ATM Cash Management for a South African Retail Bank

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date:...............................

Abstract

Cash can be seen as a fast moving consumer good. Approaching cash as inventory within the ATM cash management environment of a South African retail bank, provided the opportunity to apply well known industrial engineering techniques to the financial industry. This led to the application of forecasting, inventory management, operational research and simulation methods.

A forecasting model is designed to address the multiple seasonalities and calendar day effects that is prevalent in the demand for cash. Special days, e.g. paydays, lead to an increase in demand for cash. The weekday on which the special day falls will also influence the demand. The multiplicative Holt-Winters method is combined with an improvised distribution method to determine the demand for cash for the region and per ATM. Reordering points are calculated and simulated to form an understanding of the effect this will have on the ATM network. Direct replenishment and the traveling salesman problem is applied and simulated to determine the difference in using one or the other.

Various simulation models are build to test the operational and financial impact when certain variables are amended. It is evident that more work is required to determine the optimal combination of variable values, i.e. forecasting frequency, aggregate forecasting or individual forecasting, reorder levels, loading levels, lead times, cash swap or cash add, and the type of transportation method. Each one of these are a science in itself and cannot be seen (calculated) in isolation from the other as a change in one can affect the overall operational efficiency and costs of the ATM network.

The thesis proves that significant cost savings is possible, compared to the current set-up, when applying industrial engineering techniques to a geographical ATM network within South Africa.

Opsomming

Kontant kan gesien word as vinnig bewegende verbruikersgoedere. Deur kontant te benader as voorraad binne die ATM kontant bestuur omgewing van 'n Suid Afrikaanse kleinhandelsbank, het dit die geleentheid geskep om bekende bedryfsingenieurstegnieke toe te pas in die finansiële industrie. Dit het gelei tot die toepassing van vooruitskatting, voorraadbestuur, operasionele navorsing en simulasie metodes.

'n Vooruitskattingsmodel is ontwerp om die verskeie seisoenaliteite en kalenderdae effekte wat deel uitmaak van die vraag na kontant aan te spreek. Spesiale dae, bv. betaaldae, lei tot 'n toename in die vraag na kontant. Die weeksdag waarop die spesiale dag voorkom sal ook 'n invloed hê op die vraag. Die multiplikatiewe Holt-Winters metode is gekombineer met 'n geïmproviseerde verspreidingsmetode om die vraag na kontant vir die streek en per ATM the bepaal. Bestellingsvlakke is bereken en gesimuleer om 'n prentjie te skep van die invloed wat dit op die ATM netwerk sal hê. Direkte hervulling en die handelsreisigerprobleem is toegepas en gesimuleer om die verskille te bepaal tussen die gebruik van of die een of die ander.

Veskeie simulasie modelle is gebou om die operasionele en finansiële impak te toets, wanneer sekere veranderlikes aangepas word. Dit is duidelik dat meer werk nodig is om die optimale kombinasie van veranderlike waardes te bepaal, bv. vooruitskatting frekwensie, totale vooruiskatting of individuele vooruitskatting, bestellingsvlakke, leitye, kontant omruiling of kontant byvoeging, en die tipe vervoermetode. Elkeen van hierdie is 'n wetenskap op sy eie en kan nie in isolasie gesien en bereken word nie, want 'n verandering van een se waarde kan die hele operasionele doeltreffendheid en kostes van die ATM netwerk beïnvloed.

Die tesis bewys dat aansienlike koste besparing moontlik is, in vergelyking met die huidige opset, wanneer bedryfsingenieurstegnieke toegepas word op 'n geografiese ATM netwerk binne Suid-Afrika.

I would like to dedicate this thesis to my loving wife for her unselfish support during my absence as a husband while completing this thesis. I love and respect her very much.

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Acronyms

ATM Automated Teller Machine
CIT Cash In Transit
DC Distribution Centre
DR Direct Replenishment
FLM First Line Maintenance
MAPE Mean Absolute Percentage Error
SLM Service Level Monitor
TSP Traveling Salesman Problem
VMI Vendor Managed Inventory

Chapter 1

Introduction

1.1 Motivation for the Research

This research has been executed in a South African retail banking environment. The retail bank is responsible for the maintenance, forecasting and replenishment of over 400 Automated Teller Machines (ATMs). ATM management is done by a group of individuals who have years of experience with the client and demand behaviors of the bank and who make decisions based on their judgements. The limitation that has been identified by the bank is the lack of *scientific methods* to make better decisions.

ATM planning and replenishment is a key service area within the retail banking environment. ATMs are client delivery channels, which can be seen as a reputational risk for the bank when no cash is available. ATMs are also the only access point within the bank that clients can get their hands on physical cash. Large volumes and amounts of monies are transferred, distributed and dispensed everyday. There are a lot of costs involved within the process due to the transportation and handling of cash and on top of that there are opportunity costs associated with cash being tied up in the supply chain. Within the cash management process there are opportunities to greatly reduce the costs and to turn cash into a competitive advantage. It is imperative to eliminate any waste of time, money, materials and energy that do not contribute to the improvement of the client experience.

The retail bank of this study embarked on a process to identify vendors capable of dealing with their unique complexities. This presented the ideal opportunity to demonstrate the benefits that can be achieved when making use of industrial engineering techniques. Within the retail bank, industrial engineering is relatively unknown. Through this research it is attempted to improve the banking process by implementing more efficient and profitable business practices, establishing better customer service and increasing the ability to do more with less.

1.2 Background of Study

Despite the widespread perception in financial services that the days of cash are numbered, both the value and volume of cash continue to climb year on year throughout the developed and developing worlds. There is talk about a cashless society and people believe that plastic and digital forms of money are set to replace cash. But the cashless society is about as real a possibility as the paperless office, because people have a strong attachment to real money.

The South African Reserve Bank has reported annual rises of 10% in demand for cash for the past few years. Two thirds of all transactions are still conducted in cash with R55bn worth in banknotes in circulation and up to R3bn in cash exchanging hands every day. Of South Africans, 91%, use cash to pay for groceries, while 4% use debit card, 3% credit card and 1% a store card. This is good news for the ATM industry, as the ATM is the primary means of banknote distribution in the cash cycle.

According to South Africa's leading independent ATM provider, Spark ATM Systems (2010), during the month of May 2010, the average value of cash withdrawn was R402 per withdrawal, showing a 7.53% increase from May 2009. To date, R402 is the third highest value recorded in the Spark Cash Index. This performance is consistent with previous years. The increase of 7.53% is the fifth month in a row with increases in excess of 7%, indicating that consumers have continued to withdraw larger values of cash well into 2010.

Most large financial institutions have turned to automated cash management software to help with two major client touch points: (1) ATMs and (2) branches. James Murphy, Head of the ATM Operations Unit at the Bank of Ireland, recalls that

> *previously managing cash was a very manual process using spreadsheets that needed to be kept updated regularly. It was a much longer process and left room for human error if they were not updated correctly.*

Paul Stanko, National Funds Manager for Linfox Armaguard in Australia, says that

> *generally speaking, cash management was historically performed via spreadsheets or in-house built databases. These in-house built databases were primarily utilized to track, record, and monitor cash flows. They were very limited and labor intensive, plus they offered minimal smarts around forecasting capabilities or statistical analysis for future predictions and did not provide a complete look at cash management.*

Dan Gruber, Channel Manager ATM Products Fifth Third Processing Solutions in the United States, sums it up by saying that

> *trying to manage large amounts of cash with spreadsheets is a nightmare. It is too prone to errors and requires lots of guesswork.*

Gruber also points out that

> *it was common to error on the side of overfilling in the past. Some ATMs even had a twenty percent buffer to ensure that they never ran out of cash.*

A recent survey by Level Four Software Ltd. and ICM Research demonstrate the importance of effective cash management: 38% of respondents in the United

Kingdom said they would consider moving their bank accounts based on their banks' ATM-network availability (i.e., ATMs that are "out of cash") (Wright, 2007).

The same sentiments are shared by the retail bank, who currently also make use of spreadsheets and experience to forecast and plan replenishment. This is not to say that the existing system is performing poorly. The point is that time, resources and costs can be reduced by making use of proven techniques that will enable the planners to make better decisions. The general agreement worldwide is that cash within an ATM network need to be managed differently than before. Cash is here to stay, the question is how to manage it efficiently.

1.3 Background to the Research Problem

ATM Management consist of two sub-divisions:

1. ATM Monitoring, which is the managing and resolution of the day-to-day maintenance of ATMs, i.e. responding to error messages received in real time via a monitoring system and calls received from branches.
2. ATM Planning, which is the managing, forecasting, ordering and replenishment of cash for each ATM.

These two areas are co-dependent, because the same operational resources, people and vehicles are used to service both areas. This research will only focus on ATM Planning, while the impact that ATM monitoring will have on the utilization of people or vehicles is ignored for the purpose of this research. For future research, the scientific techniques used for ATM Planning can be expanded to include ATM Monitoring.

The retail bank's client base and ATM network is growing year-on-year and the methods used until now to plan and manage ATM cash is not capable of coping with the increased load. A more scientific approach is required to allow the bank to make better informed decisions and to be more flexible. Currently it is left to a few experienced individuals to forecast and plan. If one or all of these individuals are not available, the accuracy and overall service levels are significantly reduced. With this problem in mind it was decided in consultation with the retail bank to focus on a specific geographical region.

The strategy that the ATM Cash Management department in the retail bank follows is to divide South Africa into different geographical regions. The formation of a region is dependent on a count house (distribution center) being in close proximity to a network of ATMs. A count house is owned by the cash in transit (CIT) security company and is used to receive, process and deliver cash for a network of ATMs belonging to the count house.

Each region has its own unique challenges that will determine the way an ATM can be replenished. The bank make use of three types of vehicle routing for ATM cash replenishment:

- CIT vehicles dedicated to and managed by the bank. The CIT vehicles belong to the CIT company but are exclusive to the retail bank. The vehicles receive replenishment instructions from the bank and follow routes as determined by the CIT company. This set-up is used where the distances between ATMs are vast due to geographic conditions.
- Scheduled CIT vehicles that follow set routes and where a custodian accompanies the CIT vehicle. These vehicles belong to the CIT company and service the cash needs of multiple industries, including the retail bank.
- Scheduled CIT vehicles that follow set routes and where the custodian have their own transportation and meet the CIT vehicle at the ATM. These vehicles belong to the CIT company and service the cash needs of multiple industries, including the retail bank.

This research will focus on the Mthatha geographical region in the Eastern Cape, which is made up of one count house in Mthatha and 18 ATMs positioned at the various branches. This region is currently serviced by two dedicated cash in transit vehicles and one scheduled CIT vehicle where the custodian meets the CIT vehicle at the ATM. The Mthatha region makes use of a multi-echelon inventory system, a bulk cash supplier, count house and 18 ATMs. Each ATM's cash on hand level is monitored centrally. There is a five day replenishment lead time and the central planners have to predict when an ATM will run out of cash in the future and order the required quantity. Cash is ordered in bulk from one of South Africa's four major banks in East London. The cash is then transported to the count house by SBV (a local secure transportation service provider) and from the count house to the ATM.

With the above in mind, the research objectives can now be stated.

1.4 Research Objectives

The main objective of this thesis is to demonstrate the benefits that the retail bank can achieve by making use of practical industrial engineering techniques to maximize the uptime of their ATMs and to minimize the cost to ensure this. To achieve this the secondary objectives are to:

1. design a forecasting model to address the retail bank's unique cash demand pattern, taking into consideration multiple seasonalities, calender day effects and special days. The forecasting model will be compared to the existing forecasting model, using the Mean Absolute Percentage Error (MAPE).
2. apply a well-known operational research method, the traveling salesman problem, to the CIT vehicle routes and highlight the cost savings obtainable with this method.
3. simulate 10 different models to demonstrate the impact on the overall expenses, when changes are made to reorder levels, demand forecasting, routing and the number of vehicles.
4. compare the models and identify a strategy that best fit the bank's objectives to 1) maximize ATM availability and 2) minimize cost.

The measures that will be used to identify the best fit for point (4) are:

- ATM Shortages - The demand for cash, by clients, that can not be dispensed due to the ATM not having enough cash available.
- Number of replenishments - The number of times an ATM is replenished.
- Distance travelled - The distance in kilometers that the CIT vehicles have to travel to replenish cash.
- Cash in circulation - The amount of cash left at day end totalled over the a period.
- Costs - The costs involved to manage and plan cash replenishment.

1.5 Research Methodology

An applied structured research methodology will be followed aimed at providing information that will guide the decision making process. A literature review will be performed on each area applicable to the research objectives. The emphases of the research is on identifying and applying different techniques that impact the best fit ATM cash management strategy for the case study. Ten simulation models will be build that will highlight the operational and financial impact when variables are changed (number of vehicles or reorder levels). Operational data was provided by the ATM Management department and financial data by the Finance department.

In order to reach the objectives the following steps were executed:

Step 1: Conduct workshops with key resources in the bank to understand and document the current ATM planning and replenishment processes.
Step 2: Gather operational and financial data to be used in the design, testing and solutions of the different models.
Step 3: Conduct literature studies of each subject within the supply chain, i.e. forecasting, inventory management, transportation and logistical costs.

Step 4: Design and build forecasting and simulation models that can be compared with the current methods of the case study and with each other.
Step 5: Compare the results of the different models by making use of predefined measurables, to identify the model that best fit the objectives of the bank and make recommendations.

1.6 Research Layout

This chapter (**Chapter 1**) set the stage and explain the need for addressing the research problem.

Chapter 2 provides a brief history and overview of the ATM Industry.

Chapter 3 provides a discussion of the current ATM planning and replenishment processes and the gaps identified.

Chapter 4 provides a literature review of supply chain topics and puts it in the context of ATM cash management in a retail banking environment.

In **Chapter 5** a forecasting model is designed for a single period ahead monthly point forecast. The monthly forecast is then adjusted to accommodate weekly and daily point forecasts.

In **Chapter 6** simulation models are designed for four main models consisting of 10 experiments. Each model and sub-model will be described in detail. Each experiments' results are discussed and compared using the predefined operational and financial parameters.

Chapter 7 draws a conclusion on the research done and outlines further research topics related to ATM cash management.

Chapter 2

Overview of the Automated Teller Machine and Industry

This chapter will provide the reader an introduction into the founders of the ATM and their contribution to the ATM as we know it today. It will also provide the reader insight into the ATM industry and some of the challenges facing it.

2.1 History of the Automated Teller Machine

There are numerous men who lay claim to being the inventor of the ATM. Miller (2008) highlights some facts about these men, and they are subsequently discussed.

Luther George Simjian

Luther George Simjian started building an early version of an ATM in the late 1930's. He came up with the idea of creating a hole-in-the-wall machine that would allow customers to make financial transactions. The idea was met with a great deal of doubt. Starting in 1939, Simjian registered 20 patents related to the device. He persuaded the City Bank of New York, today Citibank, to run a six-month trial. The trial was discontinued not due to technical insufficiencies, but due to a lack of demand. Simjian wrote: *It seems the only people using the machines were a small number of prostitutes and gamblers who didn't want to* *deal with tellers face to face.*

John Shepherd-Barron

In the 1960's, John Shepherd-Barron had an idea for a 24/7 cash dispenser, while he was managing director of De La Rue Instruments. De La Rue today manufactures cash dispensers. There is a De La Rue cash dispenser in one out of every five ATM machines built. The ATM was installed outside a north London branch of Barclays Bank in 1967. He received the Order of the British Empire in 2005 for services to banking as inventor of the automatic cash dispenser, but there is some controversy over the invention. James Goodfellow developed an alternative ATM design, using PIN technology, resembling modern ATMs more than Shepherd-Barron's machine. However, Shepherd-Barron's machine was the first to be installed. Inspiration struck Shepherd-Barron while he was in the bath: *It struck me there must be a way I could get my own money, anywhere in the world or the UK. I hit upon the idea of a chocolate bar dispenser, but replacing chocolate with cash.* The machine paid out a maximum of £10 at a time.
The Shepherd-Barron dispenser actually predated the introduction of the plastic card with its magnetic strip: the machines used special cheques which had been impregnated with a radioactive compound of carbon-14, which was detected and matched against the personal identification number (PIN) entered on a keypad. A proposed six digit PIN was rejected and four digits chosen instead, because it was the longest string of numbers that his wife could remember.

James Goodfellow

James Goodfellow patented the Personal Identification Number (PIN) technology. In 1965 he was a development engineer with Smiths Industries Ltd and was given the project of developing an automatic cash dispenser. Chubb Lock & Safe Co. were to provide the secure physical housing and the mechanical dispenser mechanism. Eventually Goodfellow designed a system which accepted a machine readable encrypted card, to which he added a numerical keypad. The design was patented in May 1966 in the UK and subsequently in may other countries thereafter. These machines were marketed by Chubb Ltd and installed nationwide in the UK during the late 60s and early 70s.

John D. White

John D. White started his work in 1968. In August 1973 he installed the first ATM at Rockville Center, Long Island, for the then Chemical Bank. Chemical Bank's ad campaign announced: *On Sept. 2, our bank will open at 9:00 and never close again!* His design was patented in May 1973 for the Docutel Corporation and was filed in July 1970. The machine was called a "Credit Card Automatic Currency Dispenser". There is a statement in the patent that supports the idea of the modern ATM. *Both the original code and the updated code are scrambled in accordance with a changing key*, which is what happens today. ATMs are programmed with security keys and the code changes and is scrambled to prevent fraudulent access to the card and ATM numbers between the machine, the bank, and the network processor.

Jairus Larson

Jairus Larson did not invent the ATM, but he did develop the very first 'online' ATM (Diebold's "550"). The first ATMs were all 'off-line' versions (sometimes referred to as 'stand-alone') meaning they did not have any means to communicate with the bank.

2.2 Industry Overview

According to the World Economic Forum Global Competitiveness Report for 2008-2009, Canada has the worlds best banking system. It is followed by Sweden, Luxembourg and Australia. Canada received 6.8 out of total 7 points and topped the list. South Africa comes in at number 15, ahead of countries such as

Switzerland, United Kingdom, France, Japan and the United States.

More than 130,000 ATM units have been installed globally in 2007, improving the previous record of 119,000, set in 2000. There is currently just over 2 million ATMs worldwide and it is forecasted that there will be over 2.5 million ATMs worldwide in 2013. The fastest growth has been in developing markets as a result of improved economic conditions and a greater investment in banking technology. The world market nevertheless continues to be dominated by five countries which account for half of global installations. The five largest ATM markets make up 52% of the ATMs worldwide, and the top ten make up 68%, as shown in Table 2.1, (Retail Banking Research, 2008).

Region	**ATMs**	**Share (%)**
USA	405,000	22.8%
Japan	181,712	10.2%
China	130,000	7.3%
Brazil	122,250	6.9%
South Korea	90,428	5.1%
UK	64,120	3.6%
Spain	60,592	3.4%
Canada	55,562	3.1%
Germany	55,004	3.1%
France	55,686	2.9%

Table 2.1: Ten Largest ATM Markets, end of 2007

The aim of the South African banking sector is to break the cycle of poverty that has affected much of the country by providing consumers with a cheap and effective medium to store their cash (a bank account) and have access to it in a safe and convenient location (ATM). The South African and African ATM market is enjoying unprecedented growth for a number of reasons:

- Governments and banks have focused on servicing the traditionally under-banked market by offering affordable savings accounts and ATM cards coupled with a strong educational drive to educate the population.

- South African banks and ATM deployers have expanded into Africa and have offered internationally-renowned best-of-breed products to their African neighbours.
- Advanced cellular telecommunications networks have facilitated faster and more affordable ATM deployment into previously unserviceable rural areas.
- The lower cost of ATM hardware has allowed smaller banks to achieve the same results as their bigger counterparts.

The FinMark Trust commissioned a report titled: *The Mzansi Bank account initiative in South Africa*, which was done by Bankable Frontier Associates (2009). The Mzansi account is an entry-level bank account, based on a magnetic stripe debit card platform, developed by the South African banking industry and launched collaboratively by the four largest commercial banks together with the state-owned Postbank in October 2004. Table 2.2 presents a summary view of the nature of the monetary value of debits flowing out of the average Mzansi account, across the four private banks. The vast majority (81%) of debit values take the form of ATM withdrawals, and 12% as branch withdrawals, which represent 93% of the total value of withdrawals.

	Distribution
ATM withdrawals	81%
Branch withdrawals	12%
POS withdrawals	0%
POS purchase	4%
Debit Orders	3%
Other Debit, e.g. billpay	0%

Table 2.2: Mzansi account profile: Distribution of value of debits

This indicates that for most Mzansi account holders, at least when it comes to making purchases or paying bills, cash is still king, and they are not tapping into the potential efficiencies offered by cashless payment channels (e.g., POS, debit order, mobile phone airtime top-up, mobile phone payments, etc.). An interesting activity pattern that is consistent across all the banks is the relatively high usage by clients of their particular bank's own ATMs (ATM-on-us), as opposed to the ATMs of the other three banks (ATM-not-on-us). Clients will make withdrawals at their own bank's ATM 83% of the time. The choice at which bank to open an account, is often tied to the convenience of ATM access.

Questions facing financial institutions today is whether the ATM is purely a cash dispenser, or a strategic client delivery channel? Using the ATM as a cash dispenser is beneficial due the client's familiarity with the process. A low level of literacy is required to navigate through the user interface screens in order to withdraw cash. The limitation in choices at the ATM also ensure that the client queue move quicker. Using the ATM as a customer delivery channel will mean a shift from a homogenous to a heterogeneous client relationship and marketing vehicle. It will mean that ATMs will become points of banking. The benefit for financial institutions is that clients are able to assist themselves without having to enter the branch. This frees up branch space and capacity to deal with more complex transactions, i.e. loans. In a country like South Africa there are limitations to using an ATM as a strategic customer delivery channel. Around 24% of South African adults over 15 years old are illiterate (6 to 8 million adults are not functionally literate). The more complex the ATM choices become the more education is needed.

For deployers focusing on the ATM as a client delivery channel, old metrics such as transactions per ATM and revenue per ATM will be less relevant. These metrics will be replaced by new metrics such as percentage of client's that use an ATM, the profitability of clients that use ATMs, new accounts attributed to ATMs, balances and relationships saved due to ATMs, and the percentage of clients who are cross-sold at an ATM.

ATM marketplace and KAL ATM Software (2010) did a global ATM software survey in 2010 with 243 respondents, representing some of the world's top financial institutions. The purpose of the report is to give an annual look at the financial institutions' current trends and future expectations of ATM software. Below are some of the questions and responses by the financial institutions in the Europe, Middle East and Africa (EMEA) region.

Question: Select the three most desired new features of ATM software. The results are shown in Table 2.3

	2010	**2009**
Remote monitoring of the ATM network	47%	40%
Multivendor ATM software	36%	19%
Cash management and forecasting	34%	21%
One-to-one marketing / purchase gift cards	25%	21%
Support for cash recycling	25%	33%
Bulk-note cash deposit	23%	29%
Customer preferences	18%	N/A
Software distribution	18%	26%
Support for biometrics	18%	12%
Automated test tools	16%	19%
Envelope-free check deposit	9%	10%
Other	6%	7%

Table 2.3: Most desired new features of ATM software

When putting the question in context of this paper, Table 2.3 shows that cash management and forecasting is deemed the third most important feature to address cost savings and client retention.

Question: Respondents were asked what is the most critical change their organization or their customers' organization needs to make to its ATM network in 2010. The results are shown in Table 2.4

According to Table 2.4 operational cost reduction of the ATM network remains the top priority for financial institutions in the EMEA region.

