insertion Heuristic [26]

Input: Depot location, retail outlet location, capacity of each vehicle, demand from customers, service times

Output: Optimal routes

Step 1: Use the initialization criteria to insert the first customer into the route

Step 2: Consider the insertion point for the unrouted node that minimises the weighted average of the distance required to include a customer into the current route

Step 3: Use the selection criteria to attempt to maximise the benefits of inserting a customer into the current route, as opposed to inserting a new direct route

Step 4: If all the customers have been inserted, stop;

Else: Go back to step 2

A graphical representation of the initial solution algorithm is presented in Figure 13 to explain the steps of Algorithm 1. The initial solution algorithm is regarded as the first step to obtain a near-optimal solution [25] for vehicle routing problems. The concept of vehicle capacities and the number of vehicles used are introduced into the algorithm to ease the computational burden, as well as to help identify the seed customer. The vehicle capacities are dependent on the demands of each retail outlet and are taken into consideration when determining the feasibility of expanding the routes. In the event that the demand equals the vehicle's maximum capacity, the vehicle will return to the seed customer, represented by the Emalahleni mail centre, where the initialization of routes will be repeated.

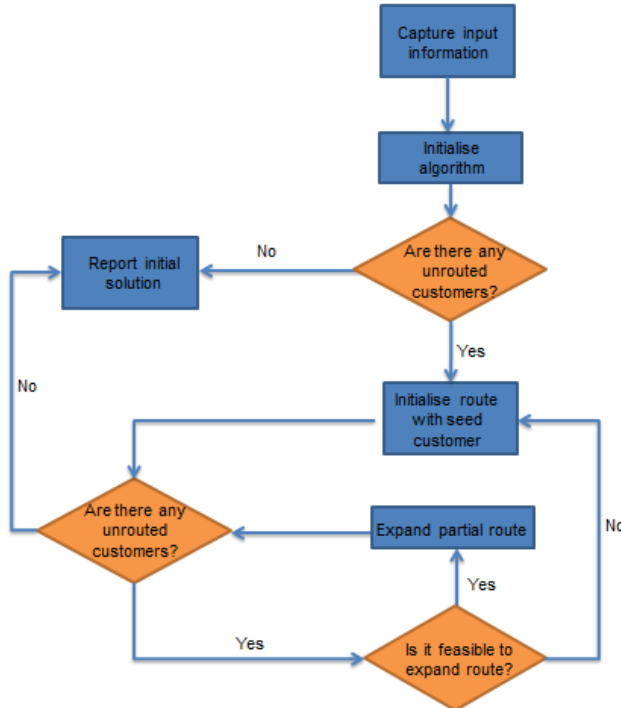


Figure 13: Overview of the initial solution algorithm

4.4 Implementing OptaPlanner

In general, vehicle routing problems have had an increase in research attention over the past few years due to ever-increasing transportation costs. OptaPlanner is an open source software that efficiently solves constraint satisfaction problems. The objectives of OptaPlanner include the following:

- To minimise transportation costs
- To minimise distances travelled
- To maximise profits
- To maximise customer satisfaction

The benefits of using OptaPlanner mainly revolve around the reasonable speed at which algorithms are solved and the “good enough” solution that is generated [33]. Once the constraints are entered into OptaPlanner, the algorithm will execute with the objective of minimising the distance travelled by vehicles. Specific analyses can then be conducted such as increasing the capacity of vehicles, changing the demand for retail outlets and increasing or decreasing the number of vehicles. These analyses can be used to identify improvement opportunities for further analysis. Retail outlets can also be added or removed, which would be useful for the Post Office in the event that a retail outlet has no parcels to be collected or alternatively, wants to investigate the feasibility of adding a new Post Office due to factors such as urbanization.

4.5 Data Pre-processing

The testing area was defined as the pilot depot and all the retail outlets serviced by the pilot depot. The Emalahleni mail centre was used as the pilot depot, which has 49 different retail outlets that need to be serviced on a daily basis, as well as five retail outlets that are serviced twice a day. Figure 35 in Appendix A shows the schedule that needs to be followed by the Post Office in the Emalahleni region to satisfy customer demands. The locations of these retail outlets were obtained from the SAPO, where the physical addresses were converted into latitudes and longitudes using Google Maps. The Advanced Programming Interface (API) coordinates were generated from the different retail outlets and entered into Google Maps to obtain a real-life representation of the retail outlets. Table 5 in Appendix B shows the latitudes and longitudes that were used for the specific retail outlets. The Emalahleni mail centre was used as the central point to calculate the x and y distances for each retail outlet to the mail centre. In order to simplify the input coordinates into OptaPlanner, the origin was shifted from the mail centre using the furthest westerly retail outlet, Bapsfontein and the most southern retail outlet, Eloff. These two retail outlets were used as the x and y axes to ensure that the input distances were accurate. The route coordinates were calculated using Algorithm 2 and were entered into OptaPlanner to generate the optimal routes for the SAPO.

Algorithm 2: Route Coordinates

Accepted universal average conversion: 1 degree = 111km

Step 1: Latitude Distance

= |Latitude coordinate for each outlet – latitude coordinate for Eloff| * 111km

Step 2: Longitude Distance

= |Longitude coordinate for each outlet – longitude coordinate for Bapsfontein| * 111km

Note: The above two steps were also performed for the depot to ensure that the coordinates remain accurate

Figure 14 is a visual representation of the retail outlets serviced on a daily basis in the Emalahleni region and was plotted using the coordinates from Table 5 in Appendix B. Figure 15 represents a zoomed in view of the Emalahleni mail centre (represented by the heart icon) in relation to the retail outlets surrounding the location, where it is evident that the mail centre is in a centralized location and serves as a focal point for the various retail outlets.

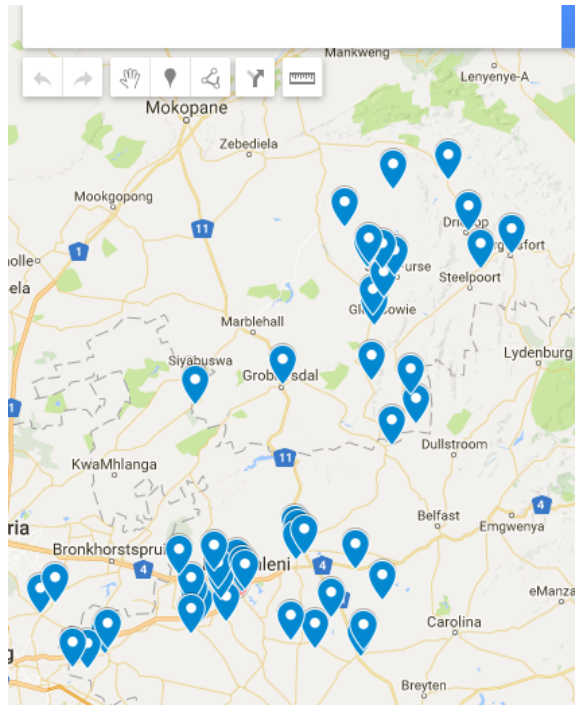


Figure 14: The chosen location

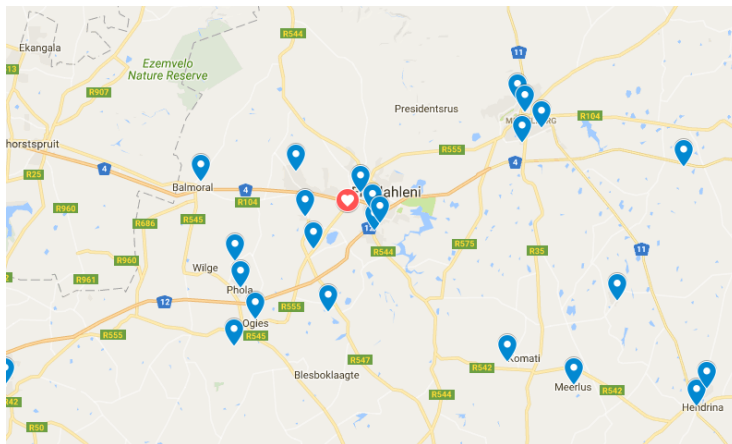


Figure 15: The Emalahleni mail centre

4.6 Determining the Demand and Capacity

Initially, the assumptions were that the capacity of the Post Office’s vans would have a major effect on the routes travelled due to the weight and space constraints of each van, while the demand would be calculated using the average parcel intake given by each retail outlet in the pilot area. After consulting with Gail Springbok from the SAPO who is the National Transport Controller and visiting the Emalahleni mail centre, this proved to be

infeasible. The SAPO classifies a parcel to be an item either bigger than 353x250x30mm and/or weighing more than 1kg. While the vans used by the SAPO do have capacities that must be adhered to, the main concerns experienced by the Post Office is ensuring that the parcels collected by postmen do not exceed the maximum length and girth of 1 metre and 2 metres respectively or exceed a maximum weight of 30kg. The different parcel sizes delivered by the Post Office can be seen in Figure 16, which is a photo taken at the Emalahleni mail centre. After further consultation with staff at the mail centre, records showed that the most common parcel size delivered by customers is a 37x25.5x20.5cm parcel with a volume of 19341.75cm³. The SAPO uses Toyota Quantum vans, which have a loading area of 4 000 000cm³. Therefore, the vans used by the Post Office have an estimated capacity of 200 parcels per van.



Figure 16: Common parcel sizes for the SAPO

The demand for each retail outlet was determined after consultation with Nkanyiso Mkhwanazi (Floor manager at the Emalahleni mail centre). It was decided to use three different demands for the retail outlets based on the popularity and location of the retail outlets. Retail outlets were segmented into three different classes, namely rural areas, high volume areas and moderate areas. A total of 12 retail outlets are serviced by the Post Office and classified as rural areas with a demand of ten parcels per day. The SAPO services five retail outlets in the Emalahleni region twice per day and these were classified as high volume retail outlets with a demand of 20 parcels per day. The remaining retail outlets were determined to have a demand of 15 parcels per day. The capacities and demands were used to calculate the baseline model in the following subsection, as well as to validate the model in the following chapter to determine the sensitivity of these inputs.

4.7 Determining the Computational Time

As discussed in the literature review, one of the most significant aspects of the proposed solution was to ensure that the computational time needed to generate routes was relatively fast. Figure 17 portrays a visual depiction of the results obtained, where it is evident that an increase in computational time results in a decrease in the total distance travelled, which ultimately results in a better solution. The graph does, however, eventually converge and after 30 minutes of running OptaPlanner, a near-optimal solution was generated and a total distance of 1202.29km was the best solution obtained. The percentage change in distances from a computational time of 30 seconds, to a computational time of 30 minutes was calculated to investigate the effect this may have on the SAPO when routes are generated in real time and time constraints are a limiting factor.

$$\begin{aligned} & (1315.1\text{km}-1202.29\text{km})/1315.1\text{km}\times 100 \\ & = 8.58\% \text{ decrease in distance} \end{aligned}$$

Figure 17 shows an exponential decline in distance over time, with an 8.58% decrease in total distance travelled between the solution obtained at 30 seconds and the solution obtained after 30 minutes by the Post Office. These factors can be assessed by the Post Office and incorporated into their business strategy to ensure that adequate computational time is allowed to generate solutions, which will ultimately result in a decrease in distances and a decrease in transportation costs. For the remainder of the chapter, a constant computational time of 30 minutes will be used to generate solutions to ensure that the insertion heuristic has converged.

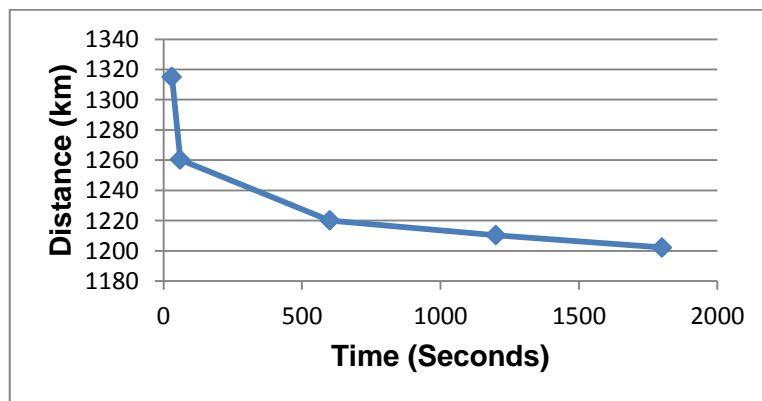


Figure 17: The change in solution quality as the computational time increases

4.8 Solving the SAPO Problem

The baseline SAPO problem was solved by two different heuristic techniques: the sequential insertion heuristic and the nearest neighbour

heuristic. In addition, the SAPO problem was also solved using a simulated annealing metaheuristic technique, where an analysis between the different algorithms was done. OptaPlanner was implemented using Eclipse. The input data is shown in Table 1:

Table 1: Constraints entered into Eclipse

Rural area demand: 10 parcels per day
Urban area demand: 15 parcels per day
High volume area demand: 20 parcels per day
Capacity of vans: 200 parcels
Number of vans used: 5
Depot: Emalahleni mail centre
Total number of retail outlets: 49
Computational time limit: 30 minutes
Note: The SAPO visits five retail outlets twice per day and these visits are incorporated into the model and the routes generated

4.8.1 The Sequential Insertion Heuristic

As discussed in the literature review, the first solution was generated using the sequential insertion heuristic. Based on all the initial solution heuristics that have previously been evaluated, Solomon concluded that the sequential insertion heuristic proved to be extremely successful in terms of the computational time needed to generate a solution, as well as the quality of the solution [25]. The computational time needed to generate a solution is an important factor for the SAPO because of external factors such as vehicle breakdowns, absent staff and fluctuations in demand having an effect on services. Figure 18 illustrates the solution generated using OptaPlanner and the constraints in Table 1. The total distance travelled by the five vans was 1 152.30km's. The computational time of 30 minutes was sufficient to obtain this solution, as changes to the distance exponentially decreased as a near-optimal solution was obtained.