	2010	2009
Reduce operational costs	36%	33%
Adopt enhanced security technologies	17%	14%
Improve the ability to remotely manage the ATM network	16%	19%
Create a better ATM customer experience	14%	N/A
Improve customer functionality	10%	29%
Improve the user interface	2%	2%
No changes needed	5%	2%

Table 2.4: Most critical changes required for ATM networks for 2010

Question: Given customers have increasingly fewer reasons to visit bank branches, how important a delivery channel do you see your ATM network as a customer touchpoint that allows you to compete effectively with other banks? More than half the respondents indicated that they see their ATM network as a "very important" delivery channel to compete effectively, as shown in Table 2.5.

Very Important	56%
Becoming more important	20%
Same as before	14%
Not applicable	5%
Becoming less important	3%
Nor important at all	2%

Table 2.5: Importance of ATM as a delivery channel

Question: Rate the order of importance of (1) ATMs, (2) Branches, (3) Call Centers, (4) Internet, and (5) the Mobile Phone in order of importance as a customer touchpoint.

According to Table 2.6 the largest number of respondents viewed the ATM as the second most important customer touchpoint, with branches being the most important.

Customer Touchpoint	Most Important	2nd most important	3rd most important	4th most important	5th most important
ATM	33%	43%	16%	7%	2%
Branch	40%	18%	14%	14%	14%
Call Center	3%	10%	25%	36%	26%
Internet	19%	23%	34%	20%	3%
Mobile Phone	4%	7%	11%	24%	55%

Table 2.6: Importance of service delivery channels

In this section the banking industry and the involvement of the ATM has been briefly discussed. It is evident that cash and ATMs play and will play a key role in servicing client's needs and that financial institutions are focusing their efforts in utilizing the ATM to its full potential.

2.3 Future Developments of ATMs

ATMs offer loads of opportunities for financial intuitions as it is a vital interface between the institution and its customers. The next paragraphs highlight some of the future developments.

A few months ago Poland became the first European country to install a biometric ATM machine that read fingerprints. Customers can withdraw cash using their fingerprints and PIN codes. The machines work on "finger vein" technology, as opposed to a fingers' topographical signature.

A University in Kenya is busy developing a facial recognition ATM. The ATM comes with a camera that sends details of a clients facial dimensions to a database for verification. Once the image is verified, the customer either enters a PIN or answers a personal security question. A thief could not use a photograph to trick the machine because the machine uses length, width and depth to recognize the image.

In the United States banks have started to use video banking. Video banking combines self-service ATMs with the personal interaction of a consultant at a distant location. The remote consultant completes the transaction and answers questions the user might have. Video banking bridges the gap between self-service and full service.

2.4 ATM Operational Components and Availability

Numerous functions are involved in operating a network of ATMs: ATMs must be purchased and installed, transactions must be processed and balances settled, paper jams must be cleared and broken parts repaired, cash must be restocked, software must be maintained and upgraded. Figure 2.1 illustrates some of the components of ATM operations, each one of which financial institutions need to manage, either in-house or by outsourcing to a third party provider, (Dove Consulting *et al.*, 2006).

Figure 2.1: Components of ATM Operations

The two key metrics of the effectiveness of a financial institution's ATM operations are ATM uptime and operating costs. The definition of uptime varies across the different financial institutions. For the majority, ATM uptime means that the ATM is fully operational, for others it means that the ATM is capable of dispensing cash (but, for example, the receipt printer is out of service). For others it means that the ATM is fully operational, but is temporarily out of cash. Large banks are the most lenient when it comes to measuring ATM uptime. Only 35% define ATM uptime as meaning that the ATM is fully operational, 38% use the definition "Able to dispense cash". Smaller banks tend to use a stricter definition of ATM uptime, with 80% defining ATM uptime as fully operational. Despite the definition of uptime varying between financial institutions, the performance targets are the same. Financial Institutions strive for an average uptime of 98.9%, meaning that an ATM will be unavailable only 1.1% of the time. In terms of actual performance, financial institutions fall short of their goal by 1.3%, with reported actual uptime averaging 97.6% across all segments.

According to a study done by Dove Consulting *et al.* (2006) in the United States the main reasons for ATM downtime are: dispenser jams - 30%, hardware faults (receipt printer, key pads, etc.) - 20%, telecom failure - 18%, cash out of stock - 16%, card reader jam - 9% and 7% other.

2.5 Cost of ATM Operations

The cost of operating an ATM is high. Embedded in these costs are inefficiencies which when addressed can bring about substantial savings. Figure 2.2 illustrates the composition of a typical ATM at a UK bank branch and an ATM at a remote site. The combined cost of maintenance and cash management, accounts for more than 50% of the operating cost of an ATM, (Accenture, 2007).

The cost of cash replenishment has been increasing as the cost of armoured vehicle services increase due to rising fuel prices and insurance premiums. As interest rates have increased, so has the cost of carrying cash in an ATM. ATM cash counts against a financial institution's reserve requirements, and is not managed aggressively. Accurately forecasting ATM cash demand has become increasingly important for financial institutions, as a means of reducing the cost of expenses. More and more deployers are actively tracking the cost of funds and implementing cash management tools (e.g., Carrekers iCom or eClassicSystems ATM Manager Pro).

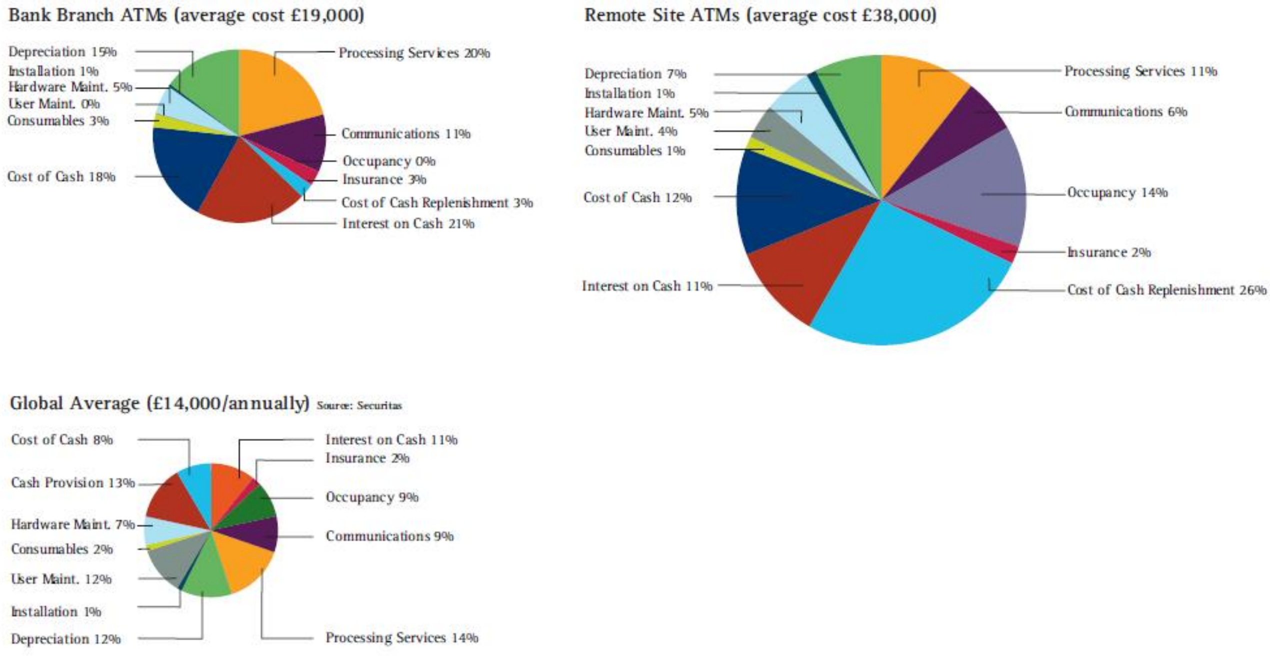

Figure 2.2: ATM ownership by a UK bank - cost composition of operation per year

This chapter gave the reader insight into the history of the ATM and the challenges facing financial institutions when it comes to utilizing their ATMs effectively. The next chapter will discuss the ATM planning and replenishment set-up at the case studies retail bank.

Chapter 3

ATM Planning and Replenishment

Introduction

This chapter will describe the retail bank's ATM planning and replenishment set-up. First a description will be given which will provide the basis for the research. Thereafter a detail discussion of the way the retail bank does its planning and replenishment will follow, which will highlight the areas of potential improvement. The current planning and replenishment process can be divided into five areas, *Data Collection*, *Forecasting*, *Planning*, *Ordering* and *Replenishment*.

3.1 Problem Description: ATM Planning and Replenishment in the Eastern Cape

The problem of replenishing cash in ATMs over a large geographical area is described here.

In conjunction with the retail bank, it was decided to focus on the Mthatha region, Eastern Cape, for the research case study, as the retail bank has greater control over the replenishment decisions in this region. The region consist of 18 ATMs and one count house (distribution center) with a central support center at the Head Office that monitors and plan replenishment for all on-site ATMs. The retail bank make use of CIT security companies to deliver cash in bulk from a major bank in East London to the count house in Mthatha, and then from the count house to the ATMs.

The local ATM branches are not responsible for ordering cash when levels are low. The ATM branches have no intelligent information to determine the cash levels within the ATM. The Eastern Cape is one of the regions the bank have a greater amount of control over as it makes use of dedicated CIT vehicles, which allows the bank control over the day, place and route of deliveries, while with scheduled CIT vehicles the bank will be subject to the predefined routes of the CIT company. Making use of scheduled CIT vehicles leads to a mismatch in terms of the location and time when the cash is needed by an ATM. The geographical distances between ATMs is also greater than in other regions and improving the way the CIT vehicles are routed can have a major impact on the uptime of ATMs, and the operational costs. The region does make use of one scheduled vehicle that replenishes three ATMs, that are in close proximity to each other but a long distance from the count house and the other ATMs.

Forecasting the cash demand of each ATM accurately is extremely difficult and error prone. The demand for cash differ from ATM to ATM and is influenced by holidays, pay days, regional events, etc., and the ability to manage these different situations is critical. Forecasting within the bank is a manual process done with MS Excel and dependant on the knowledge, business experience, judgement and common sense of the operator. There is no scientific guidance for the operator as to the cash demand per ATM. This is a huge responsibility on the abilities of the operator and leaves room for human error, especially when a skilled operator is not on duty, i.e. leave, illness etc.

Ordering cash and instructions for deliveries to ATMs is a manual process and managed via MS Excel. There is no holistic view of orders, deliveries and cash on hand in the different 'warehouses', i.e. count house, ATMs and in transit cash. This makes it difficult to accurately determine the cash available to promise or to order for an ATM.

The replenishment of an ATM takes place based on the forecasted day of when the ATM will run out of cash. On a specific day there can be a couple of ATMs that need replenishment. It is left to the CIT company to decide which ATMs to replenish and when to replenish on the day. In the first instance errors can occur when the ATM runs out of cash a day earlier or later than was predicted. The ATM can also run out of cash in the morning and will only be replenished in the afternoon due to the route being followed by the CIT company. In order to ensure that cash is delivered when and where required it is important to match up, as close as possible, the ATM cash deliveries with the ATM cash out events.

The demand for cash by the clients of the retail bank is high and during busy periods it is common to replenish the ATM the next day. Whereas with non-busy periods the ATM only need to be replenished two days to a week apart.

3.2 ATM Planning and Replenishment Processes

This section will describe the different steps followed during the process of ensuring that cash is delivered to an ATM when required.

3.2.1 Reports used for Decision Making

On a daily basis reports are generated that contain:

1. *the transactional detail*, i.e. the transaction time and amount dispensed per ATM. The report does not give a breakdown of the denominations (R200, R100, R50 and R20) dispensed.

2. *the daily dispensing*, i.e. a summary of the daily amount dispensed per ATM. No denominations are included in this report.

3. *the float at the end of the day*, i.e. the cash remaining in each ATM. The report gives a breakdown of the number of notes left per denomination per ATM.

These reports are used to forecast the demand for cash per ATM.

3.2.2 Cash Demand Forecasting

Using a spreadsheet the bank predicts the next month's demand for cash per ATM and then distributes the monthly demand into a daily forecast per ATM. The planner will make use of empirical cash demands per ATM, to do this.

The planner will start the forecast for the coming month in the second week of the current month. It takes the planner three to four days to compile the forecast. The planner starts by determining the year-on-year trend for the previous month. The demand of the previous month is adjusted to accommodate the increase or decrease in the trend. The planner will then search for a historical month with a similar pattern to the month to be forecasted, i.e. peak days. The month with the similar pattern is used to determine the distribution of demand per day. The year-on-year growth together with the data of the month with a similar pattern are used to forecast the coming month's cash demand. The planner will scan the forecasted month's daily data in order to identify zero values and special days, i.e. holidays. Where the value is zero the planner will search for historical data to determine the demand for the ATM for that day. Where there is a holiday the planner will remove the demand for that day and distribute it amongst the days preceding and following the special day. The planner will also make sure that the peak days are provided for. This is done for more than 400 ATMs.

For the process in its current form to be successful it is important that the planner knows the demand pattern of each region, as there is a great deal of business experience and judgement required to accurately predict the demand for cash per ATM.

3.2.3 Planning Replenishment of an ATM

The forecast spreadsheet is copied into a replenishment plan spreadsheet which is used to plan the daily replenishment per ATM. Every day the planner receives a float report that contains the closing balance per ATM for the previous day and a dispensing report that contain the cash dispensed the previous day per ATM. From the float report the closing balance per ATM are copied into the replenishment plan spreadsheet to replace the estimated closing balance. The actual dispensing totals per ATM is copied onto the replenishment spreadsheet to replace the forecasted dispensing totals. The spreadsheet is used to determine a variance that will indicate if a planned replenishment took place the previous day. After the actual figures have been included on the replenishment plan spreadsheet the planner will assess when the next replenishment must take place as well as the amount to replenish for each ATM. The planner will have to take into consideration, when assessing whether to replenish an ATM, that it takes five days for an ATM to be replenished, from ordering to replenishment.

The Eastern Cape region make use of a cash-add" system, where the custodian adds notes to the existing notes in the ATM canisters. A canister is a box-like container that is set to dispense a certain denomination, i.e. R100 or R50 etc., and loaded into the ATM. There is space for five canisters, but the retail bank only make use of four canisters per ATM, one for R200 notes, one for R100 notes, one for R50 notes and one for R20 notes. With a "cash-add" system, after all the canisters have been filled to the required level, some notes will be left over in the CIT company's bag that was used for the replenishment. It is very rare to have just the right amount of cash in the CIT company's bag to fill the canister to the required level. The notes that are left over in the CIT company's bag are returned to the count house to be re-banked. The planner have to, based on the forecasted cash demand, order cash to add to the ATM's balance five days into the future.

When required a cash-swap" is done in order to reconcile any differences between the balances on the ATM system reports and the ATM finance reports. During a swap all the canisters in the ATM are removed and replaced by pre-filled canisters. It is beneficial to do a swap when the cash in the ATM is at its lowest in order to minimize any re-banking costs.

3.2.4 Order Instructions to Deliver Bulk Cash to the Count House and to Replenish an ATM

From the replenishment plan spreadsheet instruction orders are generated per ATM. All relevant information regarding the order is included, i.e. ATM code, denomination split and value, applicable dates and order reference number. Orders are placed via e-mail to the CIT company's Head Office. The CIT company makes the orders available on their secured website. Each count house will log into the secured website and access their region's orders. At the same time the planner will place an order with the bulk cash supplier in East London, as well as with the retail bank's finance department to transfer the funds, for the CIT service provider to collect.

3.2.5 Replenishment of ATMs

The replenishment plan is given to ATM monitoring agents who are responsible for the issuing of a lock code. The code is required by a custodian to get access to the ATM canisters. The agents will monitor and confirm replenishments. If required, the ATM monitoring agent can intervene and change, together with the planner, the route the CIT company is following.

There are three CIT vehicles, two dedicated vehicles controlled by the bank, and one scheduled vehicle controlled by the CIT company. There is one custodian that travels with the scheduled vehicle. The two dedicated vehicles are divided into two areas of distribution. One vehicle delivers to five ATMs and the other to 10 ATMs. Three ATMs are managed by the CIT company due to the vast distances involved. The vehicle managed by the CIT company also picks up and replenish cash at other industries, i.e. retailers, banks, etc.

Currently replenishment is done with a cash-add method with a cash swap being done twice a month to balance the ATM and to clear the purge bin. The purge bin comes into play when the client requests cash and due to technical or hardware problems the cash cannot be dispensed. This cash is then redirected towards the purge bin.

The lead time from ordering cash from the bulk cash supplier up until the cash is delivered to the ATM is five days. Two days are required for the cash to be made available in the bulk cash supplier's account and packed for delivery, one day for delivery to the count house and packing of the cash at the count house per ATM, one day for replenishment of the ATM and one day for a grace period.

3.2.6 Operational Information

Table 3.1 contains operational information that was used in the case study.

Cost	
Delivery from bulk cash supplier (East London) to count house (Mthatha)	1. R 3,945 fixed cost. 2. R 1.53 per bundle. 200 notes make up one bundle. 3. R 41.78 per bag. 13 bundles make up one bag.
Insurance from bulk cash supplier to count house	1. R6.01 per R100,000, up to R 2 million. 2. If the order is > R 2 million - R 229 per order. 3. > R 5 million - R 454 per order. 4. > R 10 million - R 687 per order.
Special delivery (one day) from bulk cash supplier to count house (order placed before 11:00)	R 3,945 + R 884 + cost scale of cash ordered
Special Deilvery (one day) from bulk cash supplier to count house (order placed after 11:00)	R 18,000
Dedicated vehicle	R 78,710 per month
Cost per kilometer (dedicated vehicle)	R 3.18. The first 4,500 kilometers are free per dedicated vehicle
Rebanking of cash recovered from ATM	R 0.21 per R100
Quantity	
Maximum load per SBV vehicle	Not specified, but assured can deliver what is ordered
Maximum load per cash in transit vehicle	R 4,500,000
Maximum load per ATM	2500 notes per canister. Four canisters R200, R100, R50 and R20 which total R 925,000
Maximum amount held at count house	Not specified, hold what is delivered
Time	
Lead time from bulk cash supplier to count house	3 days
Lead time from count house to ATM	2 days
Travel time	2 hours per 100 km or 50 km/h
Replenishment time	20 minutes
SBV delivery time	Monday to Friday from 8:00 - 16:00
CIT delivery time	1. Monday to Friday from 8:00 - 16:00 2. Saturdays from 8:00 to 13:00

Table 3.1: Operational data of the Mthatha region

This chapter gave the reader an overview of the problems facing the Eastern Cape region and of how the retail bank's ATM network is being managed.

The chapter elaborated on the different steps involved in the ATM planning and replenishment process: *Data Collection*, *Forecasting*, *Planning Replenishment*, *Ordering* and *Replenishment*. The next chapter will provide a review of the literature that is relevant to ATM planning and replenishment.

Chapter 4

Literature Review

The chapter provides a review of existing literature that is relevant to the research topic and puts it in the context of an end-to-end cash management solution for a retail bank.

4.1 ATM Cash Management

Literature on the optimization of the cash supply chain in a retail banking environment is limited. Adendorff (1999) did her doctor's dissertation on the subject, by taking a scientific approach to the cash replenishment process and proved the applicability of industrial engineering principles in a service environment. The dissertation focused on the cost of cash as inventory, the design of a forecasting model and an order policy for a single branch, where the branch is responsible for the forecasting and ordering of cash.

Wagner (2007) did his Masters thesis on the optimal deployment of cash. The thesis focused on inventory, costing and routing models to optimize cash deployment for 10 ATMs. The thesis is intended to contribute to the knowledge of the economics of ATM operating networks.

This thesis serves as an extension to the work mentioned above, as each financial institution is different in a technological, operational and geographical sense. It will thus be difficult to make use of a rigid cash management system for improving the cash supply chain, as each scenario requires a unique end-to-end solution. There are quite a few variables that make each ATM network unique, even within the specific case study, each region is set up differently due to regional constraints. Providing banks with an integrated end-to-end view of their cash supply chain will have huge cost benefits and will allow banks to turn cash into a competitive advantage.

4.2 Literature on Forecasting

Why forecast when the only thing that you can be certain about is that the forecast will be wrong? If we take weather forecasting as an example, if we plan to take a walk and the weather forecast says it will rain, we will make the necessary arrangements so as not to get wet, by putting on a raincoat. In business, even though one cannot rely on the forecast it does not prevent one to make plans based on the forecast. The advantage is that everyone is prepared for what is expected and working to the same plan. All resources, people, equipment, material, capital etc. will be co-ordinated to meet the best estimate of what is forecast to happen. When the estimates change the business must be flexible enough to adjust their plans in a synchronized way to meet the new circumstances. The prediction of future events forms an important part of an organization's decision-making process. By determining the trend and seasonality for a period one can also determine possible re-order levels per period, instead of having static re-order points, one can use forecasting to more accurately predict when to deliver the goods.

An organization can base its selection of a forecast method on one of two distinct approaches:

1. *Individual selection* - analyze each data series, select the best performing method for that series and use the chosen method to forecast future observations for that series.

2. *Aggregate selection* - analyze the whole population (or a random sample), select the method best for the population (or sample) as a whole and apply that method to forecast future observations for the population.

Fildes (1989) studied 263 localities of a telephone operating company to determine the number of circuits required for special telecommunications services, such as digital data transmission. The study showed that for short lead times aggregate forecasting achieves similar accuracy to individual forecasting. For longer lead times individual forecasting achieves greater accuracy. For aggregate forecasting to compare to individual forecasting it must be carried out across a wide cross section of data and across time. When this is done the results of the study showed that aggregate forecasting is both simpler and of comparable accuracy to individual forecasting. Individual forecasting has been the preferred method of statisticians, whereas aggregate forecasting has been adopted by practitioners as a practical response to the need to forecast a large number of data series.

For predicting the daily distribution per ATM it was decided to forecast the daily demand of each ATM, and not the denominations dispensed per ATM. To determine how much cash to order for the count house (distribution center) it was decided to forecast the total region demand per month and week, instead of forecasting each ATM's demand individually. Data on individual level is usually subject to a relatively large amount of noise. More accurate forecasts can be made by considering groups of products that have similar demand patterns.

If one takes an holistic view of the demand forecasting of the ATM network of the retail bank, there are over 400 ATMs, which equate to over 400 final items and each of these items are made up of R200, R100, R50 and R20 notes, or four components that potentially need to be forecasted. For this research there are 18 final items (ATMs) made up of four components (denominations). A client will withdraw an amount at an ATM and receive different denominations that make up the amount. Instead of forecasting the demand for each denomination separately, the denominations are aggregated into the total amount dispensed for the day.

A quantitative univariate forecasting approach is taken for the case study. This involves the analysis of historical data in an attempt to identify a data pattern. Then, on the assumption that it will continue in the future, this data pattern is extrapolated. This method is useful in predicting independent demand.

The case study consist of ATMs with time series that exhibit multiple seasonal patterns of different lengths. Within a day or week or month there are multiple cycles i.e. the daily patterns for a Wednesday, a Friday and a Saturday differ while some days have similar patterns. Most existing time series models are designed to accommodate simple seasonal patterns with a small integer-valued periodicity (such as 12 for monthly data or 4 for quarterly data). There are a few models which attempt to deal with more complex seasonal patterns.

Harvey & Koopman (1993) designed a time-varying periodic spline component that provides a good way of modeling the changing electricity load pattern within the week and found that the overall forecasts are relatively accurate. Harvey *et al.* (1997) designed a model with the key feature being the setting up of the seasonal component in terms of a periodic component and a movable dummy component. The advantage of the structural time series approach was that once a regression formulation had been found it could be extended to allow the effects to evolve over time. This meant that deterministic components could be generalized so that they became stochastic. They also showed that it is possible to build in constraints that ensure that the forecasts of the seasonal component sum to 0 over a year, thereby ensuring that there is no confusion of trend and seasonal effects. Once such a model has been formulated, statistical handling via the state-space form is relatively straightforward.

Taylor (2003) studied the electricity demand forecasting for a half-hour-ahead to a day ahead, which contains more than one seasonal pattern. He shows how to adapt the Holt-Winters exponential smoothing formulation to accommodate two seasonalities. The Holt-Winters exponential smoothing method is only able to accommodate one seasonal pattern. His proposal requires a large number of values to be estimated for the initial seasonal components, especially when the frequencies of the seasonal patterns are high, which may lead to over parameterizations.

Gould *et al.* (2008) did a study on the hourly demand of a utility company and the hourly vehicle count data of a freeway. Their approach provided new state space models that allow for the forecasting of a time series with either additive or multiplicative seasonal patterns. They divided the longer seasonal lengths into sub-seasonal cycles that have similar patterns. Taylor & Snyder (2009) studied the forecasting of seasonal intraday time series that exhibit repeating intraweek and intraday cycles. They introduced a new exponential smoothing formulation that allows parts of different days of the week to be treated as identical. They applied their method to electricity load data and a series of arrivals at a call center that is open for a shorter duration at the weekends than on weekdays. They reason that a limiting feature of intraday cycle exponential smoothing is that it allows only whole days to be treated as identical. They argue that it often makes more sense to assume that just parts of days are identical. The example they use is that during daylight hours the series differs on each day of the week, but that the pattern during night hours can be treated as identical on all days of the week.

Taylor (2010) extended the three double seasonal methods in order to capture all three seasonal cycles: intraday, intraweek and intrayear. The three double seasonal methods being: (1) the double seasonal ARMA, (2) an adaptation of Holt-Winters exponential smoothing for double seasonality, and (3) a recently proposed, exponential smoothing method by Gould *et al.* (2008).

None of the above models can be used to model complex seasonal patterns such as non-integer seasonality and calendar effects, or time series with more than two non-nested seasonal patterns. Livera & Hyndman (2009) introduce a new innovation state space modeling framework based on a trigonometric formulation which is capable of tackling all of the seasonal complexities. The new approach is capable of decomposing and forecasting time series with multiple seasonality, high frequency seasonality, non-integer seasonality and dual calendar effects. They illustrated the superiority of the new modeling framework in handling complex seasonal patterns by applying it to gasoline data, call center data, and electricity demand data.

When building a forecasting model, it is important to recognize how variables like the day of the week, the week of the year, the day of the month, holidays and special events influence the demand. It is not just the holidays, but the days before and after the holidays that need special consideration as demand ebbs and flows around these events.

Forecasting ATM cash demand is difficult because the demand is dependent on:

- The specific calendar day, i.e. the 1st, 15th, 20th
- The specific day of the week, i.e. Friday, Saturday
- The combination of the two: the calendar day falling on a specific day of the week, e.g. 30th on a Saturday
- Public holidays
- The month of the year
- Year on year growth

Trading day effects or calendar effects reflect variations in the monthly time series due to the changing composition of months with respect to the number of times each day of the week occurs in the month, i.e. some days occur five times a month while other days occur four times in the month.

Simutis *et al.* (2008) proposed forecasting methods for ATM cash demand based on flexible artificial neural networks (ANN) and support vector regression algorithms. To forecast the daily cash demand they found that the flexible ANN produced slightly better results than the support vector regression algorithms.

Teddy & Ng (2010) proposed the use of a novel local learning model of the pseudo self-evolving cerebellar model articulation controller (PSECMAC) associative memory network to produce accurate forecasts of ATM cash demands. PSECMAC was developed with the aim of emulating the rapid and nonlinear function learning capability of the human cerebellum. PSECMAC manifests as a multidimensional multi-resolution associative memory network, and employs an error-correction scheme to drive the network learning and knowledge construction process. They achieved positive results which affirm the use of local learning-based computational intelligence models as promising alternatives to the commonly-used global learning based approaches for time series modeling and prediction.

4.2.1 Cash forecasting software

There are various cash forecasting software on the market. The best known software is iCom, MorphisCM, OptiCash and Pro Cash Analyser. The purpose of these cash management systems is to guarantee the availability of cash in the ATM network, to estimate the optimal amount of cash to stock plus efficiently managing and controlling day-to-day cash handling and transportation.

Most of these software make use of fuzzy expert systems, which are able to take both quantitative and qualitative factors into account. In a typical approach, a fuzzy expert system tries to imitate the reasoning of a human operator. The idea is to reduce the analogical thinking behind the intuitive forecasting to formal steps of logic. The disadvantage of the fuzzy expert system is the necessity to have an experienced expert with goodwill to give away the important and crucial information about the system for the expert system developers. In addition, there are many difficulties to adequately incorporate the expert knowledge into the rules of a fuzzy expert system.

Another disadvantage with most of these software is that the parameters of the forecasting models are determined during the system implementation stage and are held constant during the operation phase. Due to the forecasting models being complex in nature and the business environment changing continually it is difficult for the operators to update the model parameters.

4.3 Inventory Management

The Eastern Cape ATM network is set-up as a two-echelon, one warehouse (count house), n-retailer (ATM), system, with the inventory review being managed centrally by the financial institution. The branches and count house do not follow any inventory review policies. They are unaware of the cash levels in the ATM. The Inventory Management of an ATM network consist of various stochastic components, i.e. demand rates and lead times (in a lesser way). Depending on the replenishment method being used the ATM order quantity can be either fixed or variable. If a cash-add method is used the order quantity is variable, whereas with a cash-swap method it is fixed.

The concept of echelon stock was introduced by Clark & Scarf (1960). Graves (1985) studied a two-echelon inventory system for repairable items where the system consists of a repair depot and n operating sites. Each site requires a set of working items and maintains an inventory of spare items. All failed items are repaired at the repair depot, which also maintains an inventory of spare items. He considered a one-for-one replenishment policy, which is appropriate when the item has high value and infrequent failures. He also assumed a Poisson failure process. This assumption is violated whenever there are shortages at the site, i.e. the number of working items drops below the normal requirements. He also assumed that the shipment time from the repair depot to each site is deterministic and the same for all sites. The study also makes use of backorders. The Eastern Cape ATM cash management system differs from Graves' study in that (1) no cash is held on site (at the ATM), but at the count house (distribution center) and bulk cash supplier; (2) the distance of each ATM from the count house is not the same for all sites; (3) there are no backorders, if no cash is available the client will not wait for cash to become available, but rather go to another ATM.

Axsater (1990) dealt with an inventory system that consists of one warehouse and n retailers. He used deterministic transportation times, and assumed that retailers face stationary and independent Poisson demand. Unfilled demand is back ordered and the shortage cost is a linear function of the time until delivery. The paper is limited to a one-for-one replenishment policy. Orders that cannot be delivered instantaneously from the warehouse are ultimately delivered on a first come, first served basis. There are linear holding costs at all locations. Given these assumptions, they were able to derive the costs for the efficient determination of an optimal one-for-one replenishment policy.

Anily & Federgruen (1993) considered a distribution system with a single depot and n retailers with demands for a single item that occur at a specific constant (but retailer-dependent) deterministic rate. The depot places orders with an outside supplier. Goods are distributed from the depot to the retailers by a fleet of identical vehicles, combining deliveries into efficient routes. Their objective is to minimize the system-wide inventory, transportation and order costs, which they managed to show how cost effective system-wide replenishment strategies can be computed.

Most research on echelon systems has focused on installation-stock policies that use only local stock information. The progression of information technologies and the resulting availability of centralized stock information brought back the interest in echelon-stock policies. Cetinkaya & Lee (2000) presented an analytical model for coordinating inventory and transportation decisions in Vendor-managed inventory (VMI) systems. VMI is a supply-chain initiative where the supplier is authorized to manage inventories of agreed-upon stock-keeping units at retail locations. Successful businesses such as Wal-Mart and Shell Chemical are making use of VMI. In VMI, the vendor assumes responsibility for managing inventories at retailers using advanced online systems. The vendor makes decisions about the quantity and timing of resupply. This implies that inventory information at the retailer is accessible to the vendor. Some of the benefits of VMI are:

- the minimization of distorted demand information (bullwhip effect), transferred from the downstream supply-chain member (e.g., retailer) to the upstream member (e.g., vendor)
- fewer stockout situations
- reduction of inventory-carrying costs

The study assumed that inventory replenishment lead time is negligible which is not the case for ATM replenishments.

Bendaya & Raouf (1994) presented a model which can be used to determine the length of lead time that minimizes the expected total relevant cost. The lead time crashing cost (cost per unit time of lead time reduction) function is described using a piecewise linear function. The lead time is the only decision variable in their model. They assume that the order quantity is predetermined. By reducing the lead time, reduction in safety stocks can be achieved. The added cost of reducing lead time consists mainly of administrative costs, transportation cost, and the supplier's speed-up cost. They assumed a deterministic lead time with a normal distribution for demand.

Song & Zipkin (1993) presented an inventory model, where the demand rate varies. They derived some basic characteristics of optimal policies and develop algorithms for computing them. They modeled the fluctuating demand environment (the variables representing the environment are called collectively the *state-of-the-world*, or *world* for short) as a continuous-time Markov chain. By imposing the Markov property on the world, in effect they chose a "state-space representation" of the process, in which the world itself includes all relevant information about its future evolution. They also required a discrete state space. In cases where the natural formulation of the world is continuous, they essentially performed a discrete approximation. To specify how the world affects demand they used a simple world-demand specification: When the world is in state i, the demand follows a Poisson process with rate X_i. This allows for a purely random component to demand. The overall demand process forms what is called a

Markov-modulated Poisson process. The rest of the model consists of standard inventory-control model components, i.e. order lead time, either fixed or stochastic; cost rates for holding inventory and for backorders.

The retail bank currently follows a periodic review (t,S) inventory control system. Under this policy, the inventory position (which is defined as physical cash on hand plus cash on order) is reviewed every t units of time (every start of day) and if, at the moment of review, the cash level is determined to run empty within five days, a replenishment order is placed with the bulk cash supplier and the count house in order to raise the inventory position to a fixed level S.

4.4 Supply Chain

It is said that the supply chain concept grew largely out of two-stage multi-echelon inventory models. Beamon (1998) wrote an article in which he researched the different models and methods of supply chains. The paper provides a focused review of literature in supply chain modeling. He grouped the literature into four categories: (1) deterministic analytical models, in which the variables are known and specified, (2) stochastic analytical models, where at least one of the variables is unknown, and is assumed to follow a particular probability distribution, (3) economic models, and (4) simulation models. He also highlights the supply chain performance measures available in most literature. These measures may be categorized as either qualitative or quantitative. Qualitative performance measures are those measures for which there is no single direct numerical measurement. The following objectives have been identified as important:

- *Customer satisfaction:* The degree to which customers are satisfied with the product and/or service received, and may apply to internal customers or external customers. According to Christopher (2005) customer satisfaction is comprised of three elements:

  1. *Pre-transaction satisfaction:* satisfaction associated with service elements occurring prior to product purchase.

2. *Transaction satisfaction:* satisfaction associated with service elements directly involved in the physical distribution of products.
3. Post-transaction satisfaction: satisfaction associated with support provided for products while in use.

- *Flexibility:* The degree to which the supply chain can respond to random fluctuations in the demand pattern.
- *Information and material flow integration:* The extent to which all functions within the supply chain communicate information and transport materials.
- *Effective risk management:* All of the relationships within the supply chain contain inherent risk. Effective risk management describes the degree to which the effects of these risks are minimized.
- *Supplier performance:* The level of consistency with which suppliers deliver raw materials to production facilities on time and in good condition.

Quantitative performance measures can be described numerically. Quantitative supply chain performance measures may be categorized by: (1) objectives that are based on cost or profit and (2) objectives that are based on some measure of customer responsiveness. These are elaborated below:

1. Measures based on cost
   - *Cost minimization:* This is the most widely used objective. Cost is typically minimized for an entire supply chain (total cost), or is minimized for particular business units or stages.
   - *Sales maximization:* Maximize the value of sales or units sold.
   - *Profit maximization:* Maximize revenues less costs.
   - *Inventory investment minimization:* Minimize the amount of inventory costs (including product costs and holding costs).
   - *Return on investment maximization:* Maximize the ratio of net profit to capital that was employed to produce that profit.

2. Measures based on customer responsiveness
    - *Fill rate maximization:* Maximize the customer orders filled on time.
    - *Product lateness minimization:* Minimize the amount of time between the promised product delivery date and the actual product delivery date.
    - *Customer response time minimization:* Minimize the amount of time required from the time an order is placed until the time the order is received by the customer.
    - *Lead time minimization:* Minimize the amount of time required to process cash.
    - *Function duplication minimization:* Minimize the number of business functions that are provided by more than one business entity.

In supply chain modeling, the performance measures are expressed as functions of one or more decision variables. These decision variables are then chosen in such a way as to optimize one or more performance measures. The decision variables used in the reviewed models are described below:

- *Distribution scheduling:* Scheduling the distribution of cash.
- *Inventory levels:* Determining the amount and location of cash required.
- *Number of stages (echelons):* Determining the number of stages (or echelons) that will comprise the supply chain. This involves either increasing or decreasing the chain's level of vertical integration by combining (or eliminating) stages or separating (or adding) stages, respectively.
- *Distribution Center (DC) - customer assignment:* Determining which count house will serve which ATMs.
- *Buyer - supplier relationships:* Determining and developing critical aspects of the buyer-supplier relationship.
- *Product differentiation step specification:* Determining the step within the process when the product should be differentiated (or specialized).

4.5 Logistics and Cost

What is unique about ATMs and cash is that cash is not a sales driven item but rather a service driven item. The bank does not generate income by selling cash. It provides clients with a channel to withdraw their own funds and if this channel is not available it can have a negative effect on the reputation of the bank. The only physical receivable for making cash available at the ATM is a transaction fee.

An important financial dimension of decision making is resource utilization and specifically the use of fixed and working capital. The pressure in most organizations is to improve the productivity of capital. Christopher (2005) puts it in the context of return on investment (ROI) in Figure 4.1.

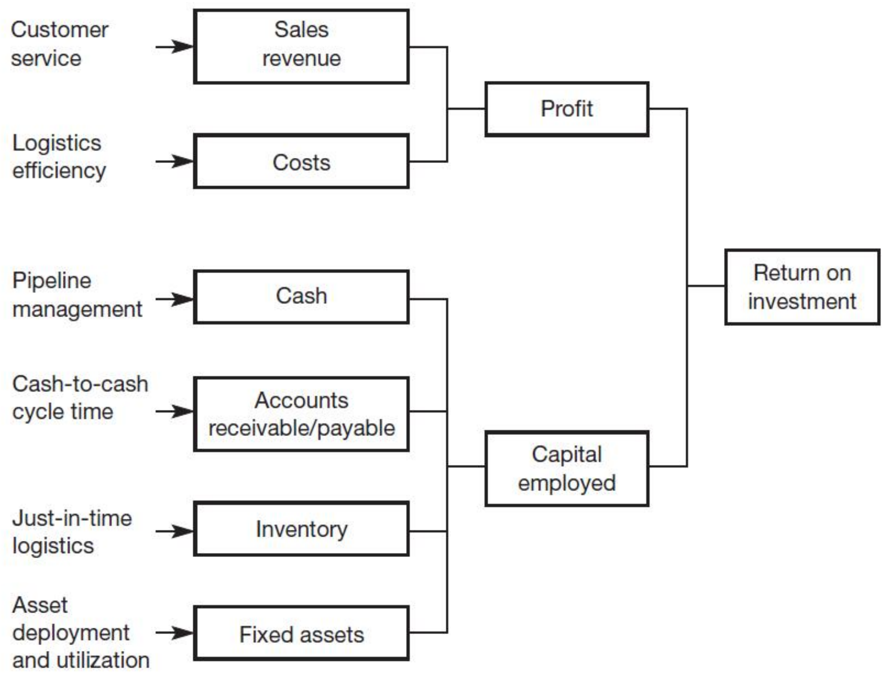

Figure 4.1: Logistics Impact on ROI

In the case of an ATM network the cash-to-cash cycle time is short, with consistently high volumes. What will be of particular interest is the ratio of the expense of an ATM versus the income per ATM and to then drive this ratio down. To achieve a low ratio it is imperative to manage the expenses.

Another big priority is improving the balance sheet through better use of resources. By examining each element of the balance sheet, it can be shown how logistics variables influence it, see Figure 4.2.

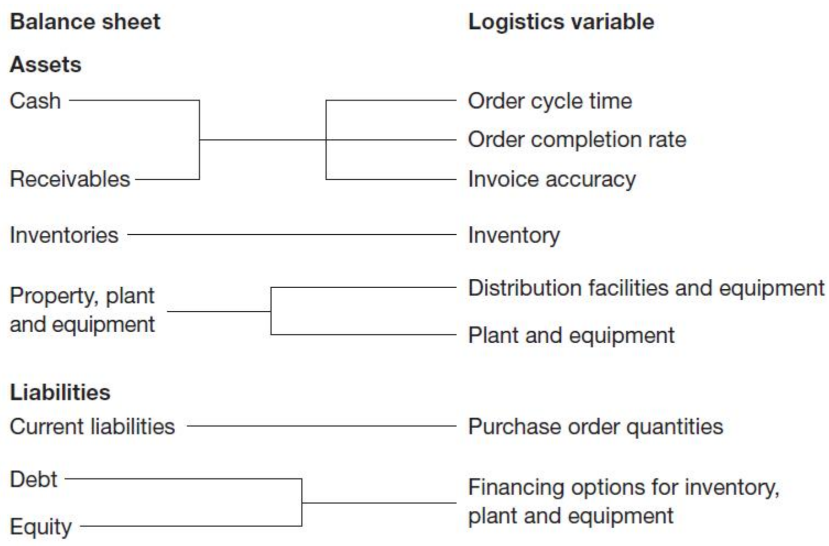

Figure 4.2: Logistics Management and the Balance Sheet

- *Cash and Receivables:* The shorter the order cycle time, from when the customer places the order to when the goods are delivered, the sooner the invoice can be issued. In the case of ATM and cash, the delivery of goods and payment is instant. The client walks up to an ATM, types in the amount required and receives the requested funds and a fee is deducted from the client's account. ATM cash is seen as a frozen asset as the bank is not able to use the asset to generate income or increase income.
- *Inventories:* The company's policies on inventory levels and stock locations will influence the size of total inventory. Also influential will be the extent

to which inventory levels are monitored and managed, and beyond that the extent to which strategies are in operation that minimize the need for inventory. There is a big drive by financial institutions for clients to use their debit card at point of sale devices. In a developing economy like South Africa this requires education and marketing as the previously unbanked still believe that cash is king.

- *Property, plant and equipment:* The logistic system is usually a heavy user of fixed assets. For the retail bank being studied the ATMs are its greatest fixed assets. Many companies have outsourced the physical distribution of their products partly to move assets off their balance sheet.
- *Current liabilities:* The current liabilities of the business are debts that must be paid in cash within a specified period of time. From the logistics point of view the key elements are accounts payable for bought-in materials, components, etc. This is an area where greater integration of purchasing with operations management can yield dividends. The traditional concepts of economic order quantities can often lead to excessive levels of raw materials inventory as those quantities may not reflect actual manufacturing or distribution requirements. If premature commitment of materials can be minimized this should lead to an improved position on current liabilities.
- *Debt/Equity:* More companies are leasing plant facilities and equipment and thus converting a fixed asset into a continuing expense. The growing use of third-party suppliers for warehousing and transport instead of owning and managing these facilities in-house is a parallel development. These changes obviously affect the funding requirements of the business, whereby that funding is achieved, i.e. through debt rather than equity. The ratio of debt to equity, will influence the return on equity and will have implications for the cash flow in terms of interest payments and debt repayment.

4.5.1 Logistic Cost Analysis

Logistics management is a flow-oriented concept with the objective of integrating resources across a pipeline which extends from suppliers to final customers. It is desirable to have a means whereby costs and performance of that pipeline flow can be assessed. One of the main reasons why the adoption of an integrated approach to logistics and distribution management has proved so difficult for many companies is the lack of appropriate cost information. Conventional accounting systems group costs into broad, aggregated categories which do not then allow the more detailed analysis necessary to identify the true costs of servicing customers buying particular product mixes. Without the facility to analyze aggregated cost data, it becomes impossible to reveal the potential for cost trade-offs that may exist within the logistics system. Generally the effects of trade-offs are assessed in two ways: from the point of view of their impact on total costs and their impact on sales revenue. However, without an adequate logistics-oriented cost accounting system it is extremely difficult to identify the extent to which a particular trade-off is cost-beneficial. The principles of logistic costing will be discussed in the next paragraph.

4.5.2 Principles of logistic costing

According to Christopher (2005), one of the basic principles of logistics costing, is that the system should mirror the materials flow. A second principle is that it should be capable of enabling separate cost and revenue analysis to be made by customer type and by market segment or distribution channel. To operationalize these principles requires an output orientation to costing.

Figure 4.3 illustrates the concept and demonstrates the difference between an output orientation based upon missions and the input orientation based upon functions. The approach requires that the activity centers associated with a particular distribution mission be identified, e.g. transport, warehousing, etc., and secondly that the incremental costs for each activity center incurred as a result of undertaking that mission must be isolated. Incremental costs are used because it is important not to take into account sunk costs or costs that would still be incurred even if the mission were abandoned. We can make use of the idea of attributable costs to operationalize the concept: *Attributable cost is a cost per unit that could be avoided if a product or function were discontinued entirely without changing the supporting organization structure.* In determining the costs of an

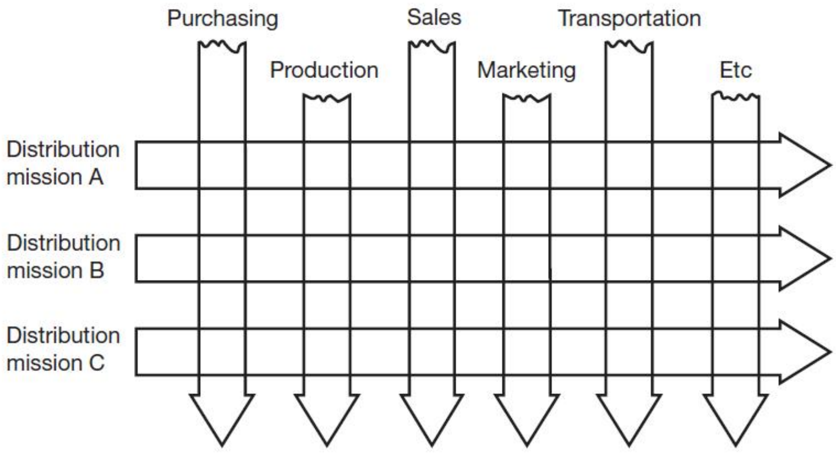

Figure 4.3: Logistics missions that cut across functional boundaries

activity center, e.g. transport, attributable to a specific mission, the question should be asked: What costs would we avoid if this customer/segment/channel were no longer serviced? These avoidable costs are the true incremental costs of servicing the customer/segment/channel.

In the area of logistic costing three methods have emerged:

- direct product profitability (DPP)
- activity based costing (ABC)
- customer profitability analysis (CPA)

These three methods are subsequently discussed.