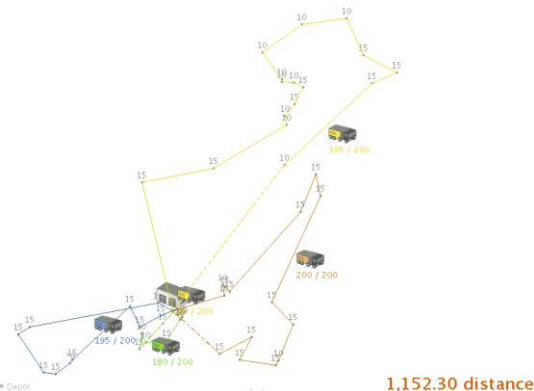


Figure 18: The insertion heuristic solution

4.8.2 The Nearest Neighbour Heuristic

The nearest neighbour heuristic was selected as an alternative solution algorithm due to the ease of implementation, as well as the short computational time required to generate a ‘good enough’ solution. The main concern regarding the nearest neighbour heuristic is previous studies indicating that the algorithm has generated routes that are much longer than the optimal route, as well as the nature of the algorithm to miss shorter routes noticeable with human insight. Figure 19 represents the solution generated by OptaPlanner using the same input data from Table 1. It is evident that the total distance travelled by the vehicles is substantially greater when compared to than the previous algorithm with a total distance of 1 395.74km’s. A difference of 243.44km’s is experienced between the two algorithms, which could have extremely costly consequences when expanding the model across South Africa over a yearly period.

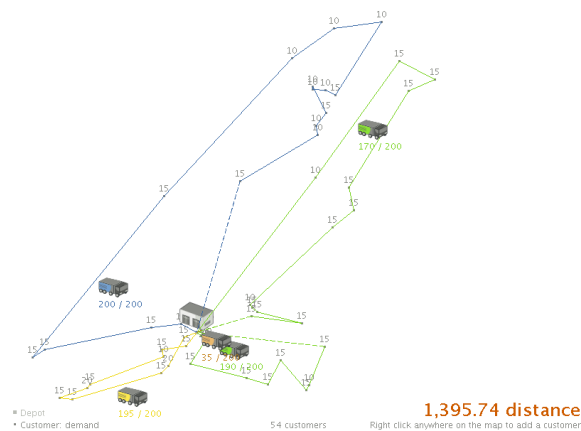


Figure 19: The nearest neighbour heuristic solution

4.8.3 Simulated Annealing Metaheuristic

The simulated annealing metaheuristic was selected as an alternative algorithm to solve the transportation problem of the SAPO. Figure 20 shows the change in solution quality as the computational time increases using the input data from Table 1. The total distance travelled by the five vans was 1045.32km’s. A difference of 106.98km’s is experienced between the metaheuristic and the sequential insertion heuristic. However, the simulated annealing metaheuristic required a computational time of 110 minutes to generate a near-optimal solution. Using a computational time of 30 minutes, a total distance of 1104.68km’s was travelled by the five vehicles using the simulated annealing metaheuristic, which amounted to a difference of 47.62km’s between the sequential insertion heuristic and the metaheuristic. To test the validity and accuracy of the metaheuristic, a comparison between five different generated solutions using the simulated annealing metaheuristic was done. Figure 20 shows that the generated solution experienced minimal change after 60 minutes, as the graph approaches a near-optimal solution, therefore, a computational time of 60 minutes was

used to test the change in the generated solutions. Table 6 in Appendix B shows the total distances of each solution with a mean of 1082.192km's and a standard deviation of 3.99km's, therefore, the metaheuristics generated reliable solutions.

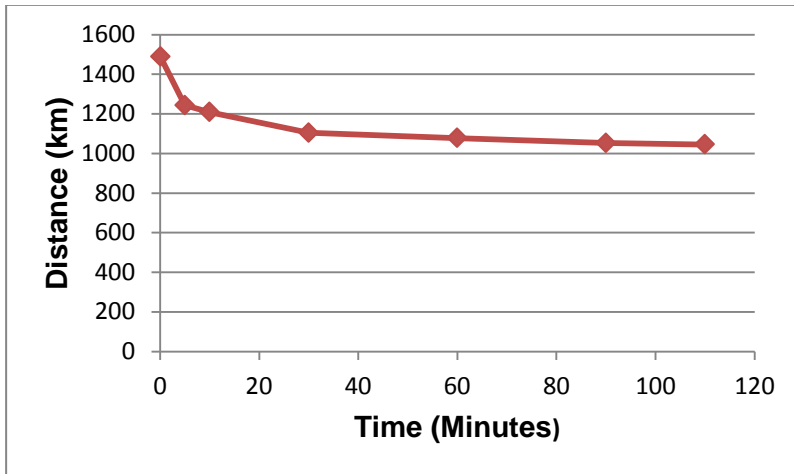


Figure 20: The change in solution quality as the computational time increases

4.8.4 Conclusion

Although the simulated annealing metaheuristic did generate a better solution quality than the heuristics, the computational time and ease of implementation of the heuristics proved to be a more suitable option for the SAPO. In addition, factors such as employees being absent from work and vehicle maintenance will require the SAPO to make changes to the algorithm, which is easier using a heuristic technique. Therefore, solving the problem using a sequential insertion heuristic proved to be a more suitable option due to a decrease in total distance of 243.44km's, as well as the reasonable computational time that was needed to generate a near-optimal solution. The remainder of this document will focus on the sequential insertion heuristic, as well as the implementation plan and future work that is required for the proposed solution.

4.9 Generating Final Routes

Figures 21 to 25 show the routes generated using OptaPlanner and represent the most efficient routes for the five vehicles used by the Emalahleni mail centre on a daily basis to collect parcels from the various retail outlets. It is evident that vehicles one, two and three cover the greatest distance and vehicles four and five are used to cover the higher volume retail outlets close to the Emalahleni mail centre.