4.5.2.1 Direct Product Profitability

Direct product profitability (DPP) is a measure commonly used by retailers, and it was first used in the retail food industry. It is somewhat analogous to customer profitability in that it attempts to identify all the costs that are attached to a product or an order as it moves through the distribution channel. The idea is that in many transactions the customer will incur costs other than the immediate purchase price of the product. Often this is termed the total cost of ownership. Sometimes these costs will be hidden and often they can be substantial and certainly big enough to reduce or even eliminate net profit on a particular item. The importance to the supplier of DPP is based on the proposition that a key objective of customer service strategy is *to reduce the customers' costs of ownership*. In other words the supplier should be looking at his products and asking the question: *How can I favorably influence the DPP of my customers by changing either the characteristics of the products I sell, or the way I distribute them?*

4.5.2.2 Activity Based Costing

The key to activity-based costing (ABC) is to seek out the 'cost drivers' along the logistics pipeline that cause costs because they consume resources. The advantage of using activity-based costing is that it enables each customer's unique characteristics in terms of ordering behaviour and distribution requirements to be separately accounted for. Once the cost attached to each level of activity is identified (e.g. cost per line item picked, cost per delivery, etc.) then a clearer picture of the true cost-to serve will emerge. Whilst ABC is still strictly a cost allocation method it uses a more logical basis for that allocation than traditional methods.

Activity based costing (ABC) began as an alternative to the traditional methods in the early 1980s when many companies started to realize the consequences of accounting systems that could generate incorrect costing information. The main reason for this happening were the changes experienced in organization's cost structures. Overheads and indirect costs increased and often became more important than direct costs (labor and material). The traditional allocation of these larger indirect and overhead costs, on the basis of direct labor costs, or volume indicators, became less accurate as the differences in the consumption of resources by products and services increased. As a consequence the impact of costing errors became increasingly larger than in the past. The knowledge of the real cost of a product and of the costs of serving specific channels and customers is becoming the key to company survival.

4.5.2.3 Customer profitability analysis

One of the basic questions that conventional accounting procedures have difficulty answering is: *How profitable is this customer compared to another?* The significance of these costs that occur as a result of servicing customers can be profound in terms of how logistics strategies should be developed. Customer profitability analysis will often reveal a proportion of customers who make a negative contribution. The reason for this is very simply that the costs of servicing a customer can vary considerably even between two customers who may make equivalent purchases. In the case of ATMs it is usually clients that generate the least fee income but the greatest loan income that make use of ATMs. The best measure of customer profitability is to ask the question: *What costs would I avoid and what revenues would I lose if I lost this customer?* This is the concept of avoidable costs and incremental revenue.

4.6 Literature on Transportation methods

Effective scheduling and routing has long been recognized as pivotal in fully leveraging the capital investment in transportation equipment and facilities. The key topics relating to routing and scheduling are single versus multiple delivery, value of load consolidation, routing methods, and vehicle scheduling.

Ross (1996) explains why in the past, the relation of load size and routing favored direct deliveries. The reason for this stemmed from two factors. The first related to transportation cost per unit, the larger the load in relation to vehicle capacity, the lower the transport cost. Full load delivery, although it required running empty return vehicles, was more efficient than multiple delivery methods. The second reason is based on the assumption that customers preferred to have their inventory requirements met by shipping as large a lot size as possible. In the past inventory planning systems focused on ordering stock according to Economic Order Quantities, maximum inventory levels, or other lot-sizing rules. The result was that transit practices using small, more frequent stops could deliver only a portion of customer demand, whereas a full truckload could perhaps meet customer lot-size requirements in full. In addition the larger the lot size, the larger the vehicle. On routes subject to multiple deliveries, so much time is spent in repeating delivery activities that only a relatively small payload can be delivered in the time allotted. As the distance between delivery sites decreases, payload can increase, but it cannot match the economies achieved by single delivery routes.

As the era of JIT arrived, the pendulum between single delivery and multiple delivery began to swing dramatically in favor of multiple-delivery, whereas unit-cost transport is still best served by as large a truckload as is possible. Customer requirements for smaller lot sizes and more frequent deliveries have caused a renewed interest in complex routing.

4.6.1 Combinatorial Optimization

The problem of deciding, amongst various routes, which route is the most cost effective to take are addressed by the field of combinatorial optimization. Combinatorial optimization problems are problems for which a finite, but often large, number of alternative feasible solutions exists. Combinatorial optimization models are often referred to as integer programming models where programming refers to planning so that these are models used in planning where some or all of the decisions can take on only a finite number of alternative possibilities. Combinatorial optimization is the process of finding one or more best solutions in a well defined discrete problem space.

4.6.1.1 The Traveling Salesman Problem

Given a set of cities along with the cost of travel between each pair of them, the traveling salesman problem, or TSP for short, is to find the cheapest way of visiting all the cities and returning to the starting point. The order in which the cities are visited is called a tour or circuit through the cities. This modest sounding exercise is in fact one of the most intensely investigated problems in computational mathematics. The TSP has seen applications in the areas of logistics, genetics, manufacturing, telecommunications, and neuroscience, to name just a few (Applegate *et al.*, 2006).

In the theory of computational complexity, the decision version of the TSP belongs to the class of *NP*-complete problems. Thus, it is assumed that there is no efficient algorithm for solving TSPs. In other words, it is likely that the worst case running time for any algorithm for the TSP increases exponentially with the number of cities, so even some instances with only hundreds of cities will take many CPUs years to solve exactly.

Good implementations of the process have a runtime that is proportional to the total number of tours. To count this number for a n-city TSP is an easy matter. Given a tour, we can choose any point as the starting city. Now from the start we have $n - 1$ choices for the second city, $n - 2$ choices for the third city, an so on. Multiplying these together we have that the total number of tours is equal to

$$(n - 1)! = (n - 1) \cdot (n - 2) \cdot (n - 3) \ ...3 \cdot 2 \cdot 1.$$

A running time proportional to $(n - 1)!$ is clearly impractical, putting the direct solution of instances with 50 or so cities well out of the reach of the combined computing power of all the world's machinery. The total number of tours for a 10 asymmetrical city problem is 362,880. For a symmetric tour problem the total number of tours are $\frac{(n-1)!}{2}$. A much better result was obtained in 1962 by Michael Held and Richard Karp, who found an algorithm and a guarantee that is proportional to $n^2 2^n$, that is, $n \times n \times 2 \times 2 \times 2 \times ... \times 2$, where there are n twos in the product. For any large value of n the Held-Karp guarantee is much less than $(n - 1)!$ (Applegate *et al.*, 2006).

An important theoretical question raised is whether or not there is a good algorithm for the TSP. To date, this question has not been settled. The discovery of a good algorithm for the TSP or a proof that no such algorithm exists would fetch a $1,000,000 prize form the Clay Mathematics Institute. It is not clear whether the TSP is a hard problem to solve. TSP has been placed in a general context within the complexity theory. In this theory problems are set as decision questions, such as asking if there is a tour of cost less than K, rather than asking for a minimum cost tour. The problem for which there exists good algorithms are known as the class P, for polynomial time. A possibly more general class is known as NP, for nondeterministic polynomial time. A problem is in NP if the answer to the decision question is yes, then there exists a means to certify this yes answer in such a way that the certificate can be checked in polynomial time. For example, if the answer is yes to the TSP question, then this can be certified by exhibiting a tour that does indeed have cost less than K. So the TSP question falls in the NP class.

The standard formulation for the problem is:

$$\text{minimize } c^T x \tag{4.1}$$

subject to

$$\sum (x_e \ : \ v \text{ is an end of } e) = 2 \text{ for all cities } v \tag{4.2}$$

$$\sum (x_e \ : \ e \text{ has exactly one end } S) \ \geq 2 \text{ for all proper subsets } S \neq \emptyset \tag{4.3}$$

$$0 \leq x_e \leq 1 \quad \text{for all edges } e \tag{4.4}$$

c^T = the cost of travel between each pair of cities
x = represent the cities

Some common applications of the TSP are:

- School Bus Routing
- Postal Deliveries
- Meals on Wheels
- Machine scheduling
- Picking items in a warehouse

- Estimate trenching costs for connecting antennas of a large ground-based telescope array
- Organizing the musical play lists on a portable device such as the iPod.
- Drilling holes on a circuit board

TSP has made some substantial contributions to operational research methods. These methods will be discussed below.

Mixed Integer Programming

One of the major accomplishments of the study of the TSP has been the aid it has given to the development of *mixed-integer programming* or MIP. A MIP model is a linear programming problem with the additional constraint that some of the variables are required to take on integer values. This extension allows MIP to capture problems where discrete choices are involved. In the past 50 years since its introduction, MIP has become one of the most important models in applied mathematics, with applications spanning nearly every industry.

The subject of mixed-integer programming has its roots in the Dantzig, Fulker, and Johnson paper, and nearly every successful solution method for MIP was introduced and studied first in the context of the TSP (Applegate *et al.*, 2006).

Branch-and-Bound

The well-know branch-and-bound search has its origins in work on the TSP. Branch-and-bound is an organized way to make an exhaustive search for the best solution in a specified set. Each branching step splits the search space into two or more subsets in an attempt to create subproblems that may be easier than the original. By repeatedly making such branchings steps we create a collection of subproblems that need to be solved, each defined by a subset of tours that include certain edges and exclude certain others. The purpose of the bounding step is to attempt to avoid a fruitless search of a subproblem that contains no solution better than those we have already discovered. The idea is that if the bound is greater than or equal to the cost of a tour we have already found, then we can discard the subproblem without any danger of missing a better tour.

Lin-Kernighan Heuristic

At the heart of the most succesful tour-finding approaches to date lies the simple and elegant algorithm of Lin & Kernighan (1973). The Lin-Kernighan algorithm is a tour improvement method. It takes a given tour and attempts to modify it in order to obtain an alternative tour of lower cost. The basic step goes back to Flood (1956), who observed that often a good tour can be obtained by repeatedly replacing pairs of tour edges by cheaper alternative pairs where possible. This is known as a 2-opt move. A natural idea to improve upon the 2-opt tours is to consider k-opt moves for larger values of k, that is, we remove k edges and reconnect the resulting tour fragments with an alternative set of k edges. The key to the Lin-Kernighan algorithm is to restrict the set of k-opt moves to allow for a strong heuristic search process for detecting an improving move. The restriction is to consider only k-opt moves that can be built from a sequence of specially constructed 2-opt moves. Thus, rather than searching for a single improvement move, the Lin-Kernighan algorithm attempts to build a sequence of 2-opt moves, that when taken together, one after another, ends up at an improved tour.

Heuristic Search

TSP has played a role in the development of many of the most widely used paradigms for heuristic-search algorithms. Such algorithms are designed to run quickly and to return a hopefully good solution to a given problem. This theme does not directly match the TSP, which asks for the best possible tour, but the problem has nonetheless served as a basic model for developing and testing ideas in this important area. Techniques that have arisen from this work are the following:

- Local search algorithms.
- The paper of Kirkpatrick *et al.* (1983) that introduced the simulated annealing method, worked with the TSP.
- Neural network algorithms. TSP was used as a primary example in the classic work of Hopefield & Tank (1985) that introduced optimizations aspects of this model.
- Genetic algorithms work with a population of solutions that are combined and modified to produce new solutions, the best of which are selected for the next generation of the population. TSP has been used in numerous studies of this paradigm.

4.6.1.2 The Vehicle Routing Problem

The solution of a Vehicle Routing Problem (VRP) calls for the determination of a set of routes, with each route performed by a single vehicle that starts and ends at its own depot, such that all the requirements of the customers are fulfilled, all the operational constraints are satisfied, and the global transportation cost is minimized. It is one of the most important combinatorial optimization problems (Toth & Vigo, 2002).

The VRP is a m-TSP problem, where m-vehicles have to cover the given cities and each city must be visited by exactly one vehicle. The VRP is often defined under capacity and route length restrictions. When only capacity constraints are present the problem is denoted as CVRP or Capacity Vehicle Routing Problem.

The symmetric VRP is defined on a complete undirected graph $G = (V, E)$. The set V = $\{0, 1, \ldots, n\}$ is a vertex set. Each vertex $i \in V \backslash 0$ represents a customer having a nonnegative demand q_i, while vertex 0 corresponds to a depot. With each edge $e \in E = (i, j) : i, j \in V, i < j$ is associated a travel cost c_e or c_{ij}. A fixed fleet of m identical vehicles, each of capacity Q, is available at the depot. The symmetric VRP calls for the determination of a set of m routes whose total travel cost is minimized and such that: (1) each customer is visited exactly once

by one route, (2) each route starts and ends at the depot, (3) the total demand of the customers served by a route does not exceed the vehicle capacity Q, and (4) the length of each route does not exceed a preset limit L. (It is common to assume constant speed so that distances, travel times and travel costs are considered as synonymous.) A solution can be viewed as a set of m cycles sharing a common vertex at the depot.
An integer linear programming formulation of the CVRP follows, where for each edge $e \in E$ the integer variable x_e indicates the number of times edge e is traversed in the solution. Let $r(Sc)$ denote the minimum number of vehicles needed to serve the customers of a subset Sc of customers. The value of $r(Sc)$ may be determined by solving an associated Bin Packing Problem (BPP) with item set Sc and bins of capacity Q. Finally, for $Sc \subset V$, let $\delta(Sc) = \{(i, j)\colon i \in Sc, j \notin Sc$ or $i \notin Sc, j \in Sc\}$. If $Sc = \{i\}$, then we simply write $\delta(i)$ instead of $\delta(\{i\})$. The CVRP formulation proposed by Laporte et al. (1985) is then:

$$\text{minimize} \sum_{e\in E} c_e x_e \tag{4.5}$$

subject to

$$\sum_{e\in\delta(i)} x_e = 2, \qquad i \in V\backslash 0, \tag{4.6}$$

$$\sum_{e\in\delta(0)} x_e = 2m \tag{4.7}$$

$$\sum_{e\in\delta(Sc)} x_e \geq 2r(Sc), \qquad Sc \subseteq V\backslash 0, Sc \neq \emptyset \tag{4.8}$$

$$x_e \in \{0,1\} \qquad e \notin \delta(0), \tag{4.9}$$

$$x_e \in \{0,1,2\} \qquad e \in \delta(0) \tag{4.10}$$

The degree constraints (4.6) state that each customer is visited exactly once, whereas the depot degree constraint (4.7) means that m routes are created. Capacity constraints (4.8) impose both the connectivity of the solution and the vehicle capacity requirements by forcing a sufficient number of edges to enter each subset of vertices. Finally, constraints (4.9) and (4.10) impose that each edge between two customers is traversed at most once and each edge incident to the depot is traversed at most twice. In this latter case, the vehicle performs a route visiting a single customer.

There are a number of variants to the basic vehicle routing problem, and some are discussed below:

Multiple Depot VRP (MDVRP)

A company may have several depots from which it can serve its customers. If the customers and the depots are intermingled then a Multi-Depot Vehicle Routing Problem should be solved. A MDVRP requires the assignment of customers to depots. A fleet of vehicles is based at each depot. Each vehicle originates from one depot, services the customers assigned to that depot, and returns to the same depot. Because MDVRP integrates three hard optimization problems, Ho *et al.* (2008) developed hybrid genetic algorithms (HGA) to deal with the problem efficiently, instead of a simple genetic algorithm (GA). There are three decisions for MDVRP problems. The decision maker first needs to cluster a set of customers to be served by the same depot, that is, the grouping problem. He then has to assign customers of the same depot to several routes so that the vehicle capacity constraint is not violated. Lastly, the decision on delivery sequence of each route is made.

Periodic VRP (PVRP)

In classical VRPs, the planning period is typically a single day. In the case of the Period Vehicle Routing Problem (PVRP), the classical VRP is generalized by extending the planning period to M days. Wen *et al.* (2010) modeled a dynamic multi-period VRP (DMPVRP) as a mixed integer linear program and solved it by means of a three-phase heuristic that works over a rolling planning horizon. The multi-obective aspect of the problem is handled through a scalar technique approach. They apply their model to the distribution of fodder to farmers at their request from one of several terminals which usually operate independent of each other, except in periods of intense activity.

Split Delivery VRP (SDVRP)

SDVRP is a relaxation of the VRP wherein it is allowed that the same customer can be served by different vehicles if it reduces overall costs. This relaxation is very important if the sizes of the customer orders are as big as the capacity of a vehicle. Mullaseril *et al.* (1997) studied the distribution of feed to cattle at a large livestock ranch. About 100,000 head of cattle are kept in large pens that are connected by a road network with six trucks delivering feed to the pens within certain time windows. They applied two heuristics to generate a set of feasible routes, (1) the extended path-scan heuristic and (2) the modified augment-merge heuristic.

Stochastic VRP (SVRP)

Stochastic VRPs (SVRP) are VRPs where one or several components of the problem are random. Three different kinds of SVRP are:

Stochastic customers: Each customer v_i is present with probability p_i and absent with probability 1 - p_i.
Stochastic demands: The demand d_i of each customer is a random variable.
Stochastic times: Service times δ_i and travel times t_{ij} are random variables.

In SVRP, two stages are used for generating a solution. A first solution is determined before knowing the realizations of the random variables. In a second stage, a recourse or corrective action can be taken when the values of the random variables are known.

VRP with Pick-Up and Delivering

The Vehicle Routing Problem with Pick-up and Delivering (VRPPD) is a VRP in which the possibility that customers return some goods is contemplated.

So in VRPPD it is needed to take into account that the goods that customers return to the delivery vehicle must fit into it. This restriction makes the planning problem more difficult and can lead to poor utilization of the vehicle capacities, increased travel distances or a need for more vehicles.

It is usual to consider restricted situations where all delivery demands start from the depot and all pick-up demands shall be brought back to the depot, so there are no interchanges of goods between the customers. One alternative is relaxing the restriction that all customers have to be visited exactly once. Another usual simplification is to consider that every vehicle must deliver all the goods before picking up any goods.

Berbeglia *et al.* (2010) provides a general framework for a dynamic one-to-one VRPPD. In one-to-one problems, each commodity (which can be seen as a request) has a given origin and a given destination. An example of a dynamic VRPPD is encountered by express courier companies located in many cities. These companies usually receive hundreds or thousands of dynamic requests in the same day. Requests consist of carrying letters or parcels from a pickup point to a delivery point. Savelsbergh & Sol (1998) proposed an optimization based algorithm for a real-world dynamic VRPPD. It captured standard constraints as well as problem specific features such as vehicles with special characteristics and different capacities, time windows, and working period restrictions. The optimization was performed over a horizon of several days and the objective was to minimize the driver's pay which depends on many factors such as the distance traveled and the number of nights away from home. The algorithm was tested over a 10-day real-life instance with more than 200 active requests at any time. When there were large numbers of requests, the solution given by the algorithm outperformed the one produced by planners.

VRP with Backhauls

The Vehicle Routing Problem with Backhauls (VRPB) is a VRP in which customers can demand or return some goods. VRPB is similar to VRPPD with the restriction that in the case of VRPB all deliveries for each route must be completed before any pickups are made. The importance of the backhaul problem is relative to the continuing effort to reduce distribution costs by taking advantage of the unused capacity of an empty vehicle traveling back to the DC. Golden *et al.* (1985) illustrated the potential for such savings: the Interstate Commerce Commission estimated that $165 million was saved nationally in 1982 by grocery stores who took advantage of backhauling.

VRP with Satellite Facilities

An important aspect of the vehicle routing problem (VRP) that has been largely overlooked is the use of satellite facilities to replenish vehicles during a route. When possible, satellite replenishment allows the drivers to continue making deliveries until the close of their shift without necessarily returning to the central depot. This situation arises primarily in the distribution of fuels and certain retail items.

Vehicle Routing Problem with Time Windows

The VRP with time windows is a extension of the constrained vehicle routing problem (CVRP) in which each capacity constraint is imposed and each customer i is associated with a time interval $[a_i, b_i]$, called a time window. The time instant in which the vehicles leave the depot, the travel time, t_{ij}, for each arc $(i, j) \in A$ and an additional service time s_i for each customer i are also given. The service of each customer must start within the associated time window, and the vehicle must stop at the customer location for s_i time instants. In case of early arrival at the location of customer i, the vehicle generally is allowed to wait until time instant a_i, i.e. until the service may start. Time windows can either be soft or hard. Soft time windows can be dishonored at a cost, while hard time windows do not tolerate arrivals after the beginning of the service time.

The chapter discussed the literature available on the subjects of: ATM Cash Management, Forecasting, Inventory Management, Supply Chain, Logistic Costing and Transportation (TSP and VRP). The next chapter will describe the design of the proposed demand forecasting model while Chapter six will apply some of the techniques discussed in this chapter by simulating different decision-making scenarios.

Chapter 5

Demand Forecasting

This chapter will guide the reader through the techniques applied to design a forecasting model for the unique demand requirements of the retail bank. What makes the demand unique is the impact that specific special days, e.g. paydays falling on a certain weekday have on the demand. For example, if a payday, 15th, falls on a Tuesday the demand will be much less than if the 15th falls on a Friday. It is thus difficult to identify a monthly or weekly pattern that repeats itself, as it is subject to the calendar day and weekday.

The forecasting method that should be used is one that meets the needs of the situation at the least cost and with the least inconvenience to the business. The forecasting method must also be flexible enough to allow for the judgement of management. Management judgement and statistical methods have complimentary strengths. Management judgement can take into account events unknown to the forecasting model, i.e. new business initiatives, strikes etc. The forecasting of ATM cash demand or similar scenarios where multiple seasonality and calendar day effects exist, is a study all on its own. It was decided to include a forecasting model into this research, to illustrate the value and improvements that can be achieved by making use of forecasting techniques and methodologies.

Several forecasting methods were considered to address the prediction of the demand for cash:

- Regression methods
- Decomposition methods
- Exponential smoothing methods
- Box-Jenkins methods

Two of the factors that need to be considered when choosing a forecasting model is cost and convenience, and for this reason it was decided to make use of the multiplicative Holt-Winters exponential smoothing method. This method is one of the most commonly used forecasting methods and it is easy to understand and adjust when required.

Referring to Bowerman *et al.* (2005) the multiplicative Holt-Winters time series can be described as:

$$y_t = (\beta_0 + \beta_1 t) \times SN_t \times IR_t \tag{5.1}$$

where:
$\beta_0 + \beta_1 t$ is the level at time T,
β_1 is the growth rate for the level,
SN_t is the seasonal factor, and
IR_t is an irregular component.

The smoothing equations:

$$\ell_T = \alpha(y_T/sn_{T-L}) + (1-\alpha)(\ell_{T-1} + b_{T-1}), \tag{5.2}$$

$$b_T = \gamma(\ell_T - \ell_{T-1}) + (1-\gamma)b_{T-1}, \tag{5.3}$$

$$sn_T = \delta(y_T/\ell_T) + (1-\delta)sn_{T-L} \tag{5.4}$$

are used, where:
ℓ_T = estimated level,
b_T = estimated growth rate,
sn_T = estimated seasonal factor,

$L =$ number of seasons in a year, and
α, γ, δ are smoothing constants between 0 and 1

The point forecast made in time period T for $y_{T+\tau}$ is calculated as:

$$y_{T+\tau}(T) = (\ell_T + \tau b_T) sn_{T+\tau-L} \quad (\tau = 1, 2, \ldots). \tag{5.5}$$

Here, $sn_{T+\tau-L}$ is the most recent estimate of the seasonal factor for the season corresponding to time period $T + \tau$.

An approximate 95% prediction interval computed in time period T for $y_{T+\tau}$ is

$$[\hat{y}_{T+\tau}(T) \pm z_{[0.025]} s_r(\sqrt{c_\tau})(sn_{T+\tau-L})], \tag{5.6}$$

with $c_1 = (\ell_T + b_T)^2$ if $\tau = 1$,

if $\tau = 2$ then $c_2 = \alpha^2(1+\gamma)^2(\ell_T + b_T)^2 + (\ell_T + 2b_T)^2$, and

if $\tau = 3$ then $c_3 = \alpha^2(1+2\gamma)^2(\ell_T + b_T)^2 + \alpha^2(1+\gamma)^2(\ell_T + 2b_T)^2 + (\ell_T + 3b_T)^2$.

To calculate c_τ if $2 \le \tau \le L$ use

$$c_\tau = \sum_{j=1}^{\tau-1} \alpha^2(1 + [\tau - j]\gamma)^2(\ell_T + j b_T)^2 + (\ell_T + \tau b_T)^2 \tag{5.7}$$

$$= \alpha^2(1 + [\tau - 1]\gamma)^2(\ell_T + j b_T)^2 + \ldots + \alpha^2(1+\gamma)^2(\ell_T + [\tau - 1] b_T)^2 + (\ell_T + \tau b_T)^2 \tag{5.8}$$

The relative standard error s_r computed in time period T is $(T > 3)$

$$s_r = \sqrt{\frac{\sum_{t=1}^{T}\left[\frac{y_t - \hat{y}_t(t-1)}{\hat{y}_t(t-1)}\right]^2}{T-3}} = \sqrt{\frac{\sum_{t=1}^{T}\left[\frac{y_t - (\ell_{t-1} + b_{t-1}) sn_{t\text{-}L}}{(\ell_{t-1} + b_{t-1}) sn_{t\text{-}L}}\right]^2}{T-3}}. \tag{5.9}$$

The sequence of steps to follow when applying the multiplicative Holt-Winters method according to Bowerman *et al.* (2005) are:

1. Find initial values for the level ℓ_0, the growth rate b_0, and the seasonal factors, $sn_{\{-11\}}, sn_{\{-10\}}, \ldots, sn_{\{0\}}$.
2. Detrend the data.
3. Calculate the average seasonal values for each of the L seasons.
4. Calculate a point forecast for y_1 from time origin 0.
5. Using the new obtained estimates, calculate the remaining estimates, i.e. ℓ_2, b_2, sn_2, etc.
6. Determine the smoothing constants, α, γ, and δ, that minimizes the sum of the squared forecast errors (SSE).

5.1 Forecasting the ATM Cash Demand for the Eastern Cape

There are 18 ATMs in the Mthatha, Eastern Cape geographical area and one count house (distribution centre). Bulk cash is ordered from one of the major banks, in East London and delivered by SBV to the count house. From the count house the cash is distributed to the different ATMs when required.

The forecasting objective is to determine the weekly demand for cash of the Mthatha area, to be delivered from East London to the count house. Since the lead time to deliver cash from East London to Mhtata is three days, it was decided to research the ordering of cash in bulk for the area as a whole on a weekly basis, instead of ordering daily from East London when required. This will give the bank more flexibility to react to fluctuations in ATM demand, instead of having to predict what will happen on a daily basis three to five days in the future. It will be shown that it is possible to dampen the daily fluctuations by making use of a weekly float at the count house. It sometimes happens that an ATM's demand increases substantially on an otherwise quiet day, while another ATM might experience a decrease in demand on an otherwise normal day, for whatever reason. If a daily forecast was used, the ATM whose demand increased would have suffered a great shortage and the ATM whose demand decreased would have a surplus of cash, the two events being independent of each other. By ordering cash for the week for the total area the increase or decrease of one ATM's demand is accommodated for by making use of a float that is readily available to support the fluctuations in demand.

Empirical daily dispensing data were gathered for periods of up to three years, January 2007 to November 2009. Where the ATM was not in existence since 2007, a shorter period of data was used for those ATMs. To achieve the weekly forecast objective the first step is to determine the monthly dispensing amount for the Mthata area.

To determine the monthly cash demand, each ATM's daily dispensing, over the three year period, was totaled to get a summation of the ATM daily dispensing amount for the Mthatha area as a whole, e.g. each ATM's (i) dispensing total for 5 March 2009 (d) was totaled to end up with a grand dispensing total $D = \sum_{d=1}^{k}\sum_{i=1}^{n} D_{d,i}$, for 5 March 2009. This was repeated for each calendar date of the empirical data.

The total daily dispensing was then accumulated for the month, to be left with monthly dispensing totals for January 2007; February 2007; March 2007 ... etc. The monthly dispensing totals were then used to forecast the monthly cash demand in the Mthatha area for December 2009, January 2010 and February 2010.

The empirical data of the first two years (24 months) was used to find the values for the initial seasonal factors. Regression was used to fit a trend line, see Figure 5.1, to the first 24 months of dispensing values, to find the initial values of the level and growth rate.

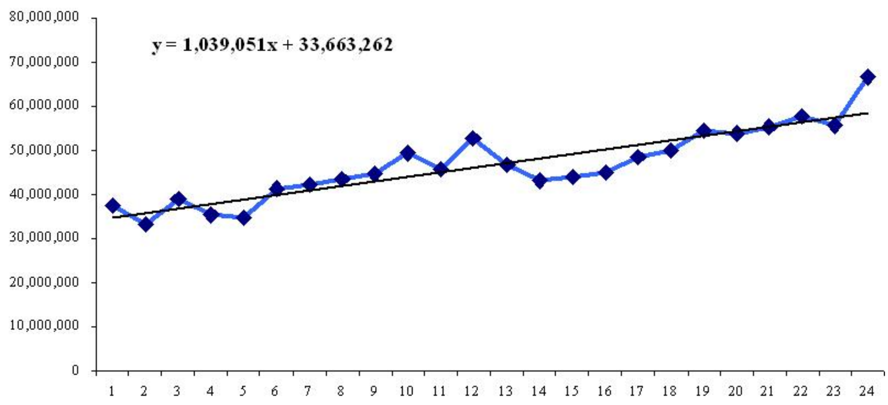

Figure 5.1: Regression of the first 24 months

To find the initial seasonal factors, the least square regression equation was used to compute $\hat{y}_t$ for each of the months used in finding the least square equation. Secondly it was necessary to detrend the data by computing $S_t = \frac{y_t}{\hat{y}_t}$ for each month used to estimate the least square regression line. The results are shown in Table 5.1.

Thirdly the average seasonal values were computed for each of the L seasons. For example, to find the average seasonal value for the first month take the values of period one and 13, in the **Detrended** column in Table 5.1, and average the two values. Add each month's average seasonal value together to end up with a total average seasonal value. See Table 5.2 for the results.

Lastly in determining the initial seasonal factors the average seasonal values were multiplied by a correction factor, [12 (L) / 12.0033 (sum of average seasonal values)] of 0.9997228. See Table 5.3 for the results.

The initial values calculated above for the level, trend and seasonal factors were then inserted into the multiplicative Holt-Winters equation, equation 5.5,

Period	Actual Demand	Month	Regression Estimates	Detrended
1	37 348 380.00	1	34 702 313	1.0763
2	33 395 090.00	2	35 741 364	0.9344
3	38 814 770.00	3	36 780 415	1.0553
4	35 340 690.00	4	37 819 466	0.9345
5	34 923 300.00	5	38 858 517	0.8987
6	41 228 380.00	6	39 897 568	1.0334
7	42 197 530.00	7	40 936 619	1.0308
8	43 317 000.00	8	41 975 670	1.0320
9	44 681 020.00	9	43 014 721	1.0387
10	49 272 910.00	10	44 053 772	1.1185
11	45 656 650.00	11	45 092 823	1.0125
12	52 723 120.00	12	46 131 874	1.1429
13	46 574 640.00	1	47 170 925	0.9874
14	43 105 800.00	2	48 209 976	0.8941
15	44 007 780.00	3	49 249 027	0.8936
16	45 054 870.00	4	50 288 078	0.8959
17	48 488 910.00	5	51 327 129	0.9447
18	49 852 990.00	6	52 366 180	0.9520
19	54 342 790.00	7	53 405 231	1.0176
20	53 925 740.00	8	54 444 282	0.9905
21	55 347 250.00	9	55 483 333	0.9975
22	57 753 450.00	10	56 522 384	1.0218
23	55 520 920.00	11	57 561 435	0.9646
24	66 759 520.00	12	58 600 486	1.1392

Table 5.1: Detrend first 24 months of data

M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	SUM
1.0763	0.9344	1.0553	0.9345	0.8987	1.0334	1.0308	1.0320	1.0387	1.1185	1.0125	1.1429	
0.9874	0.8941	0.8936	0.8959	0.9447	0.9520	1.0176	0.9905	0.9975	1.0218	0.9646	1.1392	
1.0318	0.9142	0.9744	0.9152	0.9217	0.9927	1.0242	1.0112	1.0181	1.0701	0.9885	1.1411	12.0033

Table 5.2: Average seasonal values

to predict the demand for one period (month) ahead. The Excel Solver add-in was used to calculate the values of, α, γ, and δ, that minimizes the sum of the squared forecast errors (SSE). From the point forecasts the forecast errors were calculated to be used in determining the accuracy of the forecast.

The next step is to calculate the daily cash demand for the Mthata area from

Season	Seasonal Index
1	1.0315
2	0.9140
3	0.9742
4	0.9149
5	0.9215
6	0.9924
7	1.0239
8	1.0109
9	1.0179
10	1.0698
11	0.9883
12	1.1407

Table 5.3: Initialized seasonal indexes

the monthly demand calculated above. The weekly demand will be calculated from the daily demand. An improvised method is designed to deal with the complexities of the calendar day and special day effect, i.e. where the 15th this month is on a Friday and the next month on a Tuesday, this will have an effect on the cash being dispensed on that day.

The daily dispensing amount of the empirical data is divided into seven sets. Each set represents a day of the week on which the month starts. All months starting for example on a Monday are grouped together, i.e. January 2007; October 2007; June 2009 etc. For each month within a set, the daily dispensing percentage is calculated in relation to that specific month's total dispensing, i.e. (see Table 5.4):

$$\begin{aligned}\text{Dispensing percentage for 10 January 2009} &= \frac{\text{10 January 2009 Dispensing}}{\text{Total Dispensing for January 2009}} \\ &= \frac{896,080}{37,348,380} \\ &= 2.4\%\end{aligned}$$

The reason for doing it this way is because of the calendar day and week day effect, i.e. 15th falling on a Friday or a 20th falling on a Wednesday etc. The distribution for the week and month would be different for these two examples. Each month starting on the same day have very similar distributions. Once the daily dispensing percentage in relation to the month is established the daily mean and standard deviation are calculated, i.e. taking Wednesday the 10th, the mean of the daily dispensing percentage equates to 2.71% and the standard deviation to 1.33%. The mean and standard deviation are used to determine the upper bound and lower bound of the confidence interval, which are used to eliminate outliers.

MONDAY																	
		Rand Values					Percentage Distribution										
DoM	**DoW**	**01/2007**	**10/2007**	**09/2008**	**12/2008**	**06/2009**	**01/2007**	**10/2007**	**09/2008**	**12/2008**	**06/2009**	**Count**	**Mean**	**StdDev**	**90% Confidence**	**Upper Bound**	**Lower Bound**
1	Mon	20,180	1,925,700	2,511,130	2,950,670	2,939,960	0.05%	3.91%	4.54%	4.42%	4.65%	5	3.51%	1.96%	1.44%	4.95%	2.08%
2	Tue	1,186,430	1,415,300	1,789,660	2,073,310	1,720,110	3.18%	2.87%	3.23%	3.11%	2.72%	5	3.02%	0.22%	0.16%	3.18%	2.86%
3	Wed	1,500,540	1,998,660	2,559,600	2,881,480	3,353,160	4.02%	4.06%	4.62%	4.32%	5.31%	5	4.46%	0.53%	0.39%	4.85%	4.07%
4	Thu	1,245,310	1,320,620	1,696,330	2,238,400	2,228,640	3.33%	2.68%	3.06%	3.35%	3.53%	5	3.19%	0.33%	0.24%	3.43%	2.95%
5	Fri	1,268,070	1,346,340	2,075,730	2,422,530	2,561,120	3.40%	2.73%	3.75%	3.63%	4.05%	5	3.51%	0.50%	0.36%	3.88%	3.15%
6	Sat	702,370	1,023,420	1,198,400	1,397,100	1,452,980	1.88%	2.08%	2.17%	2.09%	72.30%	5	2.10%	0.15%	0.11%	2.21%	1.99%
7	Sun	15,690	47,750	52,030	21,070		0.04%	0.10%	0.09%	0.03%		4	0.07%	0.03%	0.03%	0.09%	0.04%
8	Mon	1,219,950	1,282,110	1,604,410	2,414,240	2,041,960	3.27%	2.60%	2.90%	3.62%	3.23%	5	3.12%	0.39%	0.28%	3.41%	2.84%
9	Tue	984,690	976,840	1,078,840	5,023,500	1,619,040	2.64%	1.98%	1.95%	7.52%	2.56%	5	3.33%	2.37%	1.74%	5.07%	1.59%
10	Wed	896,080	895,000	1,058,820	3,364,900	1,517,650	2.40%	1.82%	1.91%	5.04%	2.40%	5	2.71%	1.33%	0.98%	3.69%	1.74%
11	Thu	811,970	875,610	1,019,780	2,345,980	1,423,880	2.17%	1.78%	1.84%	3.51%	2.25%	5	2.31%	0.70%	0.52%	2.83%	1.80%
12	Fri	943,990	1,215,420	1,547,970	2,953,530	1,900,790	2.53%	2.47%	2.80%	4.42%	3.01%	5	3.04%	0.80%	0.59%	3.63%	2.46%
13	Sat	692,240	708,720	915,260	1,796,710	1,156,040	1.85%	1.44%	1.65%	2.69%	1.83%	5	1.89%	0.48%	0.35%	2.24%	1.54%
14	Sun	25,250	44,850		45,480	720	0.07%	0.09%		0.07%	0.00%	4	0.06%	0.04%	0.03%	0.09%	0.03%
15	Mon	3,381,540	4,135,530	4,166,930	5,273,080	5,370,150	9.05%	8.39%	7.53%	7.90%	8.50%	5	8.27%	0.59%	0.43%	8.70%	7.84%
16	Tue	1,693,990	1,874,360	2,239,680	35,100		4.54%	3.80%	4.05%	0.05%		4	3.11%	2.06%	1.69%	4.80%	1.41%
17	Wed	1,180,060	1,273,570	1,486,250	3,185,050	2,337,760	3.16%	2.58%	2.69%	4.77%	3.70%	5	3.38%	0.89%	0.66%	4.04%	2.72%
18	Thu	936,240	1,072,280	923,560	2,400,530	1,815,350	2.51%	2.18%	1.67%	3.60%	2.87%	5	2.56%	0.73%	0.53%	3.10%	2.03%
19	Fri	3,973,350	5,335,250	5,745,080	3,124,080	5,756,830	10.64%	10.83%	10.38%	4.68%	9.11%	5	9.13%	2.58%	1.89%	11.02%	7.23%
20	Sat	1,704,440	2,180,820	2,345,200	2,509,310	2,583,960	4.56%	4.43%	4.24%	3.76%	4.09%	5	4.21%	0.31%	0.23%	4.44%	3.98%
21	Sun	74,900			11,040	9,300	0.20%			0.02%	0.01%	3	0.08%	0.11%	0.10%	0.18%	-0.02%
22	Mon	1,851,160	2,614,100	3,153,250	4,133,400	2,206,550	4.96%	5.31%	5.70%	6.19%	3.49%	5	5.13%	1.02%	0.75%	5.88%	4.38%
23	Tue	1,015,320	1,536,460	2,129,700	2,894,490	1,719,460	2.72%	3.12%	3.85%	4.34%	2.72%	5	3.35%	0.72%	0.53%	3.88%	2.82%
24	Wed	977,360	1,467,600	15,310	3,009,940	1,468,890	2.62%	2.98%	0.03%	4.51%	2.32%	5	2.49%	1.61%	1.19%	3.68%	1.30%
25	Thu	1,642,990	2,179,650	3,087,510	24,260	3,058,580	4.40%	4.42%	5.58%	0.04%	4.84%	5	3.86%	2.19%	1.61%	5.46%	2.25%
26	Fri	1,772,370	2,566,640	2,885,630	32,740	4,124,720	4.75%	5.21%	5.21%	0.05%	6.53%	5	4.35%	2.49%	1.83%	6.18%	2.51%
27	Sat	1,192,160	1,628,930	1,883,540	1,676,350	2,399,750	3.19%	3.31%	3.40%	2.51%	3.80%	5	3.24%	0.47%	0.34%	3.59%	2.90%
28	Sun	43,450	85,310	200		46,490	0.12%	0.17%	0.00%		0.07%	4	0.09%	0 .07%	0.06%	0.15%	0.03%
29	Mon	1,314,590	2,007,720	2,761,440	2,230,970	2,596,610	3.52%	4.07%	4.99%	3.34%	4.11%	5	4.01%	0.64%	0.47%	4.48%	3.53%
30	Tue	1,142,520	1,712,830	3,416,010	1,765,540	3,786,770	3.06%	3.48%	6.17%	2.64%	5.99%	5	4.27%	1.68%	1.24%	5.51%	3.03%
31	Wed	1,939,180	2,525,520		2,524,740		5.19%	5.13%		3.78%		3	4.70%	0.80%	0.76%	5.46%	3.94%
Month Rand Value		**37,348,380**	**49,272,910**	**55,347,250**	**66,759,520**	**63,197,220**											

Table 5.4: Daily Demand Forecasting - Monday Set

The outliers are eliminated by making use of a 90% confidence interval. Referring to Table 5.5, the values falling outside the upper- or lower bound are left out when calculating the mean of the specific day. The daily dispensing percentage mean (excluding the outliers) will then need to be divided into the total mean percentage to calculate each day's daily dispensing percentage, i.e. the mean on Wednesday the 10th, 2.13%, is divided by the total mean, 104.91% to end up with 2.03% . This is to ensure that the total daily dispensing percentage equals 100%. The result is a daily dispensing percentage for a month starting on a Monday. The steps are repeated for each day of the week.

MONDAY								
		Percentage Distribution included in Calculation						
DoM	**DoW**	**01/2007**	**10/2007**	**09/2008**	**12/2008**	**06/2009**	**Mean**	**Final Distribution**
1	Mon		3.91%	4.54%	4.42%	4.65%	4.38%	4.17%
2	Tue	3.18%	2.87%		3.11%		3.05%	2.91%
3	Wed			4.62%	4.32%		4.47%	4.26%
4	Thu	3.33%		3.06%	3.35%		3.25%	3.10%
5	Fri	3.40%		3.75%	3.63%		3.59%	3.42%
6	Sat		2.08%	2.17%	2.09%		2.11%	2.01%
7	Sun	0.04%		0.09%			0.07%	0.06%
8	Mon	3.27%		2.90%		3.23%	3.13%	2.99%
9	Tue	2.64%	1.98%	1.95%		2.56%	2.28%	2.18%
10	Wed	2.40%	1.82%	1.91%		2.40%	2.13%	2.03%
11	Thu	2.17%		1.84%		2.25%	2.09%	1.99%
12	Fri	2.53%	2.47%	2.80%		3.01%	2.70%	2.57%
13	Sat	1.85%		1.65%		1.83%	1.78%	1.70%
14	Sun	0.07%			0.07%		0.07%	0.06%
15	Mon		8.39%		7.90%	8.50%	8.26%	7.88%
16	Tue	4.54%	3.80%	4.05%			4.13%	3.94%
17	Wed	3.16%				3.70%	3.43%	3.27%
18	Thu	2.51%	2.18%			2.87%	2.52%	2.40%
19	Fri	10.64%	10.83%	10.38%		9.11%	10.24%	9.76%
20	Sat		4.43%	4.24%		4.09%	4.25%	4.05%
21	Sun		0.00%	0.00%	0.02%	0.01%	0.01%	0.01%
22	Mon	4.96%	5.31%	5.70%			5.32%	5.07%
23	Tue		3.12%	3.85%			3.48%	3.32%
24	Wed	2.62%	2.98%			2.32%	2.64%	2.52%
25	Thu	4.40%	4.42%			4.84%	4.55%	4.34%
26	Fri	4.75%	5.21%	5.21%			5.06%	4.82%
27	Sat	3.19%	3.31%	3.40%			3.30%	3.15%
28	Sun	0.12%				0.07%	0.09%	0.09%
29	Mon		4.07%			4.11%	4.09%	3.90%
30	Tue	3.06%	3.48%				3.27%	3.11%
31	Wed	5.19%	5.13%				5.16%	4.92%
							104.91%	**100.00%**

Table 5.5: Daily Percentage Distribution - Monday Set

To forecast the daily cash demand, the monthly forecast, calculated with the multiplicative Holt-Winters method, is multiplied by the daily dispensing percentages. For example, to forecast the daily demand for December 2009, the month's forecasted demand, R 99,292,663 is multiplied by each day's dispensing percentage for the Tuesday set. December 2009 begins on a Tuesday. The monthly forecast compensates for growth, level (mean) and seasonality whereas the daily dispensing percentages are a reflection of the daily distribution per month. Each month starting on the same day has a similar distribution. To compensate for public holidays the demand predicted for that day is distributed between the days preceding and following the public holiday. The distribution was left to the judgement of the operator.

To determine the weekly forecast for the Mthatha area, the daily forecast is rolled up into weekly demand. A forecasting week is seen as Saturday to Friday.

The result of the forecasting exercise is monthly, weekly and daily forecasted cash demand for the Mthatha area. Each month-end the actual monthly dispensing will have to be captured and the smoothing constants recalculated.

5.2 Limitation of the Dispensing Data

Inherent in the data used for the research are anomalies or gaps, such as out of cash days and out of service days. Out of cash and out of service anomalies refer to days where the ATM department did not plan correctly for the replenishment of an ATM or where an ATM stopped functioning due to a technical fault. The result of this is that the demand for that day is shifted and causes abnormal demands on otherwise standard days. This will have an effect on the forecasting model as it is not a true reflection of the daily demand for cash. By making use of a more scientific approach it is believed that the anomalies can be eliminated which will lead to even better predictable cash demand and client service.

5.3 Demand Forecasting Results

The Mean Absolute Percentage Error (MAPE) will be used to measure the accuracy of the proposed forecasting solution, as well as to compare it with the current forecasting method. This is done for the periods December 2009, January 2010 and February 2010.

5.3.1 Daily Demand Forecast

When one compares the forecasting method used by the retail bank today with the proposed forecasting method based on forecasted amounts, there does not seem to be a difference between the two methods as can be seen in Figure 5.2. The difference becomes clearer when looking at the MAPE.

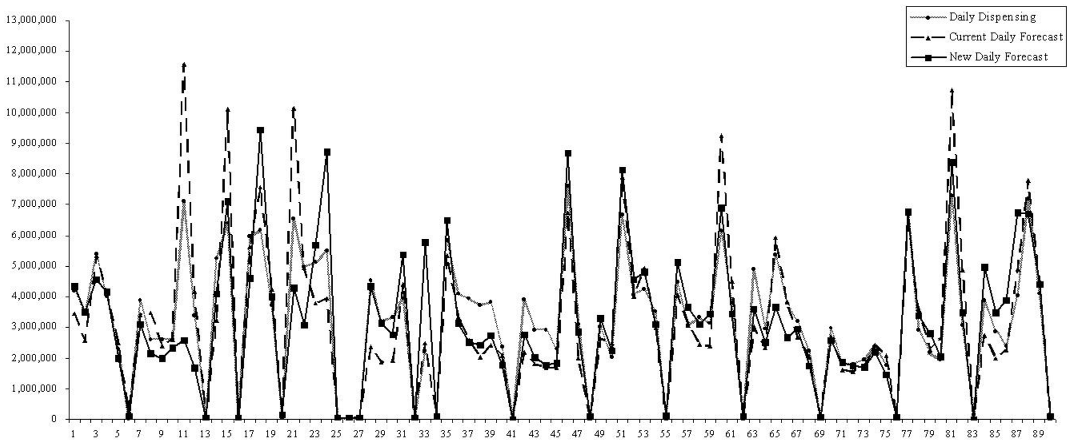

Figure 5.2: Daily cash demand for three month period, December 2009, January 2010 and February 2010

Figure 5.3 illustrates the percentage forecast errors of the forecast method used currently and the proposed method. When the absolute of these percentage errors are averaged, as in Table 5.6, a clearer picture of the improvement is evident.