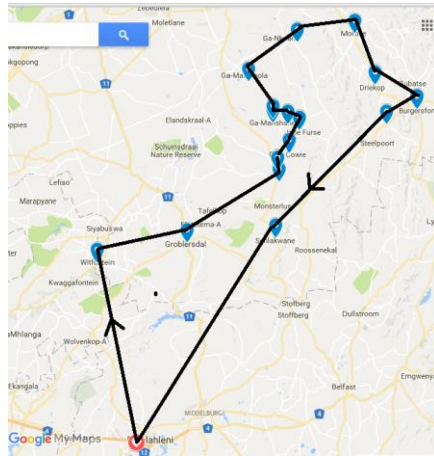


Figure 21: Vehicle one generated route

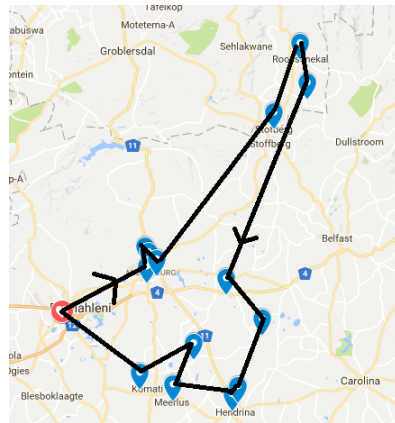


Figure 22: Vehicle two generated route

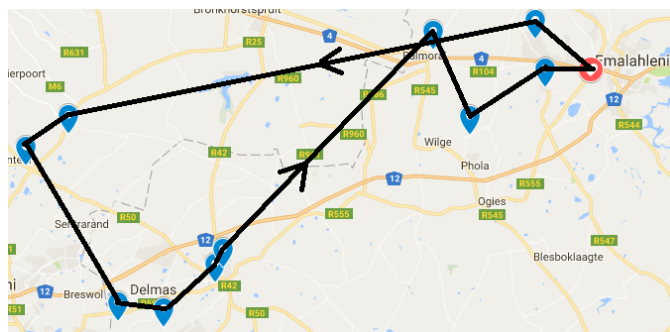


Figure 23: Vehicle three generated route

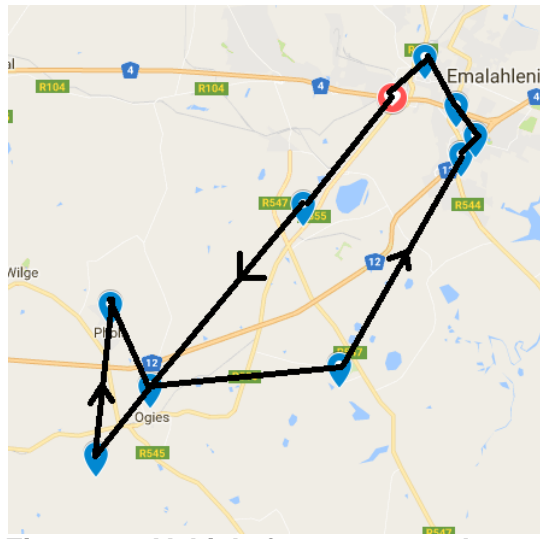


Figure 24: Vehicle four generated route

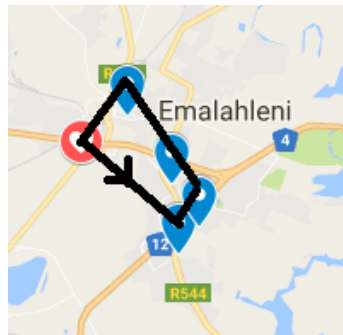


Figure 25: Vehicle five generated route

The current ‘as-is’ routes travelled by the SAPO follow a strict log book, where the five vehicles used by the Post Office collect parcels from retail outlets in specific areas. Figure 35 in Appendix A shows the route schedule followed by the SAPO with one vehicle used to service each district, apart from the Middelburg, Emalahleni and Emalahleni shuttle region, which are all serviced by one vehicle throughout the day. The current ‘as-is’ distances were calculated for each route travelled by each vehicle using the formula:

$$Distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

The distances were summed to calculate the total distances travelled by all vehicles, which totalled 1467.95km’s and a cost saving of:

$$\begin{aligned}
 &1467.95\text{km} - 1152.3\text{km} \\
 &= 315.65\text{km per day}
 \end{aligned}$$

Figure 26 shows the fluctuations in petrol prices over the past six months, where an average price of R12.39/litre was used for further calculations.

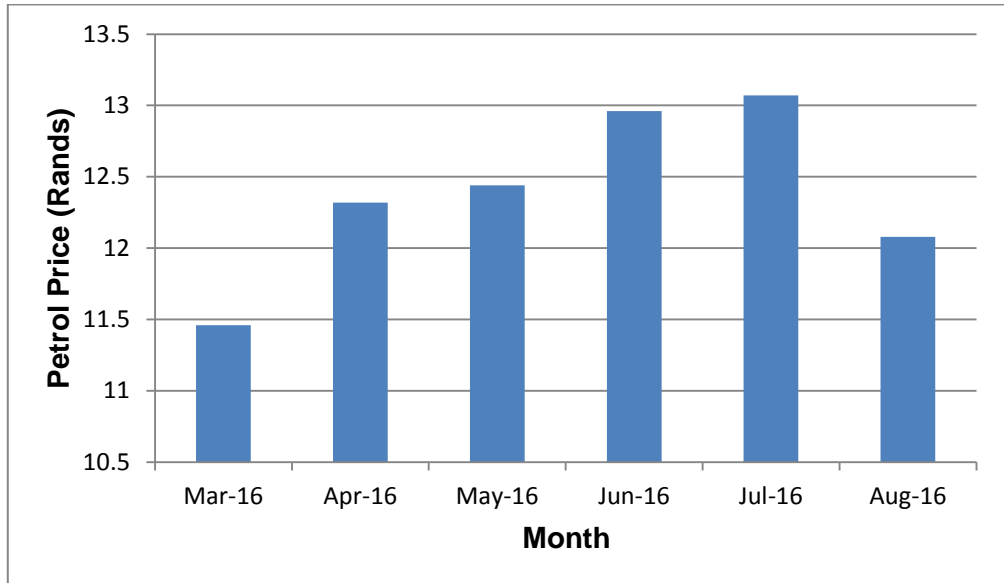


Figure 26: Average inland petrol price over the past six months

The total cost saving of the near-optimal solution amounted to R3910.90 per day, which results in an annual cost saving of R1 220 200.80, excluding Sundays when the Post Office is closed. Expanding this model nationwide has the potential to save the SAPO millions of Rands on a yearly basis and further emphasises the relevance of incorporating route optimisation in the SAPO's daily procedures.

Chapter 5

Solution Verification and Validation

To evaluate the robustness of the proposed solution with regard to ever-changing input data, it was necessary to test the algorithm using different situations and constraints. As discussed in the previous chapter, there are numerous off the shelf software tools available for the SAPO to use, therefore, testing the model was done to analyse the feasibility of using OptaPlanner as a chosen solution.

5.1 Investigating the Impact of the Number of Vehicles

Due to the concern over the effect the number of operating vehicles used by the Emalahleni mail centre will have on the effectiveness of the output, it was decided to test the impact of the number of vehicles using OptaPlanner. Figures 27 to 31 shows the effect of increasing the number of vehicles using a constant computational time of 30 minutes, as well as constant demands for the various retail outlets. The results of the test show a significant change to the total distances travelled by the various numbers of vehicles. Figure 31 generated a solution that was not feasible because the demand of the retail outlets exceeded the capacity of the vehicles, therefore, the Emalahleni mail centre would not be able to service all the retail outlets using three vehicles.



Figure 27: Generated solution using nine vehicles

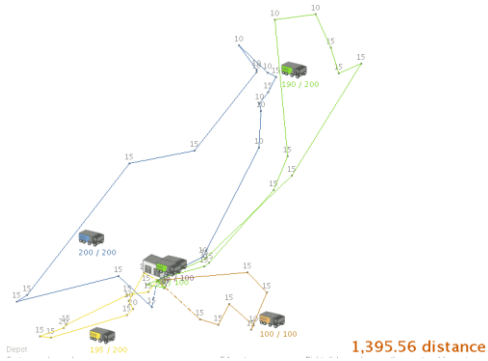


Figure 28: Generated solution using six vehicles

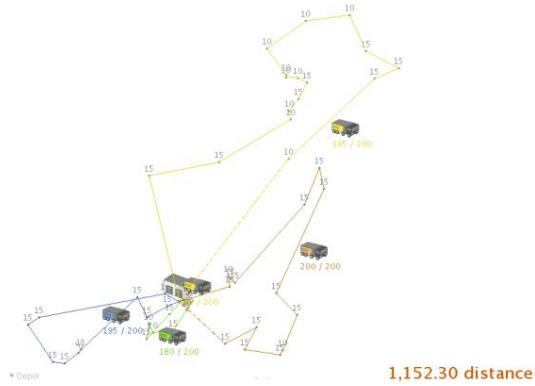


Figure 29: Generated solution using five vehicles

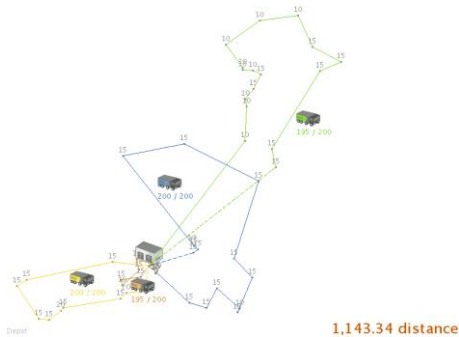


Figure 30: Generated solution using four vehicles

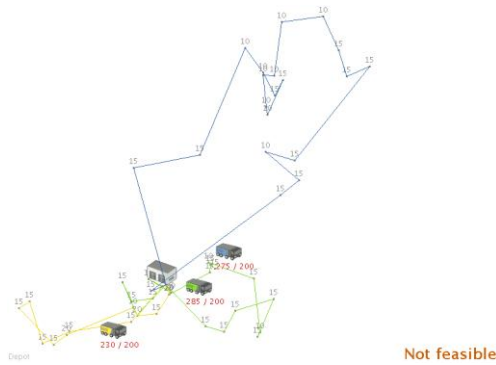


Figure 31: Generated solution using three vehicles

The number of vehicles used by the SAPO is an important factor to take into consideration due to the fact that vehicle maintenance and repairs require changes to be incorporated into the algorithm, thus impacting the routes travelled by the vehicles. Figure 32 shows the change in distance travelled as the number of vehicles increases, where a difference of 536.31km's is experienced when comparing nine vehicles to four vehicles.

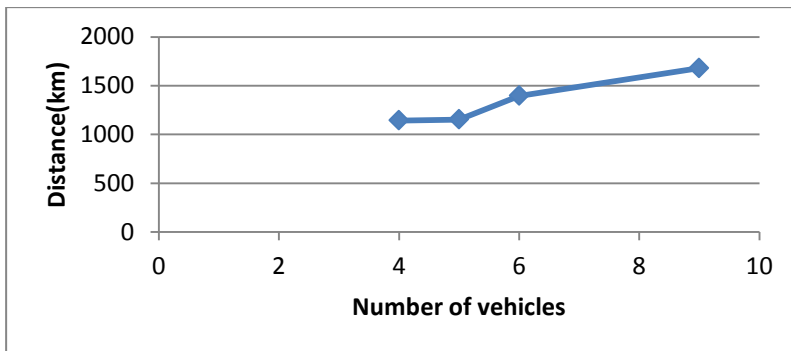


Figure 32: Line graph showing the change in distances as the number of vehicles increases

5.1.1 Cost Analysis of the Number of Vehicles Used

A cost analysis was done to see how substantial the effect of the number of vehicles was to the net profit of the SAPO. A major contributing factor to the success of using OptaPlanner is the fact that the algorithm generates a solution that is near-optimal. The average petrol price from Figure 26 of R12.39/litre was used. For the purpose of the cost analysis, the average litre per kilometre of each van used by the Post Office is assumed to be constant at a consumption rate of 13.8 litres/100km [36]. Table 2 shows the cost analysis for the different number of vehicles and the total cost per day was calculated using the formula:

- $[(\text{Total Distance (km)} * 13.8 \text{ litres}/100\text{km}) * \text{R}12.39/\text{litre}]$

Table 2: Cost analysis for the number of vehicles used by the SAPO

	Figure 27	Figure 28	Figure 29	Figure 30	Figure 31
Vehicles	9	6	5	4	3
Total Distance (km)	1679.65	1395.56	1152.3	1143.34	Not Feasible
Consumption Rate (l/100km)	13.8	13.8	13.8	13.8	13.8
Average Petrol price (Rands/litre)	12.39	12.39	12.39	12.39	12.39
Total Cost per day	R2871.88	R2386.16	R2055.75	R1954.91	Not Feasible

The results shown in Table 2 indicate a clear difference in costs for the number of vehicles used and is a factor that must be considered by the SAPO when generating the near-optimal solution. There is a difference of R916.97 between nine vehicles and four vehicles, which over a yearly period would amount to R334 694.05. In addition to the costs saved from petrol, various other factors contribute to the cost savings of using fewer vehicles and include:

- Maintenance costs
- Service costs
- Driver's salaries
- Depreciation of vehicles

5.2 Effect of Demand

The SAPO is mandated by law to collect and deliver mail from retail outlets across the country, irrespective of their location. The demand of retail outlets differs across the country and is dependent on the location and population of people within each specific district. The retail outlets surrounding the Emalahleni mail centre experience the same fluctuations in demand, where some of the more common retail outlets such as Ogies and Tasbet Park are scheduled for two visits on a daily basis. In comparison, some of the more informal areas such as Sekwati and Marishane do not have the same demanding requirements. Table 3 shows the effect of the demand on the generated solution, where the demands are kept constant for all the retail outlets. The capacity of vehicles, as well as the computational time remained constant and the number of vehicles used was five. The demand of 10 and 15 generated similar solutions, whereas the demand of 20 generated a solution that was not feasible. The demand of 20 was not feasible because the total demand exceeded the capacity of the five vehicles used, which would have a major impact on backlogs experienced by the Post Office and an additional vehicle would have to be incorporated into the solution to address this problem.

Table 3: Effect of the demand on the generated solution

Demand	Distance (km)
10	1154.38
15	1173.54
20	Not Feasible

5.3 Uncapacitated Vehicle Routing Problem Without Time Windows

A test was done to assess the impact of having an uncapacitated vehicle routing problem without time windows to assess the effect this has on the SAPO. An alternative approach could be taken by the Post Office where a specified number of parcels are allocated to each retail outlet and the two vehicles used by the Post Office may only collect that specified number of parcels or less. The Post Office can allocate demands for each retail outlet based on previous records of customer deliveries. Figure 33 shows the distances travelled when the two vans do not have capacity restrictions. The results obtained depict a significant decrease in total distances travelled by the vans and can result in a significant decrease in fuel used. The main concern with using this approach is the effect this approach may have on the routes, where major backlogs can result in a surplus of parcels at numerous retail outlets. Another defining factor concerning this model is the pressure placed on drivers where staff work shifts from 7:30 to 16:30 and parcels need to be collected and delivered to the mail centre on a daily basis. At the same time, the positives associated with this approach is that drivers are fully utilized and the remaining staff can be utilized elsewhere.



Figure 33: Generated solution for the uncapacitated vehicle routing problem without time windows

5.4 Cost Analysis for Diesel Vans

This test sought to compare the difference in price of using a diesel truck, as opposed to the petrol vans currently used by the SAPO. The SAPO currently has five vehicles operating in the Emalahleni region and all the vehicles currently operate using petrol as a source of fuel. Figure 34 depicts the diesel prices over the past 6 months, with an average of R10.77/litre. The average petrol price in South Africa over the past six months was R12.39/litre, thus resulting in a cost saving of R1.62/litre. The implementation costs of diesel vans are shown in Table 4, where the average consumption rate of both petrol and diesel vans are kept constant, as well as the total distances travelled by both vans.