	Current daily forecast	**New daily forecast**	**% Improvement**
MAPE	74.06%	58.01%	21.67%
MAPE (excl. values > 100%)	26.46%	22.64%	14.44%

Table 5.6: Daily Mean Absolute Percentage Errors

Table 5.6 displays the MAPE difference between the current- and new daily forecast method. When all the points are taken into consideration the new

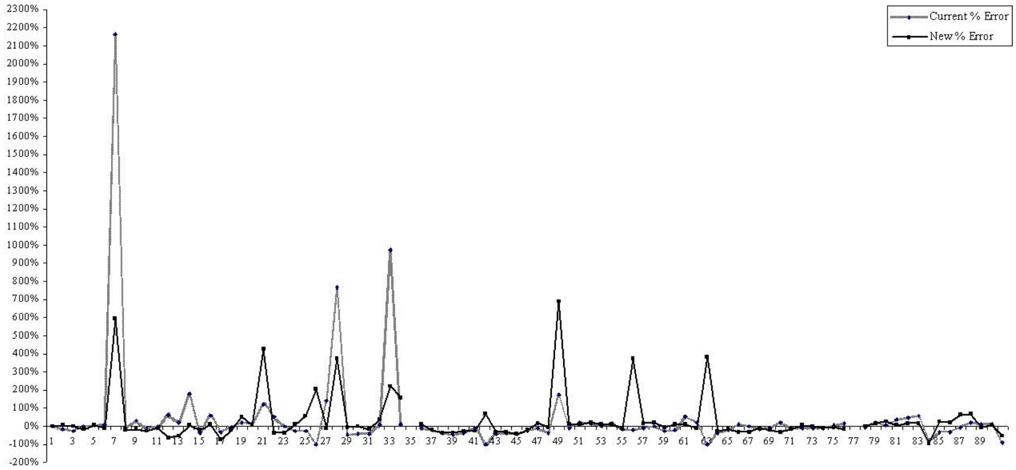

Figure 5.3: Daily percentage forecast errors of the current method and the proposed method

method produces an improvement of 21.67% over the current method. When the percentage errors exceeding 100% are eliminated the improvement is 14.44%. It is clear that even with the new method the MAPE for daily forecasting is very high. One of the reasons for this is due to the anomalies within the data that affects the demand pattern.

5.3.2 Weekly Demand Forecast

The daily forecasts (current- and new method) of the Mthatha area are accumulated into weekly forecasts, with the week stretching from Saturday to Friday. Fourteen weeks of cash demand are forecasted and a comparison done between the actual dispensing and the current- and new forecasting values as shown in Figure 5.4.

Figure 5.5 illustrates the forecasting percentage errors for the two methods. When these absolute percentage errors are averaged, an 18.91% improvement is achieved for the weekly forecast when comparing the proposed forecasting method to the current method, see Table 5.7.

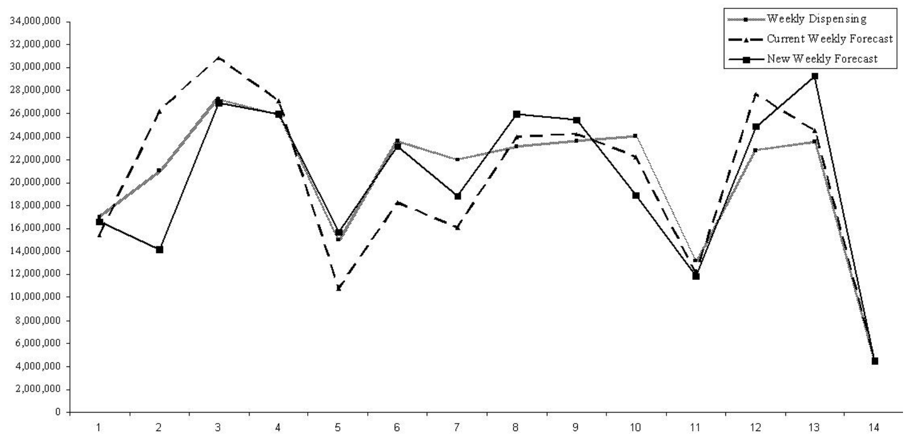

Figure 5.4: Weekly cash demand for three month period, December 2009, January 2010 and February 2010

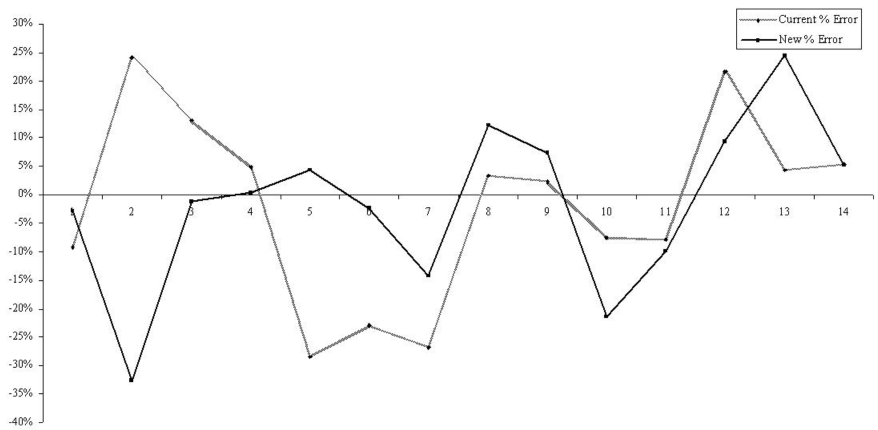

Figure 5.5: Weekly percentage forecast errors of the current method and the proposed method

Current weekly forecast	New weekly forecast	% Improvement
13.01%	10.55%	18.91%

Table 5.7: Weekly Mean Absolute Percentage Errors

5.3.3 Monthly Demand Forecast

The monthly demand is forecasted by applying the multiplicative Holt-Winters method. Figure 5.6 illustrates the actual monthly demand and the forecasted monthly demand using the current- and the new method.

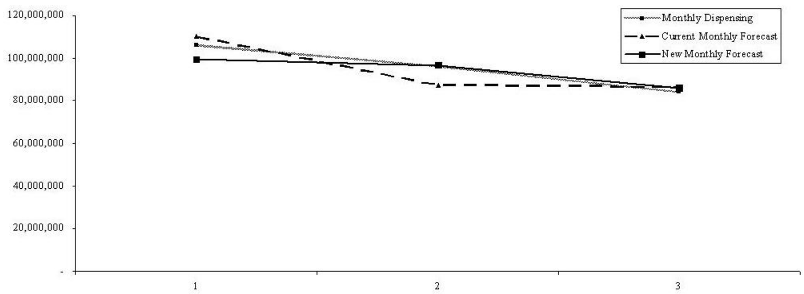

Figure 5.6: Monthly cash demand for three month period, December 2009, January 2010 and February 2010

Figure 5.7 illustrates the forecasting percentage errors of the two methods. When these absolute percentage errors are averaged, an 42.36% improvement is achieved for the monthly forecast when comparing the proposed forecasting method to the current method, see Table 5.8.

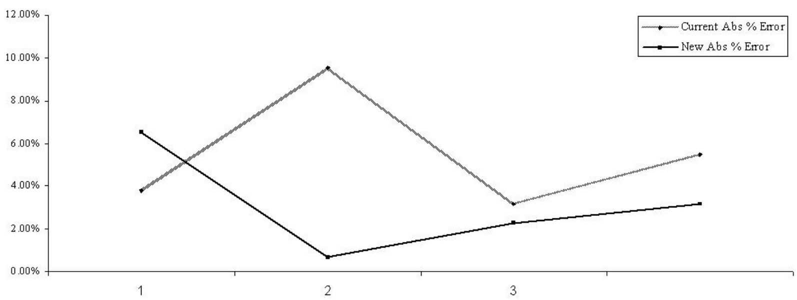

Figure 5.7: Monthly percentage forecast errors of the current method and the proposed method

Current monthly forecast	New monthly forecast	% Improvement
5.50%	3.17%	42.36%

Table 5.8: Monthly Mean Absolute Percentage Errors

From the different forecasting horizons, daily, weekly and monthly, it is evident that the MAPE reduces the longer the period becomes. This is due to the noise levels of the shorter period being absorbed by the longer period. By making use of a standard forecasting method and an improvised distribution method it is evident that significant improvements can be achieved. The author is of the opinion that even better forecasting accuracy is achievable and that this field need to be explored in more detail.

This chapter explained the techniques followed to design a forecasting method that addresses the unique cash demand needs of the retail bank, from the application of the multiplicative Holt-Winters method to the design of an improvised distribution method to accommodate the calendar day and special day effects. The next chapter will discuss the simulation models that were developed to compare different scenarios with each other.

Chapter 6

Decision-Making with Simulation Models

To illustrate the operational and financial impact of the forecasting, inventory and routing methods discussed in the previous chapters, several What-If scenarios were developed and evaluated with Arena simulation software. The simulation models represent a logical model of the current processes and their constraints, i.e. working hours, replenishment times, distances between ATMs etc. The aim of the models is to address questions about the best set-up for the replenishment of cash within the Mthatha area. The benefit of building these simulation models is that one can quickly get answers to many questions about the system by simply manipulating the model attributes and variables. It allows for mistakes, rather than to run a real life pilot of the different scenarios, which is impractical and can potentially cost millions of rands to accomplish.

Detailed dispensing data for December 2009, January 2010, and February 2010 were used to drive the models. The dispensing data of the 18 ATMs for these periods were read into the simulation models from a spreadsheet.

The bank currently uses three vehicles; two dedicated vehicles and one CIT managed vehicle. Each of the dedicated vehicles delivers to a section of the Mthatha area, one delivers to 10 ATMs and the other to five ATMs. The CIT managed vehicle delivers to three remote, but in close proximity to each other,

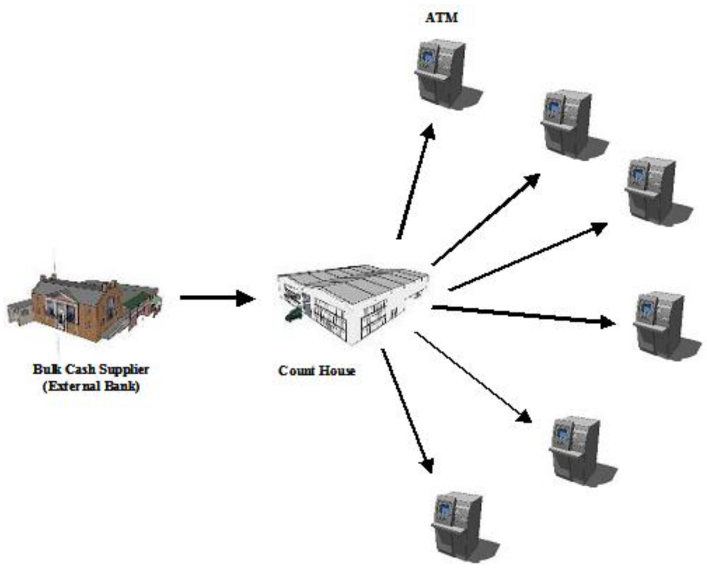

Figure 6.1: Overview of the echelon levels

ATMs. In order to simulate the transportation of cash from the bulk cash supplier to the count house and from the count house to the ATMs it was assumed that each vehicle will travel at 50 km/h. The distances between the ATM locations were obtained from *http://www.saexplorer.co.za/*. The kilometer values are not exact, but will give a good indication of the distances. The symmetrical distance (in kilometers) matrix in Table 6.1 was used.

ATM 19 represents the count house in Mthatha. The rest of the numbers, 1, ..., 18 each represents an ATM.

Figure 6.2 gives the reader an idea as to the geographical layout of the Eastern Cape region. The map still refers to Mthatha as Umtata, as the name only changed recently.

There are a large number of combinations of variables and their values (forecasting frequency, aggregate forecasting or individual forecasting, reorder levels, loading levels, lead times, cash swap or cash add, number of vehicles, transportation methods, etc.) that can be simulated to illustrate the principles of certain

ATM	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19	0	96	12	10	8	173	82	80	116	85	96	118	50	15	144	12	80	116	96
1		0	96	96	96	227	85	174	209	156	106	81	144	96	216	96	174	209	106
2			0	14	15	173	82	80	116	85	96	118	50	9	144	1	80	116	96
3				0	8	173	82	80	116	85	96	118	50	7	144	14	80	116	96
4					0	173	82	80	116	85	96	118	50	11	144	15	80	116	96
5						0	148	131	125	88	268	290	166	173	53	173	131	125	268
6							0	132	163	88	167	162	123	15	144	82	132	163	167
7								0	35	65	170	194	45	80	80	80	1	35	170
8									0	85	201	223	75	116	75	116	35	1	201
9										0	180	204	86	85	59	85	65	85	180
10											0	37	125	96	240	96	170	201	1
11												0	147	118	262	118	194	223	37
12													0	50	117	50	45	75	125
13														0	144	9	80	116	96
14															0	144	80	75	240
15																0	80	116	96
16																	0	35	170
17																		0	201
18																			0

Table 6.1: Symmetrical distance matrix for Mthatha ATMs (kilometers)

decisions and to prove certain concepts. It was decided to only simulate specific combinations of variables and values. This is by no means an exhaustive exercise as only 10 experiments in total were modeled, but will give the reader a very good indication as to the impact of certain inventory management and transportation decisions.

Four main models were applied, which will be explained in detail later in the chapter. Each of the four models consists of sub experiments, where the variables were manipulated to test various What-If scenarios. The reader is referred to Table 6.2 to familiarize him/herself with the high-level structure and differences among the simulation models.

Model 1:

Direct replenishments (DR) are made from the count house to an ATM, triggered by reorder levels. Once a week a replenishment is made from the bulk cash supplier to the count house. The weekly replenishment amount is determined by

Figure 6.2: Eastern Cape region

forecasting the total cash demand of the Mthatha area, for the next period (week). The number of vehicles used for replenishment, is also adjusted, to understand the impact this will have on operations and costing. Within this main structure three experiments are modeled. Each experiment will represent a different reorder level.

Model 2:

Direct replenishments (DR) are made from the count house to an ATM, triggered by reorder levels. Each time an ATM's reorder level is reached, an order is also placed at the bulk cash supplier to replenish the count house. The bulk cash size is determined by the number of ATMs that were replenished the previous day.

Model	Forecasting DR	Forecasting TSP	Forecasting Time	No Forecasting DR	No Forecasting TSP
Model 1					
Experiment 1	•				
Experiment 2	•				
Experiment 3	•				
Model 2					
Experiment 1				•	
Experiment 2				•	
Experiment 3				•	
Model 3					
Experiment 1		•			
Experiment 2			•		
Experiment 3		•			
Model 4					•

Table 6.2: Structure of the simulation experiments

The idea is to replenish the cash at the count house with cash from the bulk cash supplier without using forecasting. The number of vehicles, used for replenishment, is also adjusted, to understand the impact this will have on operations and costing. Within this main structure three experiments are modeled. Each experiment will represent a different reorder level.

Model 3:

Each day at a fixed time, ATM cash levels are reviewed and if the ATM's cash level is below the reorder point, the specific ATM will form part of a set of ATMs that will be replenished the next day. The replenishment tour is scheduled to (1) follow the shortest path (experiment 1) or (2) replenish ATMs that are predicted to run empty first (experiment 2). Once a week a replenishment is made from the bulk cash supplier to the count house. The weekly replenishment amount is determined by forecasting the total cash demand for the Mthatha area, for the next period (week). Experiment one and two are modeled with only two dedicated vehicles. The current vehicle set-up, two dedicated vehicles and one CIT managed vehicle, is also modeled, using the shortest path and reorder levels (experiment 3).

Model 4:

Each day at a fixed time, ATM cash levels are reviewed and if the ATM's cash level is below the reorder point, the specific ATM will form part of a set of ATMs that will be replenished the next day. The replenishment tour is scheduled to follow the shortest path, via the TSP. Once the set of ATMs to be replenished are determined an order is placed for an amount, equal to the amount of the set of ATMs, at the bulk cash supplier. This model only uses two dedicated vehicles and there is no forecasting involved.

A cash-swap method is used in all the models. With a cash-swap the canisters in the ATM are removed and replaced by pre-filled canisters. This eliminates the need to determine the demand for each denomination, as each canister is filled with 2000 notes regardless of the denomination levels in the ATM at the time of replenishment.

Several combinations of denominations can make up an amount requested by the client, e.g. R250 = 2 × R100 and 1 × R50 or R90 = 1 × R50 and 2 × R20. The two main methods used to determine this make-up is (1) least bill picking and (2) equal bill picking. For the Mthatha area the bank makes use of a *least bill picking* method, which will seek to dispense the least number of notes that make up the requested amount. This can be seen as an integer programming problem with (1) the objective being to minimize the number of notes dispensed, (2) the variables being the denominations, R200 (x_1), R100 (x_2), R50 (x_3) and R20 (x_4) and (3) the constraint being the amount requested.

When replenishing, the idea is to replenish the ATM when the cash levels are close to zero. Because of the *least bill picking* method the ATM always have R20 notes left over. For the simulation models it was decided to keep the replenishment amount constant over the three months for each ATM. A canister can take a maximum of 2400 notes, i.e. if it is a R200 canister the value will be R480,000. It was decided to limit the number of notes in each canister to 2000. The main reason for this is that if the quality of the notes in the canister is poor the ATM will struggle with the dispensing action if the canister is loaded to its maximum. When each canister is loaded with 2000 notes the amount in the ATM equates to R740,000, see Table 6.3.

Denomination	**Number of Notes**	**Rand Value**
R200	2000	R400,000
R100	2000	R200,000
R50	2000	R100,000
R20	2000	R40,000
		R740,000

Table 6.3: ATM Replenishment quantity

When ordering cash from the bulk cash supplier the order is placed for the number of notes of each denomination and not for a rand value. To determine the number of notes to order for each denomination, the week's forecasted rand value is divided by the replenishment value of R740,000. This represent the number of ATMs that can be replenished for the week, e.g. R20,000,000 $\div$ R740,000 = 27.027 ATMs. If we continue with the example of R20,000,000 and 27.027 ATMs, this means that 54,054 notes of each denomination will have to be ordered, i.e. R200 $\times$ 54,054 = R10,810,800 and R50 $\times$ 54,054 = R2,702,700, which make up the R20,000,000.

When an ATM reaches its reorder level and cash is ordered from the count house and zero cash is available for delivery, the amount ordered is seen as a shortage, but a delivery will still take place. A counter is created for the count house to indicate the shortages in Rand value. For all the models and experiments it was assumed that an ATM delivery will always take place, even though cash might not be available at the count house. The count house shortage will only serve as an indicator as to which model / experiment will result in the greatest amount of shortages at the count house.

6.1 Current Set-up at the Bank

The ATM planning model that was used by the bank during the three month period (December 2009 to February 2010) produced the following results:

- The total ATM downtime, due to cash planning equates to ca. 19 days, i.e. 221 hours ÷ 12 hours/day. These shortage amounts are not reflected in the data used for this thesis. The data set only contains actual amounts dispensed.
- A total of 742 deliveries were made to ATMs. This takes into consideration the deliveries made by the two dedicated vehicles (640) and the one scheduled vehicle (102).
- A total of 57 deliveries were made from the bulk cash supplier in East London to the count house in Mthatha.
- The total distance traveled by the two dedicated vehicles is 25,530 km. The kilometers traveled seems low when taking into consideration that 640 deliveries were made by these two vehicles. Further analysis to understand why the figure is so low was not done. There is no distance traveled information for the CIT managed vehicle as this vehicle has a fixed cost regardless of the distances traveled.
- The total cash in circulation was R2,038,830,110. At the end of each day all the cash left in the ATMs, count house and in-transit are accumulated to calculate the end-of-day cash balance. The end-of-day cash balances are accumulated to determine the total cash in circulation during the three month period.
- The maximum end-of-day amount that was in circulation equates to R33,369,210.

- The opportunity cost was R335,150. The opportunity cost is calculated by taking the interest rate (6%) that the bank would have earned, had it left the cash in a bank account and dividing this by the number of days in a year (365) to determine the interest rate per day (0.016438%). The daily interest rate is multiplied by each day's end-of-day cash balance to determine the opportunity cost for the day and by accumulating the daily opportunity costs, to obtain the opportunity cost for the three month period.

- The vehicle costs for the two dedicated vehicles were R472,260 (R78,710 per vehicle per month) and for the scheduled vehicle R46,971 (R15,657 per vehicle per month).

- The cost to deliver the cash from the count house to the ATMs was R59,925 (25,530 km - 9,000 km = 16,530 km $\times$ R3.18/km). Each of the two dedicated vehicles are allowed 4,500 km without being charged for it, thus the 9,000 km in the calculation.

- The cost to deliver the bulk cash from the supplier in East London to the count house in Mthatha was R375,500.

- There is also a rebanking cost of R231,293. This is the cost to take the cash returned from the ATMs, after replenishment, to the bank and to deposit it. This cost is eliminated by the research models, as the research models deplete all the cash at the count house and never rebank. A cost that will be added by the research models is the holding and handling cost to store the cash in bulk at the count house for a week.

What is not known from the period under study is how many times did the count house not have cash available to replenish an ATM, and what were the values of these shortages. It is also not possible to quantify the improvement of the total distance traveled from the count house to the ATM when comparing the different experiments with the current set-up, due to the current set-up figures received from the Cash Management department being under suspicion, as it show much fewer kilometers than could reasonably have been traveled.

6.2 Cost Calculations

The cost calculations will be explained in the subsequent sections by making use of some examples. The operational results are important to determine the financial impact.