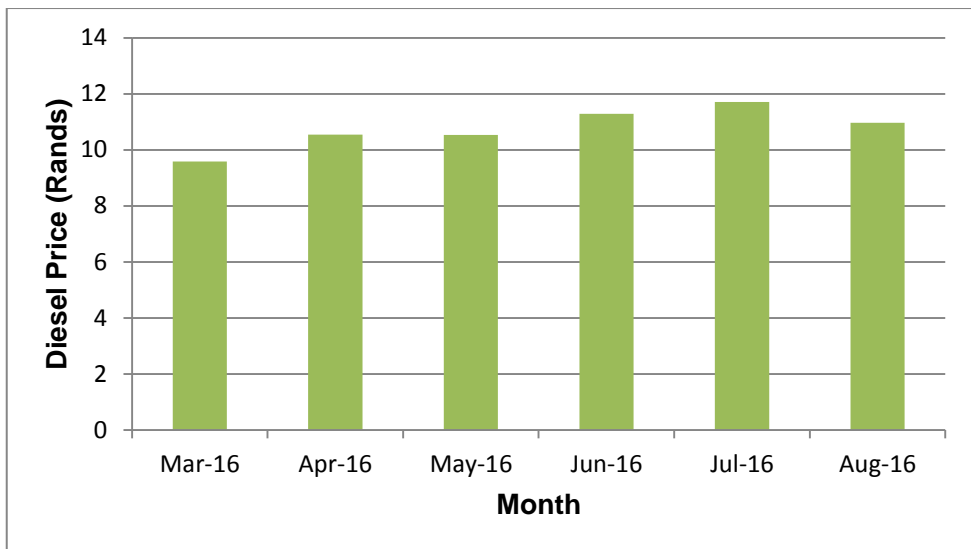


Figure 34: Average inland diesel price over the past six months

Table 4: Implementation costs of diesel vans

Number of vehicles	Income	Cost
5	Average trade-in value for a 2008 Toyota Quantum van (R145 000)	R 725 000
	Savings in diesel costs (R1.62/km * 1152.30km's per day)	R1866.73
	Income sub cost:	R726866.73
	Expenses	
5	Purchase five new diesel Toyota Quantum vans (R384 900 each)	R1 924 500
	Expenses sub cost:	R1 924 500
Net Loss		(R1 197 633.27)

Payback Analysis: $1866.73x + 725\ 000 = 1924500$
 $x = 642.57$ days

Therefore, based on the above calculation, purchasing new vehicles would not be a feasible option for the SAPO due to the limited funds available. It would take nearly two years for the cost savings to generate a profitable output and there is uncertainty with respect to the future prices of petrol and diesel that makes the risk far greater than the benefits.

5.5 Solution Validation

At the start of the project, the objectives of the project were the following:

- I. To analyse the current 'as-is' supply chain of the SAPO and propose improvement opportunities to the processes involved
- II. To minimise the costs involved in transporting parcels from retail outlets to mail centres
- III. To maximise customer satisfaction by ensuring that parcels effectively reach their respective mail centre within a given time window
- IV. To investigate various route optimisation problems that can be customized to suite the SAPO transportation system

To ensure that the objectives of the project were validated, a model was used to redesign and improve the current real world problems experienced by the SAPO. The model was solved using a heuristic technique to generate near-optimal routes that could be incorporated by the SAPO into their parcel delivery division. After consulting with various managers at the Post Office such as Simon Mboyane (Senior Manager of the mail centre), as well as Susan Mukanganyama (Quality Assurance Engineer and National Manager) approval was received regarding the solution design and project approach. The transportation sector is an area of great concern for the SAPO and was

the second highest expense during the 2015 financial year behind labour costs. The aim of project presented in this report is to maximise customer satisfaction through a higher precision rate of the SAPO's courier service, while minimising the costs involved in the transportation sector. The project will be further investigated by Susan Mukanganyama before being presented to senior management at the Post Office with the possibility of implementation. The solution algorithm generated near-optimal routes that will minimise the costs involved in transporting parcels, as well as reduce backlogs experienced by retail outlets and ultimately maximise customer satisfaction through efficient deliveries.

Chapter 6

Conclusion

The SAPO is an organisation that has experienced financial net losses over the past few years, however, the SAPO has the potential to recover from that decline and compete in a highly competitive logistics industry. A proposed improvement opportunity of route optimisation was further examined as a technique to help the Post Office improve their supply chain processes and in particular, in the transportation sector, to ensure that the costs involved in the supply chain processes are minimised and customer satisfaction is maximised. The report aimed at minimising the transportation costs of the Emalahleni mail centre. The sequential insertion heuristic was used as an algorithm to solve the model, which reduced the total distance travelled by the SAPO by 315.65km per day. The overall net savings of the generated solution amounted to R1 220 200.80 per annum, which is a significant cost saving considering that transportation costs was the SAPO's second highest expense during the 2015 financial year. In addition, the reduction in total distances travelled by the SAPO will also have various environmental impacts and result in a reduction of carbon emissions. A simulated annealing metaheuristic was completed, however, the computational time of the metaheuristic proved to be infeasible for the SAPO. The next step for the completion of the project is to further assess different metaheuristic techniques to analyse the difference in distances to the sequential insertion heuristic. The computational time of the metaheuristics will also be assessed to determine the feasibility of the solution for the SAPO.

6.1 Implementation Plan

The solutions generated by OptaPlanner provide good solutions for the SAPO as a base model, however, the solution is not viable unless it is tested against the current routes travelled by the SAPO. This chapter provides a brief implementation plan for the future work that could be completed to ensure that the vehicle routing problem solutions generated are more feasible for the SAPO. The accuracy and flexibility of the solutions generated will drive the future research to be carried out by the Post Office to ensure that real time changes and improvements can be made by the Post Office where applicable. Time schedules will be analysed to ensure that the schedules are edited to suit the new routes of the SAPO. The implementation of OptaPlanner can be run on a standard PC that the Post Office already has installed, therefore, can be incorporated relatively quickly into their current systems. Lastly, OptaPlanner is an open source software package and will not require purchasing of additional software, which benefits the Post Office due to their current financial difficulties.

6.2 Future Work

Improved vehicle routing models have played a critical role to ensure more efficient route planning is done by organisations and a large contribution to the research in this field has been conducted over the past few years with 60% of vehicle routing research being published after 2009 [35]. The future work done will focus on improving the flexibility of the model, as well as improving the speed, quality and computational time of the results to ensure that the optimal routes determined can have lasting benefits for the SAPO to incorporate into their supply chain across all divisions, including their mail division. The vehicle routing solution will first be integrated into the Post Office's systems, which will first go live at the Emalahleni region, before being expanded across the country. The validity of the results will then be assessed for the Emalahleni region, where improvement opportunities or faults will be analysed and improved before the model is expanded. The ultimate goal would be to incorporate the model into the matrix of the SAPO's strategy to ultimately minimise transportation costs and increase profits. Rural areas will also be considered, where the inputs into the model are not as accessible to the SAPO. The model must, therefore, be sufficiently flexible to accurately model rural areas in Soweto, as well as more prioritised areas such as Tshwane. Furthermore, the model may incorporate real time adjustments to traffic and multi-objective optimisation where the total distance travelled and the number of vehicles used is minimised. Lastly, other metaheuristics will be analysed to determine the most suitable technique for the SAPO.