6.2.1 Opportunity Cost

$$\text{Opportunity Cost} =$$
$$\sum_{i=1}^{n=90}\left([\text{End-of-Day Cash in Circulation}]_i \times \frac{\text{Annual Interest Rate}}{\text{Number of days in the year}}\right)$$
$$= \left([R25,000,144]_1 \times \frac{6\%}{365}\right) + \left([R20,400,899]_2 \times \frac{6\%}{365}\right) + ... + \left([R31,123,000]_{90} \times \frac{6\%}{365}\right)$$

OR

$$\text{Total Cash in Circulation during 90 day period} \times \frac{\text{Annual Interest Rate}}{\text{Number of days in the year}}$$
$$= R2,900,154,574 \times \frac{6\%}{365}$$
$$= R476,738$$

6.2.2 Vehicle Cost

The Vehicle Cost is a fixed cost that will be explained by using the example of two dedicated vehicles and one scheduled Vehicle.

$$\text{Vehicle Cost} =$$
$$(\text{Number of Dedicated Vehicles} \times \text{Cost of Dedicated Vehicle per Month} \times \text{Number of Months})$$
$$+ (\text{Number of Scheduled Vehicles} \times \text{Cost of Scheduled Vehicle per Month} \times \text{Number of Months})$$
$$= (2 \times R78,710 \times 3) + (1 \times R15,657 \times 3)$$
$$= R519,231$$

6.2.3 Count House to ATM Cost

The Count House to ATM cost is the variable cost per kilometer traveled for delivering cash between the count house and the ATMs. The first 4,500 km per dedicated vehicle is free, while there is no charge per kilometer for scheduled vehicles. The cost will be explained by making use of 4 dedicated vehicles.

$$\begin{aligned}
&\text{Count House to ATM Cost} = \\
&[\text{Kilometers traveled during the 90 day period} - (4,500\text{km} \times \text{Number of Vehicles})] \times \text{Cost per Kilometer} \\
&= [25,072\text{km} - (4,500\text{km} \times 4)] \times \text{R}3.18 \\
&= \text{R}22,488
\end{aligned}$$

6.2.4 Bulk Cash Supplier to Count House

$$\begin{aligned}
&\text{Bulk Cash Supplier to Count House} = \\
&\text{Total Bundles} + \text{Total Bags} + \text{Total Insurance} + \text{Total Fixed Cost per Delivery}
\end{aligned}$$

BUNDLES =

$$\sum_{i=1}^{w=13} \left(\left(\left(\frac{\text{Week's forecasted rand value}}{\text{ATM Replenishment Amount}} \right) \times \text{Number of notes loaded in a canister} \right.\right.\right.$$

$$\left.\left.\left. \times \text{Number of denominations} \right) \div \text{Number of notes that make up one bundle} \right) \times \text{Cost per Bundle}$$

$$= \left(\left(\left(\frac{\text{R}20,000,000_1}{\text{R}740,000} \right) \times 2,000 \text{ notes} \times 4 \right) \div 200 \right) \times \text{R}1.53 + \left(\ldots \right.$$

BAGS =

$$\sum_{i=1}^{w=13}\Bigg(\Bigg(\Bigg(\Bigg(\frac{\text{Week's forecasted rand value}}{\text{ATM Replenishment Amount}}\Bigg) \times \text{Number of notes loaded in a canister}$$

$$\times \text{Number of denominations}\Bigg) \div \text{Number of notes that make up one bundle}\Bigg) \div$$

$$\text{Number of bundles in a bag}\Bigg) \times \text{Cost per Bag}$$

$$= \Bigg(\Bigg(\Bigg(\Bigg(\frac{\text{R}20{,}000{,}000_1}{\text{R}740{,}000}\Bigg) \times 2{,}000 \text{ notes} \times 4\Bigg) \div 200\Bigg) \div 13\Bigg) \times \text{R}41.78 + \Bigg(\ldots$$

INSURANCE = R687 per order

FIXED COST PER DELIVERY = R3,945 per order

The results of the different simulation models will now be presented and discussed in detail. The evaluation and summary of these simulation experiments is discussed in Setion 6.7.

6.3 Model One - Forecasting, Reorder Points and Direct Replenishment

Every Monday a bulk cash order is placed, with one of the major banks in East London. The cash is delivered to the count house in Mthatha, on Friday, for the week starting on Saturday and ending on Friday. The amount to be delivered is determined by forecasting the cash demand for next week's period. When an ATM reaches its reorder point it is replenished from the count house.

In this model a $(s,\ Q)$ inventory policy is followed for the ATMs, e.g. (100,000, 740,000). When an ATM's cash level reaches s = R 100,000, an order for Q = R740,000 is placed at the count house. A direct delivery is then made to the ATM. The dedicated vehicle will transport cash to the ATM and return directly to the

	Forecasting			No Forecasting	
Model	DR	TSP	Time	DR	TSP
Model 1					
Experiment 1	•				
Experiment 2	•				
Experiment 3	•				
Model 2					
Experiment 1				•	
Experiment 2				•	
Experiment 3				•	
Model 3					
Experiment 1		•			
Experiment 2			•		
Experiment 3		•			
Model 4					•

Table 6.4: Perspective of Experiments - Model 1

count house. Because the cash-swap is used instead of cash-add, a fixed quantity of cash is ordered and the cash left in the ATM is returned to the count house float. When an ATM is replenished the cash on hand in the ATM is removed and replaced by R740,000 or four canisters containing 2000 notes per canister (R200, R100, R50 and R20). The three experiments were modeled with ATM reorder points of 100,000, 300,000 and 500,000. Each ATM in the Mthatha area have exactly the same reorder point, the reorder points are not ATM specific. For each of the experiments the number of dedicated vehicles being used, was adjusted, from 2 to 4 to 6 to 8 to 10 and 20. The vehicles are not allocated to specific ATMs, any vehicle can deliver to any ATM.

6.3.1 Experiment 1 - Reorder point = R100,000

For Experiment 1, a reorder point of R100,000 is used and the dedicated vehicles adjusted from 2 to 10 and 20. Only dedicated vehicles are used in this experiment. The results of the simulation experiment are shown in Table 6.5.

	Vehicles						
	2	**4**	**6**	**8**	**10**	**20**	**Current Set-up**
ATM Shortages (R)	50,240,140	33,275,900	32,842,410	32,515,300	30,085,850	30,044,090	0
Count House Shortage (R)	35,266	675,136	596,156	683,246	683,246	683,246	0
Deliveries - Count House to ATM	323	346	346	345	348	349	742
Deliveries - Bulk Cash Supplier to Count House	13	13	13	13	13	13	57
Total Distance Traveled (km)	23,756	25,072	25,088	25,011	25,330	25,330	25,530
Total Cash in Circulation (R)	3,572,819,784	3,003,141,064	2,968,623,764	2,664,218,866	2,900,154,574	2,885,410,024	2,038,830,110
Max End-of-Day Cash in Circulation (R)	75,744,964	61,486,884	61,732,844	54,329,334	61,142,944	59,544,774	33,369,210
COSTS							
Opportunity Cost (R)	587,313	493,667	487,992	437,953	476,738	474,314	335,150
Vehicle Cost (R)	472,260	944,520	1,416,780	1,889,040	2,361,300	4,722,600	519,231
Count House to ATM Cost (R)	46,924	22,488	0	0	0	0	59,925
Bulk Cash Supplier to Count House Cost (R)	97,894	97,894	97,894	97,894	97,894	97,894	375,500
Rebanking Cost (R)	0	0	0	0	0	0	231,293

Table 6.5: Simulation Results for Model 1, Experiment 1 - R100,000 reorder point

It is evident that there is no operational difference when increasing the number of vehicles, from 10 vehicles onwards, as can be seen in Table 6.5 when looking at the values of 10 vehicles and 20 vehicles. The only significant difference is with the vehicle cost, where each extra vehicle comes at a fixed cost.

Referring to Table 6.5 the results of Model 1, Experiment 1 in comparison with the current set-up is discussed below:

- It is clear that regardless of the number of vehicles, that ATM shortages will occur when using a reorder point of R100,000. The ATM shortage values may appear large, but the situation would not have been that dire if there where no anomalies in the dispensing data used, which resulted in unusual large or unusual small cash demands on otherwise normal days.

- There are times when an ATM will request cash from the count house while the count house will not have enough cash available. This can be the result of the weekly forecast error. The count house shortage increases as the number of vehicles increases due to the vehicles being able to replenish ATMs more often.

- The deliveries from the count house to the ATM lead to an improvement of over 50%. With two vehicles a reduction of 56% is achieved, from 742 to

323 deliveries, with 10 vehicles - 53%, from 742 to 348 and with 20 vehicles - 53%, from 742 to 349.

- The deliveries from the bulk cash supplier to the count house are reduced by 77%, from 57 to 13. This is due to deliveries, in the current set-up, being made when cash is required, whereas with Model 1, Experiment 1, bulk cash is delivered in a more structured manner, once a week.

- The total distance traveled by the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled for Model 1 Experiment 1 (looking at 10 vehicles) is 25,330 km for 348 deliveries. It is evident from the above that the total distance traveled due to the current set-up should be significantly greater than the distance traveled due to Model 1, Experiment 1.

- The total cash in circulation increases due to the cash being ordered in bulk for the week and held in a float at the count house, whereas currently there is no float.

- The maximum end-of-day cash in circulation increases, because of a float being held at the count house.

- The opportunity cost increases, as there is more cash in circulation due to the float at the count house.

- The vehicle cost increases with each vehicle being added. In the current set-up it costs R519,231 for two dedicated vehicles and one CIT managed vehicle. The current set-up is only improved upon when two vehicles are used, i.e. viz R472,260.

- The delivery cost from the count house to the ATM, depending on the number of vehicles used, can be eliminated. The first 4,500 km is free for dedicated vehicles, thus when using 10 vehicles, 45,000 km is free, which is more than the distance traveled in Model 1, Experiment 1 for 10 vehicles.

- The delivery cost from the bulk cash supplier to the count house is reduced by 74%, from R375,500 to R97,894.

- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

Model 1, Experiment 1 is not a viable option mainly due to the large number of ATM shortages, opportunity costs and the vehicle costs.

6.3.2 Experiment 2 - Reorder point = R300,000

For Model 1, Experiment 2, a reorder point of R300,000 is used and the dedicated vehicles adjusted from 2 to 10 and 20. Only dedicated vehicles are used in this experiment. The results of the simulation experiment are shown in Table 6.6.

	Vehicles						
	2	4	6	8	10	20	Current Set-up
ATM Shortages (R)	22,388,710	6,992,480	5,506,870	5,757,450	5,687,380	5,655,680	0
Count House Shortage (R)	7,269,076	9,537,088	10,195,123	11,504,478	10,343,793	10,827,988	0
Deliveries - Count House to ATM	404	450	461	459	460	459	742
Deliveries - Bulk Cash Supplier to Count House	13	13	13	13	13	13	57
Total Distance Traveled (km)	29,700	32,509	33,605	33,307	33,559	33,307	25,530
Total Cash in Circulation (R)	2,820,412,004	2,408,472,100	2,355,250,416	2,479,181,805	2,416,943,865	2,451,214,215	2,038,830,110
Max End-of-Day Cash in Circulation (R)	58,918,454	47,345,126	47,940,641	49,223,766	48,372,771	47,968,686	33,369,210
COSTS							
Opportunity Cost (R)	463,629	395,913	387,164	407,536	397,306	402,939	335,150
Vehicle Cost (R)	472,260	944,520	1,416,780	1,889,040	2,361,300	4,722,600	519,231
Count House to ATM Cost (R)	65,826	46,138	21,003	0	0	0	59,925
Bulk Cash Supplier to Count House Cost (R)	97,894	97,894	97,894	97,894	97,894	97,894	375,500
Rebanking Cost (R)	0	0	0	0	0	0	231,293

Table 6.6: Simulation Results for Model 1, Experiment 2 - R300,000 reorder point

The more vehicles being used the better the operational values become, but at a cost, due to the fixed cost of each extra vehicle.

Referring to Table 6.6 the results of Model 1, Experiment 2 in comparison with the current set-up are discussed below:

- The ATM shortages become less when more vehicles are employed, using a reorder point of R300,000. The vehicles have a longer time period to respond to an ATM's request for cash, and can replenish ATMs more times than in Model 1, Experiment 1 (R100,000).

- There are times when an ATM will request cash from the count house while the count house will not have enough cash available. This can be the result of the weekly forecast error. The count house shortage increases as the number of vehicles increases. As the ATM shortages become less, the count house shortages increase. Overall the total shortages are less than Model 1, Experiment 1.

- The deliveries from the count house to the ATM lead to an improvement of over 35%. With two vehicles an improvement of 45% is achieved, from 742 to 404 deliveries, with 10 vehicles - 38%, from 742 to 460 and with 20 vehicles - 38%, from 742 to 459.

- The deliveries from the bulk cash supplier to the count house are improved by 77%, from 57 to 13 deliveries. This is due to deliveries in the current set-up being made when cash is required, whereas with Model 1, Experiment 2, bulk cash is delivered in a more structured manner, i.e. viz once a week.

- The total distance traveled due to the current set-up is 25,530 for a total of 742 deliveries, whereas the total distance traveled for Model 1, Experiment 2 (looking at 10 vehicles) is 33,559 km for 460 deliveries. It is evident from the above that the total distance traveled due to the current set-up should be significantly greater than the distance traveled due to Model 1, Experiment 2, and therefore an improvement is achieved.

- The total cash in circulation increases due to the cash being ordered in bulk for the week and held in a float at the count house, whereas currently there is no float.

- The maximum end-of-day cash in circulation increases, also because of a float being held at the count house.

- The opportunity cost increases, as there is more cash in circulation due to the float at the count house.

- The vehicle cost increases with each vehicle being added. In the current set-up it costs R519,231 for two dedicated vehicles and one CIT managed vehicle. This is only improved upon when two vehicles are used, i.e. R472,260.

- The delivery cost from the count house to the ATM, depending on the number of vehicles used, can be eliminated. The first 4,500 km is free for dedicated vehicles, thus when using 10 vehicles, 45,000 km is free, which is more than the distance traveled in Model 1, Experiment 2 for 10 vehicles.
- The delivery cost from the bulk cash supplier to the count house is reduced by 74%, from R375,500 to R97,894.
- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

Model 1, Experiment 2 is not a viable option mainly due to the large number of count house shortages and the vehicle costs.

6.3.3 Experiment 3 - Reorder point = R500,000

For Model 1, Experiment 3, a reorder point of R500,000 is used and the dedicated vehicles adjusted from 2 to 10 and 20. Only dedicated vehicles are used in this experiment. The results of the simulation experiment are shown in Table 6.7.

	Vehicles						
	2	**4**	**6**	**8**	**10**	**20**	**Current Set-up**
ATM Shortages (R)	13,202,950	991,740	745,830	328,470	491,780	484,020	0
Count House Shortage (R)	11,027,376	17,260,583	17,281,273	17,580,628	17,344,828	18,046,378	0
Deliveries - Count House to ATM	476	638	668	681	686	688	742
Deliveries - Bulk Cash Supplier to Count House	13	13	13	13	13	13	57
Total Distance Traveled (km)	35,385	46,281	47,934	48,756	49,236	49,417	25,530
Total Cash in Circulation (R)	2,503,697,210	2,506,214,285	2,460,339,182	2,552,432,881	2,516,132,301	2,553,314,929	2,038,830,110
Max End-of-Day Cash in Circulation (R)	52,526,324	49,322,726	48,648,811	47,326,616	47,254,126	49,427,916	33,369,210
COSTS							
Opportunity Cost (R)	411,567	411,980	404,439	419,578	413,611	419,723	335,150
Vehicle Cost (R)	472,260	944,520	1,416,780	1,889,040	2,361,300	4,722,600	519,231
Count House to ATM Cost (R)	83,904	89,933	66,570	40,564	13,470	0	59,925
Bulk Cash Supplier to Count House Cost (R)	97,894	97,894	97,894	97,894	97,894	97,894	375,500
Rebanking Cost (R)	0	0	0	0	0	0	231,293

Table 6.7: Simulation Results for Model 1, Experiment 3 - R500,000 reorder point

Referring to Table 6.7 the results of Model 1, Experiment 3 in comparison with the current set-up is discussed below:

- The ATM shortages become less when more vehicles are employed, using a reorder point of R500,000. The vehicles have a longer time period to respond to an ATM's request for cash, and can replenish ATMs more times than in Model 1, Experiment 1 (R100,000) and Model 1, Experiment 2 (R300,000). When employing 10 vehicles and more at a reorder point of R500,000 the ATM shortages almost become non-existent.

- There are times when an ATM will request cash from the count house while the count house will not have enough cash available. This can be the result of the weekly forecast error. The count house shortage increases as the number of vehicles increases. As the ATM shortages become less, the count house shortages increase. Overall the total shortages of Model 1, Experiment 2 is the least.

- The deliveries from the count house to the ATM lead to an improvement of over 5%. With two vehicles reduction of 35% is achieved, from 742 to 476 deliveries, with 10 vehicles - 7%, from 742 to 686 and with 20 vehicles - 7%, from 742 to 688.

- The deliveries from the bulk cash supplier to the count house are improved by 77%, from 57 to 13 deliveries. This is due to deliveries in the current set-up being made when cash is required, whereas with Model 1, Experiment 3, bulk cash is delivered in a more structured manner, i.e. once a week.

- The total distance traveled due to the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled due to Model 1, Experiment 3 (looking at 10 vehicles) is 49,236 km for 686 deliveries. It is evident from the above that the total distance traveled due to the current set-up should be significantly more than the distance traveled due to Model 1, Experiment 3, and therefore an improvement is achieved.

- The total cash in circulation increases due to the cash being ordered in bulk for the week and held in a float at the count house, whereas currently there is no float.

- The maximum end-of-day cash in circulation increases, also because of a float being held at the count house.
- The opportunity cost increases, as there is more cash in circulation due to the float at the count house.
- The vehicle cost increases with each vehicle being added. In the current set-up it costs R519,231 for two dedicated vehicles and one CIT managed vehicle. This is only improved upon when two vehicles are used, i.e. R472,260.
- The delivery cost from the count house to the ATM, depending on the number of vehicles used, can be eliminated. The first 4,500 km is free for dedicated vehicles, thus when using 10 vehicles, 45,000 km is free, which leaves 4,236 km or R13,470, compared to the distance in the current set-up of 59,925 km.
- The delivery cost from the bulk cash supplier to the count house is reduced by 74%, from R375,500 to R97,894.
- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

Model 1, Experiment 3 is not a viable option mainly due to the large amount of count house shortages and the vehicle costs.

Figure 6.3 illustrates the relationship among Model 1, Experiment 1, 2 and 3 based on number of vehicles, reorder point and ATM shortages. The graph highlights the fact that ATM shortage can be reduced by increasing the reorder point and number of vehicles. Looking at the R500,000 reorder point section there is no benefit in reducing the ATM shortages when employing more than six vehicles.

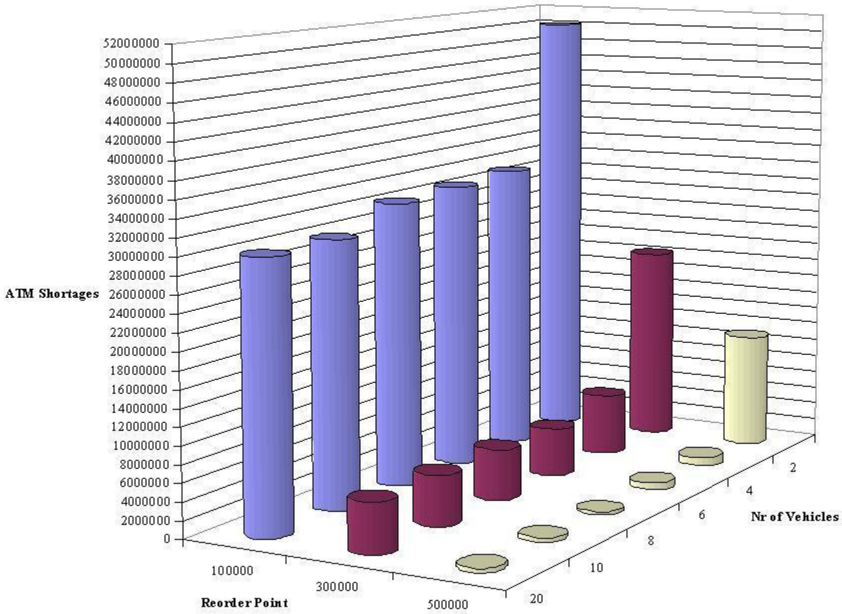

Figure 6.3: Model 1 - Relationship between the number of vehicles, reorder points and ATM shortages

6.4 Model Two - No Forecasting, Reorder Points and Direct Replenishment

The replenishment policy of model 2 is the same as in model 1. A (s,Q) e.g. (100,000, 740,000), inventory policy is followed with direct replenishment. The difference is that this model does not make use of forecasting. Whenever an ATM reaches its reorder point it triggers an order for cash at the count house and also at the bulk cash supplier. The ATM order is replenished as soon as the preparation of the cash at the count house is completed. A direct delivery is then made to the ATM. The daily orders received at the bulk cash supplier are accumulated into one big order that is prepared and shipped all at once the next day.

The model is defaulted with cash at the count house equal to two times the cash required per ATM, thus one ATM will start with R740,000 $\times$ 2 = R1,480,000 at the count house and R740,000 in the ATM. When replenishing from the bulk

	Forecasting			No Forecasting	
Model	DR	TSP	Time	DR	TSP
Model 1					
Experiment 1	•				
Experiment 2	•				
Experiment 3	•				
Model 2					
Experiment 1				•	
Experiment 2				•	
Experiment 3				•	
Model 3					
Experiment 1		•			
Experiment 2			•		
Experiment 3		•			
Model 4					•

Table 6.8: Perspective of Experiments - Model 2

cash supplier only the cash used to replenish an ATM is replenished at the count house, i.e. R740,000.

It must be noted that for this model, the cost of delivery from the bulk cash supplier to the count house was not calculated. It is expected to be nearly the same as the current set-up, because the number of deliveries are almost the same.

6.4.1 Experiment 1 - Reorder point = R100,000

For Model 2, Experiment 1, a reorder point of R100,000 is used and the dedicated vehicles adjusted from 2 to 10 and 20. Only dedicated vehicles are used in this experiment. The results of the simulation experiment are shown in Table 6.9. No forecasting is used in this experiment.

Referring to Table 6.9 the results of Model 2, Experiment 1 in comparison with the current set-up are discussed below:

	Vehicles						
	2	**4**	**6**	**8**	**10**	**20**	**Current Set-up**
ATM Shortages (R)	50,240,140	33,278,210	28,939,690	31,017,130	30,085,850	30,044,090	0
Count House Shortage (R)	0	0	0	0	0	0	0
Deliveries - Count House to ATM	323	346	348	350	348	349	742
Deliveries - Bulk Cash Supplier to Count House	50	54	52	52	53	52	57
Total Distance Traveled (km)	23,756	25,072	25,196	25,553	25,330	25,338	25,530
Total Cash in Circulation (R)	2,540,907,980	2,584,064,510	2,583,862,090	2,593,684,150	2,583,871,980	2,595,732,750	2,038,830,110
Max End-of-Day Cash in Circulation (R)	37,291,070	36,754,230	37,710,670	38,627,530	38,065,640	37,966,970	33,369,210
COSTS							
Opportunity Cost (R)	417,684	424,777	424.744	426,359	424,746	426,696	335,150
Vehicle Cost (R)	472,260	944,520	1,416,780	1,889,040	2,361,300	4,722,600	519,231
Count House to ATM Cost (R)	46,924	7,072	0	0	0	0	59,925
Rebanking Cost (R)	0	0	0	0	0	0	231,293

Table 6.9: Simulation Results for Model 2, Experiment 1 - R100,000 reorder point

- It is clear that regardless of the number of vehicles, that ATM shortages will occur when using a reorder point of R100,000. The ATM shortage values may appear large, but the situation would not have been that dire if there where no anomalies in the dispensing data used, which resulted in unusual large or unusual small cash demands on otherwise normal days. The accuracy of the weekly forecast will also play a part in the ATM shortages.

- The count house shortage is zero due to safety stock being held at the count house float and cash being delivered from the bulk cash supplier in East London to the Mthatha count house in short intervals.

- The deliveries from the count house to the ATM lead to a reduction of over 50%. With two vehicles an improvement of 56% is achieved, from 742 to 323 deliveries, with 10 vehicles - 53%, from 742 to 348 and with 20 vehicles - 53%, from 742 to 349.

- The deliveries from the bulk cash supplier to the count house are nearly the same as in the current set-up, due to cash being ordered from the bulk cash supplier when required, which is the same principle followed in the current set-up.