Bibliography

- [1] SA Post Office - Business Listing, Complaints, Compliments and Reviews - helloworld.com [Internet]. Helloworld.com. 2016 [cited 13 May 2016]. Available from: <http://helloworld.com/sa-post-office/compliments-and-complaints#write-a-review>
- [2] South African Post Office on its 2015 strategic plan and current position | PMG. 2016. South African Post Office on its 2015 strategic plan and current position | PMG. [ONLINE] Available at: <https://pmg.org.za/committee-meeting/20963/>. [Accessed 19 March 2016].
- [3] A SA Post Office on its Annual Report and status update; State of Nation Address implications for telecommunications: Parliamentary Researcher briefing | PMG. 2016. SA Post Office on its Annual Report and status update; State of Nation Address implications for telecommunications: Parliamentary Researcher briefing | PMG. [ONLINE] Available at: <https://pmg.org.za/committee-meeting/20044/>. [Accessed 19 March 2016].
- [4] Minaya E. USPS Posts Annual Loss, Though Revenue Rises [Internet]. WSJ. 2016 [cited 12 May 2016]. Available from: <http://www.wsj.com/articles/usps-posts-annual-loss-though-revenue-rises>
- [5] Fiscal Year 2015 Integrated Financial Plan [Internet]. 2016 [cited 12 May 2016]. Available from: <https://about.usps.com/who-we-are/financials/integrated-financial-plans/fy2015.pdf>
- [6] USPS investigates dynamic routing for parcels and express mail « Post & Parcel [Internet]. Postandparcel.info. 2013 [cited 12 May 2016]. Available from: <http://postandparcel.info/53679/news/it/usps-investigates-dynamic-routing-for-parcels-and-express-mail/>
- [7] Samson T. U.S. Postal Service taps optimization software to slash transportation costs [Internet]. InfoWorld. 2016 [cited 12 May 2016]. Available from: <http://www.infoworld.com/article/2632253/technology-business/u-s-postal-service-taps-optimization-software-to-slash-transportation-costs.html>
- [8] Wisner, J., Tan, K.C. & Leong, G., 2015. Principles of supply chain management: a balanced approach. Cengage Learning.
- [9] Monczka, R., Handfield, R., Giunipero, L. and Patterson, J., 2015. Purchasing and supply chain management. Cengage Learning.
- [10] Saffari, H., Makui, A., Mahmoodian, V. and Pishvaei, M.S., 2015. Multi-objective robust optimization model for social responsible closed-loop supply chain solved by non-dominated sorting genetic algorithm. Journal of Industrial and Systems Engineering, 8(3), pp.42-59.
- [11] Sansone, R.P. and Schumacher, K.H., Pitney Bowes Inc., 1991. Optimizing mail delivery systems by routing. U.S. Patent 5,068,797.
- [12] Dror, M. ed., 2012. Arc routing: theory, solutions and applications. Springer Science & Business Media

- [13] Hertz, A., 2005. Recent trends in arc routing (pp. 215-236). Springer US.
- [14] Undirected rural postman problem - Google Search. 2016. Undirected rural postman problem - Google Search.[Accessed 20 March 2016]
- [15] Toth, P. and Vigo, D. eds., 2014. Vehicle routing: problems, methods, and applications (Vol. 18). Siam.
- [16] Kumar, S.N. and Panneerselvam, R., 2012. A survey on the vehicle routing problem and its variants. *Intelligent Information Management*, 4(3), p.66.
- [17] Vehicle routing problem - Google Search. 2016. vehicle routing problem - Google Search. [ONLINE] Available at: <https://www.google.co.za/search?q=vehicle+routing+problem>. [Accessed 23 March 2016].
- [18] Grobler, J., 2008. Particle swarm optimization and differential evolution for multi-objective multiple machine scheduling (Doctoral dissertation, University of Pretoria)
- [19] Land, A.H. and Doig, A.G., 2010. An automatic method for solving discrete programming problems. In *50 Years of Integer Programming 1958-2008* (pp. 105-132). Springer Berlin Heidelberg.
- [20] Mardaneh, E., Lin, Q. and Loxton, R., 2015. A heuristic algorithm for optimal fleet composition with vehicle routing considerations. *Optimization Methods and Software*, pp.1-18.
- [21] Vidal, T., Crainic, T.G., Gendreau, M. and Prins, C., 2013. Heuristics for multi-attribute vehicle routing problems: A survey and synthesis. *European Journal of Operational Research*, 231(1), pp.1-21.
- [22] Solomon, M.M., 1987. Algorithms for the vehicle routing and scheduling problems with time window constraints. *Operations research*, 35(2), pp.254-265.
- [23] Clarke and Wright's Savings Algorithm [Internet]. 2016 [cited 14 May 2016]. Available from: http://pure.au.dk/portal-asb-student/files/36025757/Bilag_E_SAVINGSNOTE.pdf
- [24] Time oriented nearest neighbour heuristic - Google Search. 2016. Time oriented nearest neighbour heuristic - Google Search. [ONLINE] Available at: <https://www.google.co.za/search?q=time+oriented+nearest+neighbour+heuristic> [Accessed 04 May 2016].
- [25] Joubert, J.W. and Claasen, S.J., 2006. A sequential insertion heuristic for the initial solution to a constrained vehicle routing problem. *ORiON: The Journal of ORSSA*, 22(1), pp.105-116.
- [26] Oliveira, J., Carravilla, M., 2009. Heuristics and Local Search: Constructive heuristics for the TSP, Version 2
- [27] Du, D., Pardalos, P., 2013. *Handbook of Combinatorial Optimization: Supplement, Volume 1*
- [28] Beheshti, Z. and Shamsudding, S.M.H., 2013. A review of population-based meta-heuristic algorithms. *Int. J. Adv. Soft Comput. Appl*, 5(1), pp.1-35.
- [29] Tseng, L.Y., 2003. *Metaheuristic Methods and Their Applications*.

- [30] Quintiq - Supply Chain Planning & Optimization software [Internet]. Quintiq. 2016 [cited 14 May 2016]. Available from: <http://www.quintiq.com/>
- [31] RouteXL [Internet]. Routexl.nl. 2016 [cited 14 May 2016]. Available from: <https://www.routexl.nl/blog/faq/?lang=en>
- [32] Jsprit [Internet]. GitHub. 2016 [cited 14 May 2016]. Available from: <https://github.com/graphhopper/jsprit/wiki/Walkthrough---Algorithm>
- [33] OptaPlanner User Guide [Internet]. Docs.jboss.org. 2016 [cited 15 May 2016]. Available from: http://docs.jboss.org/optaplanner/release/6.4.0.Final/optaplanner-docs/html_single/index.html#architectureOverview
- [34] 13. swap city heuristic - Google Search [Internet]. Google.co.za. 2016 [cited 15 May 2016]. Available from: https://www.google.co.za/search?q=swap+city+heuristic&rlz=1C1AVSX_enZA518ZA525&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiMo eqhs9zMAhWMCKMAKHe_vDakQ_AUICCgC&biw=1366&bih=667#imgrc=b9EsUjPBfVIMEM%3A
- [35] Lahyani, R., Khemakhem, M. and Semet, F., 2015. Rich vehicle routing problems: From a taxonomy to a definition. *European Journal of Operational Research*, 241(1), pp.1-14.
- [36] Toyota Quantum Prices - 2015-2016 Toyota Quantum | Specs & Prices of Quantum in South Africa [Internet]. Autodealer.co.za. 2016 [cited 16 August 2016]. Available from: <http://www.autodealer.co.za/new-cars/Toyota/Quantum/Prices-Specs>
- [37] Tseng, L.Y., 2013. Metaheuristic Methods and Their Applications. *erişim tarihi*, 18.
- [38] Letchford, A.N. and Salazar-González, J.J., 2015. Stronger multi-commodity flow formulations of the Capacitated Vehicle Routing Problem. *European Journal of Operational Research*, 244(3), pp.730-738.
- [39] Archetti, C., Bianchessi, N. and Speranza, M.G., 2015. A branch-price-and-cut algorithm for the commodity constrained split delivery vehicle routing problem. *Computers & Operations Research*, 64, pp.1-10
- [40] Dellaert, N., Saridarq, F.D., Van Woensel, T. and Crainic, T.G., 2016. Branch & Price Based Algorithms for the Two-Echelon Vehicle Routing Problem with Time Windows.
- [41] Karakatič, S. and Podgorelec, V., 2015. A survey of genetic algorithms for solving multi depot vehicle routing problem. *Applied Soft Computing*, 27, pp.519-532
- [42] Jawarneh, S. and Abdullah, S., 2015. Sequential insertion heuristic with adaptive bee colony optimisation algorithm for vehicle routing problem with time windows. *PloS one*, 10(7), p.e0130224.

Appendix A

Post Office We deliver, whatever it takes.		WITBANK TRANSPORT & LOGISTICS ROUTE LOG				REV:02 DATE: 21-09-2011 PAGE: 1 OF 1			
HENDRINA		Planned Km		214.61					
Km in:	Codes:	Driver:		Reg no:					
Km out:	Bag B	Date:		Assistant:					
Km Trav:	Trag T								
Time out									
Time in									
Sequence	Witbank Depart	ETA	ATA	ETD	ATD	Deliver:	Pick Up:	Customer Signature	Reason for failure
1	MEERLUS	08:39		08:49		B	T		
2	BLINKPAN	09:23		09:23					
3	PULLENSHOPE	09:54		09:54					
4	HENDRINA	10:24		10:24					
5	KwAZAMUKUHLE	10:38		10:38					
6	RIETKUIL	11:11		11:11					
7	TASBET PARK	11:53		12:08					
8	WITBANK	12:14		12:29					
9	LERAAATSFONTEIN	12:33		12:48					
10	TASBET PARK	12:51		13:06					
11	WITBANK	13:12		13:27					
	Witbank Arrive	13:28							
This is an instruction: Follow this route log keeping to the time and sequence Record actual kilometers and volumes daily							Reason for failure		
DRIVER'S COMMENT:							1	Did not Depart on time	
							2	Detour	
							3	No Parking	
							4	Acc on Road	
							5	Traffic	
							6	Office not open	
							7	Bags not Ready	
DRIVER'S SIGNATURE:									
SUPERVISOR'S SIGNATURE:									

Figure 35: Route schedule for Emalahleni district

Appendix B

Table 5: Retail outlet locations for Emalahleni

Delmas		Latitude	Longitude	Latitude Distance (y)	Longitude Distance (x)
1	OGIES	-26.0433	29.059133	17.86	71.68
2	PHOLA	-26.0011	29.036449	22.54	69.16
3	VOLTAGO	-25.9652	29.028553	26.52	68.29
4	KENDAL	-26.0786	29.027699	13.94	68.19
5	DELMAS	-26.1498	28.675398	6.03	29.09
6	ELOFF	-26.2042	28.604616	0.00	21.23
7	SUNDRRA	-26.1975	28.541013	0.74	14.17
8	BAPSFONTEIN	-26.0039	28.413354	22.23	0.00
9	WELBEKEND	-25.9648	28.47247	26.57	6.56
10	BOTLENG	-26.1307	28.686177	8.15	30.28
11	DELMAS	-26.1498	28.675323	6.03	29.08
12	OGIES	-26.0433	29.059133	17.86	71.68
Hendrina					
13	MEERLUS	-26.1305	29.532987	8.17	124.28
14	BLINKPAN	-26.0999	29.433322	11.57	113.22
15	PULLENSHOPE	-26.0181	29.59665	20.65	131.35
16	HENDRINA	-26.1586	29.715852	5.06	144.58
17	KWAZAMUKUHLE	-26.1352	29.730506	7.66	146.20
18	RIETKUIL	-25.9512	29.806577	28.08	154.65
19	TASBET PARK	-25.9249	29.236332	31.00	91.35
20	WITBANK	-25.8746	29.215315	36.59	89.02
21	LERAATSFONTEIN	-25.9152	29.244249	32.08	92.23
22	TASBET PARK	-25.9269	29.23188	30.78	90.86
23	WITBANK	-25.8746	29.215315	36.59	89.02
Middelburg					
24	Mhluzi	-25.7517	29.4492576	50.22	114.99
25	Middelburg	-25.767	29.45943	48.52	116.11
26	Middelburg Mall	-25.807	29.455408	44.09	115.67
27	Middelburg Docex	-25.7872	29.484676	46.28	118.92
Pepilani					

28	ARNOT	-25.8399	29.696157	40.43	142.39
29	SEHLAKWANE	-25.1451	29.760047	117.55	149.48
30	MPUDULE	-24.9411	29.772553	140.20	150.87
31	NEBO	-24.9000	29.766581	144.77	150.21
32	GLEN COWIE	-24.8376	29.813702	151.68	155.44
33	JANE FURSE	-24.7547	29.855937	160.89	160.13
34	SEKWATI	-24.7307	29.807763	163.55	154.78
35	MARISHANE	-24.7276	29.747604	163.90	148.10
36	MAKADIKWE	-24.7109	29.74845	165.75	148.20
37	MASEMOLA	-24.5760	29.649705	180.72	137.23
38	STOFFBERG	-25.3836	29.842923	91.08	158.68
Witbank					
39	LEAATSFONTEIN	-25.8992	29.233399	33.85	91.02
40	COALVILLE	-26.0329	29.16667	19.00	83.62
41	BLACKHILL	-25.9498	29.145809	28.23	81.30
42	CLEWER	-25.9066	29.133371	33.03	79.92
43	BALMORAL	-25.8594	28.977868	38.27	62.66
44	HLALANIKAHLE	-25.8453	29.119933	39.84	78.43
Burgersfort					
45	LAERSDRIFT	-25.162	29.401834	115.68	109.72
46	TONTELDOOS	-25.3023	29.943061	100.10	169.80
47	ROOSSENEKAL	-25.1934	29.92095	112.19	167.34
48	STEELPOORT	-24.7315	30.206044	163.46	198.99
49	BURGERSFORT	-24.6778	30.331614	169.43	212.93
50	DRIEKOP	-24.5902	30.159711	179.15	193.85
51	MOROKE	-24.4028	30.077801	199.95	184.75
52	NGWABE	-24.4356	29.848056	196.31	159.25
53	SEKHUKHUNE	-24.8198	29.9679	153.66	172.55
Witbank Shuttle					
54	Witbank Post Office	-25.9151	29.244127	32.09	92.22
	Witbank Mail Centre	-25.8834	29.196804	35.60	86.96

Table 6: The change in solution quality of the simulated annealing metaheuristic

	Distance (km)
1	1080.44
2	1077.98
3	1084.12
4	1089.06
5	1079.36
Mean	1082.192
Variance	15.9434
Standard Deviation	3.99

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