- The total distance traveled due to the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled for Model 2, Experiment 1 (looking at 10 vehicles) is 25,330 km for 348 deliveries. It is evident from the above that the total distance traveled due to the current set-up should be significantly greater than the distance traveled due to Model 2, Experiment 1, and therefore an improvement is achieved.

- The total cash in circulation is less than in Model 1, Experiment 1. This can be the result of a combination between the reorder point being so low and cash only being ordered from the bulk cash supplier when required as opposed to cash being ordered for a week. Because of the reorder point being so low, the bulk cash being ordered will be less than the bulk cash being ordered for a week. At a certain reorder point this turns around and more cash will be in circulation than with a weekly order.

- The maximum end-of-day cash in circulation, R37 million, compares favorably with the current set-up in which R33 million is in circulation. This is also much lower than in Model 1, Experiment 1.

- The opportunity cost increases, as there is more cash in circulation due to the float at the count house.

- The vehicle cost increases with each vehicle being added. In the current set-up it costs R519,231 for two dedicated vehicles and one CIT managed vehicle. This is only improved upon when two vehicles are used, i.e. R472,260.

- The delivery cost from the count house to the ATM, depending on the number of vehicles used, can be eliminated. The first 4,500 km is free for dedicated vehicles, thus when using 10 vehicles, 45,000 km is free, which is more than the distance traveled due to Model 2, Experiment 1 for 10 vehicles.

- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

The major difference between Model 1, Experiment 1 and Model 2, Experiment 1 is the number of deliveries from the bulk cash supplier to the count house, the total cash in circulation and the maximum end-of-day cash in circulation, which are all less than the values in Model 1. Model 2 produces substantially more deliveries. It would seem that forecasting is not a differentiating factor between the models, and that without forecasting the operational figures look better than with forecasting, excluding deliveries from the bulk cash supplier.

6.4.2 Experiment 2 - Reorder point = R300,000

For Model 2, Experiment 2, a reorder point of R300,000 is used and the dedicated vehicles adjusted from 2 to 10 and 20. Only dedicated vehicles are used in this experiment. The results of the simulation experiment are shown in Table 6.10. No forecasting is used in this experiment.

	Vehicles						
	2	**4**	**6**	**8**	**10**	**20**	**Current Set-up**
ATM Shortages (R)	22,388,710	6,897,310	5,520,880	5,757,340	5,687,380	5,655,680	0
Count House Shortage (R)	0	0	0	0	0	0	0
Deliveries - Count House to ATM	404	451	461	459	460	459	742
Deliveries - Bulk Cash Supplier to Count House	51	53	53	55	55	55	57
Total Distance Traveled (km)	29,700	32,758	33,605	33,307	33,559	33,307	25,530
Total Cash in Circulation (R)	3,719,876,100	4,529,141,930	4,764,473,350	4,764,743,550	4,749,298,130	4,732,218,230	2,038,830,110
Max End-of-Day Cash in Circulation (R)	66,752,530	82,808,110	88,417,720	88,539,330	87,979,000	87,107,520	33,369,210
COSTS							
Opportunity Cost (R)	611,486	744,516	783,201	783,245	780,707	777,899	335,150
Vehicle Cost (R)	472,260	944,520	1,416,780	1,889,040	2,361,300	4,722,600	519,231
Count House to ATM Cost (R)	64,850	14,758	6,605	0	0	0	59,925
Rebanking Cost (R)	0	0	0	0	0	0	231,293

Table 6.10: Simulation Results for Model 2, Experiment 2 - R300,000 reorder point

Referring to Table 6.10 the results of Model 2, Experiment 2 in comparison with the current set-up are discussed below:

- The ATM shortages become less when more vehicles are employed, using a reorder point of R300,000. The vehicles have a longer time period to respond to an ATM's request for cash, and can replenish ATMs more times than in Model 2, Experiment 1 (R100,000). The ATM shortages are the same as in Model 1, Experiment 2, because in both experiments the assumption was made, that regardless if there is cash available or not at the count house a delivery will be made to an ATM requesting cash, and that a count house counter will be held that accumulate these shortages and report on it.

- The count house shortage is zero due to safety stock being held at the count house float and cash being delivered from the bulk cash supplier in East London to the Mthatha count house in short intervals.
- The deliveries from the count house to the ATM lead to an improvement of over 35%. With two vehicles a reduction of 45% is achieved, from 742 to 404 deliveries, with 10 vehicles - 38%, from 742 to 460 and with 20 vehicles - 38%, from 742 to 459.
- The deliveries from the bulk cash supplier to the count house are nearly the same as in the current set-up, due to cash being ordered from the bulk cash supplier when required, which is the same principle as followed in the current set-up.
- The total distance traveled due to the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled for Model 2, Experiment 2 (looking at 10 vehicles) is 33,559 km for 460 deliveries. It is evident from the above that the total distance traveled due to the current set-up should be significantly greater than the distance traveled by Model 2, Experiment 1, and therefore an improvement is achieved.
- The total cash in circulation is greater than in Model 1 - Experiment 2, and Model 2 - Experiment 1. This is due to the reorder point and cash being ordered from the bulk cash supplier when required as opposed to cash being ordered for a week. At a reorder point of R300,000 more bulk cash will be ordered than when weekly orders are placed.
- The maximum end-of-day cash in circulation increases as more bulk cash are being held at the count house float, and is greater than that of Model 1 - Experiment 2.
- The opportunity cost increases, as there is more cash in circulation due to the reorder point and ordering policy.
- The vehicle cost increases with each vehicle being added. In the current set-up it costs R519,231 for two dedicated vehicles and one CIT managed vehicle. This is only improved upon when two vehicles are used, i.e. R472,260.

- The delivery cost from the count house to the ATM, depending on the number of vehicles used, can be eliminated. The first 4,500 km is free for dedicated vehicles, thus when using 10 vehicles, 45,000 km is free, which is more than the distance traveled due to Model 2, Experiment 2 for 10 vehicles.

- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

The major difference between Model 1, Experiment 2 and Model 2, Experiment 2 is the number of deliveries from the bulk cash supplier to the count house, the cash in circulation and the opportunity costs. Model 2 produces substantially more bulk cash deliveries. Making use of an order policy where cash at the count house is replenished the next day by cash from bulk cash supplier (no forecasting), increases the cash in circulation which leads to an increase in the opportunity costs. The forecasting model, Model 1, produces better results than the non-forecasting model, Model 2, when the reorder point increases.

6.4.3 Experiment 3 - Reorder point = R500,000

For Model 2, Experiment 3, a reorder point of R500,000 is used and the dedicated vehicles adjusted from 2 to 10 and 20. Only dedicated vehicles are used in this experiment. The results of the simulation experiment are shown in Table 6.11. No forecasting is used in this experiment.

Referring to Table 6.11 the results of Model 2, Experiment 3 in comparison with the current set-up are discussed below:

- The ATM shortages become less when more vehicles are employed, using a reorder point of R500,000. The vehicles have a longer time period to respond to an ATM's request for cash, and can replenish ATMs more times than in Model 2, Experiment 1 (R100,000) and Model 2, Experiment 2

	Vehicles						
	2	**4**	**6**	**8**	**10**	**20**	**Current Set-up**
ATM Shortages (R)	13,202,950	1,015,640	393,600	491,780	484,020	0	
Count House Shortage (R)	0	0	0	0	0	0	0
Deliveries - Count House to ATM	476	641	670	683	686	688	742
Deliveries - Bulk Cash Supplier to Count House	52	55	57	57	57	57	57
Total Distance Traveled (km)	35,385	46,470	48,067	48,880	49,236	49,417	25,530
Total Cash in Circulation (R)	5,450,530,170	9,801,454,480	10,897,704,370	11,457,673.410	11,489,304,580	11,479,494,200	2,038,830,110
Max End-of-Day Cash in Circulation (R)	105,875,930	204,779,060	227,211,680	235,631,670	237,686,340	236,185,110	33,369,210
COSTS							
Opportunity Cost (R)	895,978	1,611,198	1,791,403	1,883,453	1,888,653	1,887,040	335,150
Vehicle Cost (R)	472,260	944,520	1,416,780	1,889,040	2,361,300	4,722,600	519,231
Count House to ATM Cost (R)	83,904	28,470	21,067	12,880	13,470	0	59,925
Rebanking Cost (R)	0	0	0	0	0	0	231,293

Table 6.11: Simulation Results for Model 2, Experiment 3 - R500,000 reorder point

(R300,000). When employing 10 vehicles and more at a reorder point of R500,000 the ATM shortages almost become non-existent. The ATM shortages are the same as in Model 1, Experiment 3, because in both experiments the assumption was made, that regardless if there is cash available or not at the count house a delivery will be made to an ATM requesting cash, and that a count house counter will be held that accumulate these shortages and report on it.

- The count house shortage is zero due to safety stock being held at the count house float and cash being delivered from the bulk cash supplier in East London to the Mthatha count house in short intervals.

- The deliveries from the count house to the ATM lead to an improvement of over 5%. With two vehicles a reduction of 35% is achieved, from 742 to 476 deliveries, with 10 vehicles - 7%, from 742 to 686 and with 20 vehicles - 7%, from 742 to 688.

- The deliveries from the bulk cash supplier to the count house are nearly the same as in the current set-up, due to cash being ordered from the bulk cash supplier when required, which is the same principle as followed in the current set-up.

- The total distance traveled due to the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled for Model 2, Experiment 3 (looking at 10 vehicles) is 49,236 km for 688 deliveries. It is evident from the above that the total distance traveled due to the current set-up should be significantly greater than the distance traveled due to Model 2, Experiment 3, and therefore an improvement is achieved.

- The total cash in circulation is greater than Model 1, Experiment 3, and Model 2, Experiment 2. This is due to the reorder point and cash being ordered from the bulk cash supplier when required as opposed to cash being ordered for a week. At a reorder point of R500,000 more bulk cash will be ordered than when weekly orders are placed.
- The maximum end-of-day cash in circulation increases as more bulk cash are being held at the count house float, and is greater than that of Model 1, Experiment 3.
- The opportunity cost increases, as there is more cash in circulation due to the reorder point and ordering policy.
- The vehicle cost increases with each vehicle being added. In the current set-up it costs R519,231 for two dedicated vehicles and one CIT managed vehicle. This is only improved upon when two vehicles are used, i.e. R472,260.
- The delivery cost from the count house to the ATM, depending on the number of vehicles used, can be eliminated. The first 4,500 km is free for dedicated vehicles, thus when using 10 vehicles, 45,000 km is free, which leaves 4,236 km or R13,470, compared to the cost in the current set-up of 59,925.
- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

The major difference between Model 1, Experiment 3 and Model 2, Experiment 3 is the number of deliveries from the bulk cash supplier to the count house, the cash in circulation and the opportunity costs. Model 2 has substantially more bulk cash deliveries. Making use of an order policy where cash at the count house is replenished the next day by cash from bulk cash supplier (no forecasting), increases the cash in circulation which leads to an increase in the opportunity costs. The forecasting model, Model 1, produces better results than the non-forecasting model, Model 2, when the reorder point increases.

Figure 6.4 illustrates the relationship among Model 2, Experiment 1, 2 and 3 based on number of vehicles, reorder point and ATM shortages. The graph highlights the fact that ATM shortage can be reduced by increasing the reorder point and number of vehicles. Looking at the R500,000 reorder point section there is no benefit in reducing the ATM shortages when employing more than eight vehicles.

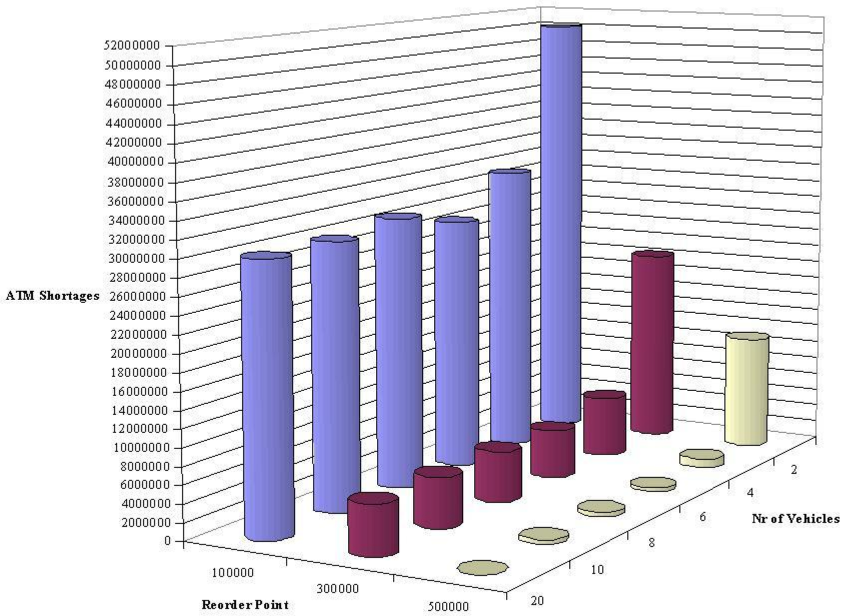

Figure 6.4: Model 2 - Relationship among the number of vehicles, reorder points and ATM shortages

	Forecasting			No Forecasting	
Model	DR	TSP	Time	DR	TSP
Model 1					
Experiment 1	•				
Experiment 2	•				
Experiment 3	•				
Model 2					
Experiment 1				•	
Experiment 2				•	
Experiment 3				•	
Model 3					
Experiment 1		•			
Experiment 2			•		
Experiment 3		•			
Model 4					•

Table 6.12: Perspective of Experiments - Model 3

6.5 Model Three - Forecasting and TSP / Time

The weekly forecast is conducted the same way as in Model 1, with a difference in the replenishment of the ATMs. Whereas in the first model direct replenishment was used this model makes use of routing the delivery vehicles. The reorder points are no longer being kept constant over the whole three month period, but are made dynamic. Two reorder point strategies were simulated:

1. *Monthly reorder points:* Monthly reorder points were determined for each of the three months, December 2009; January 2010 and February 2010. To calculate the reorder points the daily forecasted demand for the Mthatha area as a whole, was averaged for each month, e.g. R1,000,000 for 1 December 2009, R1,050,000 for 2 December 2009, ..., R2,000,000 for 31 December 2009, were averaged to produce an average daily dispensing demand for December 2009. The month's daily average demand was then multiplied by a safety factor of two to calculate the reorder point for the month. A safety factor of 2 was used to allow two days of replenishment. For example it

Month	Average Daily Dispensing	Reorder Point × 2	Reorder point rounded
December 2009	R210,435	R420,871	R430,000
January 2010	R192,246	R384,792	R390,000
February 2010	R189,367	R378,734	R380,000

Table 6.13: Monthly Reorder Points for the Mthata Area

can happen that an ATM reaches its reorder point at 10:00 in the morning, but it will only be picked up at 12:00 on the planning report and due to the routing being followed, the ATM might only be replenished at 15:00 the next day. The monthly reorder point was then rounded up to the nearest R10,000 to work with a rounded value, see Table 6.13.

2. *Interval reorder points per ATM:* The interval reorder points were determined by splitting each month, per ATM, into three intervals: beginning of the month (1^{st} to 12^{th}), middle of the month (13^{th} to 22^{nd}) and end of the month (23^{rd} to end of the month). An interval of three was chosen as each of these periods follows a similar pattern, where at the beginning of the month the demand is much lower then the middle and later part of the month, in the middle of the month the demand tends to increase again up to the 22^{nd} and then slows down again towards the end of the month. The interval reorder points per ATM was simulated to illustrate the effect that a more dynamic reorder point will have on the overall operations. The daily forecasted demand were split into the three intervals and each interval were averaged. This was done for each ATM, whereas the monthly reorder points were done for all the ATMs. The interval reorder point of each ATM was then multiplied by a safety factor of 2 and rounded up to the nearest R10,000 to work with a rounded value, see Table 6.14.

A (t, s, Q) inventory policy is followed for the replenishment of the ATMs in this model. The simulation model was designed to generate a report, every day at 12:00, of the ATM cash levels at this time, highlighting those ATMs that are below their reorder points.

	December 2009			January 2010			February 2010		
ATM	1^{st} to 12^{th}	13^{th} to 22^{nd}	3^{rd} to month end	1^{st} to 12^{th}	13^{th} to 22^{nd}	3^{rd} to month end	1^{st} to 12^{th}	13^{th} to 22^{nd}	3^{rd} to month end
1	R370,000	R530,000	R440,000	R370,000	R510,000	R480,000	R270,000	R540,000	R610,000
2	R400,000	R590,000	R510,000	R350,000	R520,000	R470,000	R310,000	R520,000	R590,000
3	R290,000	R460,000	R370,000	R230,000	R430,000	R370,000	R240,000	R360,000	R350,000
4	R390,000	R530,000	R440,000	R330,000	R480,000	R560,000	R310,000	R540,000	R520,000
5	R280,000	R410,000	R460,000	R320,000	R290,000	R290,000	R210,000	R330,000	R410,000
6	R290,000	R380,000	R350,000	R280,000	R360,000	R370,000	R210,000	R360,000	R370,000
7	R370,000	R590,000	R440,000	R360,000	R500,000	R470,000	R310,000	R530,000	R520,000
8	R340,000	R540,000	R430,000	R340,000	R520,000	R460,000	R290,000	R490,000	R490,000
9	R480,000	R790,000	R600,000	R470,000	R650,000	R550,000	R380,000	R600,000	R610,000
10	R340,000	R540,000	R460,000	R310,000	R380,000	R470,000	R240,000	R420,000	R430,000
11	R230,000	R360,000	R390,000	R210,000	R340,000	R360,000	R220,000	R370,000	R410,000
12	R320,000	R320,000	R410,000	R340,000	R270,000	R350,000	R260,000	R250,000	R340,000
13	R440,000	R690,000	R590,000	R420,000	R650,000	R620,000	R370,000	R620,000	R630,000
14	R320,000	R380,000	R450,000	R200,000	R200,000	R170,000	R340,000	R480,000	R590,000
15	R400,000	R590,000	R510,000	R350,000	R520,000	R470,000	R310,000	R520,000	R590,000
16	R370,000	R590,000	R440,000	R360,000	R500,000	R470,000	R310,000	R530,000	R520,000
17	R340,000	R540,000	R430,000	R340,000	R520,000	R460,000	R290,000	R490,000	R490,000
18	R280,000	R410,000	R460,000	R320,000	R290,000	R290,000	R210,000	R330,000	R410,000

Table 6.14: Interval Reorder Points per ATM

Every ATM is allocated to a vehicle. Model 3, Experiment 1 and 2 make use of two dedicated vehicles, whereas Model 3, Experiment 3 makes use of two dedicated vehicles and one scheduled vehicle. Each vehicle is allocated specific ATMs based on the geographical locations of the ATMs. The vehicles are identical in the capacity and speed at which it can make deliveries.

The ATMs that are below their reorder points are then allocated to a specific vehicle. The ATMs allocated to a vehicle (geographical area) is fed into LINGO to determine the shortest path to travel from the count house to each ATM and returning to the count house again. The traveling salesman problem algorithm is used to determine the shortest path. The sequence of ATMs to visit, as created by LINGO, is uploaded into the simulation model via a flat file. The sequence provided by LINGO is used as is, meaning that a tour, starting from the count house, can either begin with the first ATM or the last ATM in the sequence, as the distances between ATMs are symmetrical. Whether to start the sequence with the first or last ATM was not taken into consideration. This becomes important when it is possible to determine which of the ATMs in the sequence will run empty first. Starting the sequence with the first or last ATM can eliminate potential shortages.

Another point to consider is that each vehicle, traveling at 50 km/h, can realistically only replenish a route shorter than 400km, or 8 hours. Enough time must also be provided for the replenishment of the ATMs, which is 20 minutes per ATM. The CIT company can start replenishing an ATM from 08:00 in the morning up until 16:00. The vehicle can travel before and after this time. The objective of the traveling salesman problem is to find the minimum distance traveled. In this study, when the objective exceeds 400km it is up to the user to decide which ATM(s) to exclude from the sequence. This will normally be the ATM(s) that have either the most cash left or those that, based on their rate of demand, will run empty last. This function can be automated to give the user suggestions, from which they must choose which ATM(s) not to replenish on the tour.

For Model 3, Experiment 1 and 2 two dedicated vehicles are used. The vehicles are split between two geographical sections of the Mthatha area. The distances between the delivery points are shown in Table 6.15 and Table 6.16.

ATM	19	5	7	16	8	17	9	12	14
19	0	173	80	80	116	116	85	50	144
5		0	131	131	125	125	88	166	53
7			0	1	35	35	65	45	80
16				0	35	35	65	45	80
8					0	1	85	75	75
17						0	85	75	75
9							0	86	59
12								0	117
14									0

Table 6.15: Symmetrical distance matrix for Geographical Section 1 (kilometers)

The experiments of Model 3 will now be described:

6.5.1 Experiment 1 - Forecasting and TSP

Model 3, Experiment 1 simulates a weekly forecast for cash to be delivered to the count house. At noon a report is generated, highlighting ATMs below their reorder points per month (Mthatha area) or per interval (individual ATMs). The traveling salesman problem is applied to determine the shortest route for delivery.

ATM	19	1	2	15	3	4	6	10	18	11	13
19	0	96	12	12	10	8	82	96	96	118	15
1		0	96	96	96	96	85	106	106	81	105
2			0	1	14	15	82	96	96	118	9
15				0	14	15	82	96	96	118	9
3					0	8	82	96	96	118	7
4						0	82	96	96	118	11
6							0	167	167	162	82
10								0	1	37	96
18									0	37	37
11										0	118
13											0

Table 6.16: Symmetrical distance matrix for Geographical Section 2 (kilometers)

If an ATM reaches its reorder point after the delivery vehicle has been dispatched, the ATM becomes part of the next cycle of deliveries. The results of the simulation are shown in Table 6.17.

	Monthly Reorder Points	**Interval Reorder Points**	**Current Set-up**
ATM Shortages (R)	15,864,440	14,624,980	0
Count House Shortage (R)	494,422	1,480,000	0
Deliveries - Count House to ATM	444	466	742
Deliveries - Bulk Cash Supplier to Count House	13	13	57
Total Distance Traveled (km)	36,338	36,840	25,530
Total Cash in Circulation (R)	2,499,590,032	2,539,407,069	2,038,830,110
Max End-of-Day Cash in Circulation (R)	50,910,423	43,960,133	33,369,210
COSTS			
Opportunity Cost	410,892	417,437	335,150
Vehicle Cost	472,260	472,260	519,231
Count House to ATM Cost	86,935	88,532	59,925
Bulk Cash Supplier to Count House Cost	97,894	97,894	375,500
Rebanking Cost (R)	0	0	231,293

Table 6.17: Simulation Results for Model 3, Experiment 1

Referring to Table 6.17 the results of Model 3, Experiment 1 in comparison with the current set-up are discussed below:

- ATM shortages occur regardless of the reorder point method used. The ATM shortages are less when making use of the interval reorder point method.

- There are times when an ATM will request cash from the count house while the count house will not have enough cash available. This can be the result of the weekly forecast accuracy. The count house shortage increases with the interval reorder point method.

- The number of deliveries from the count house to the ATM lead to a reduction of over 35%. With the monthly reorder point method an improvement of 40% is achieved, from 742 to 444 deliveries and with the interval reorder point method - 37%, from 742 to 466 deliveries.

- The number of deliveries from the bulk cash supplier to the count house is reduced by 77%, from 57 to 13. This is due to deliveries, in the current set-up, being made when cash is required, whereas with Model 3, Experiment 1, bulk cash is delivered in a more structured manner, once a week.

- The total distance traveled due to the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled for Model 3, Experiment 1 is about 36,000 km for less than 470 deliveries. It is evident that the total distance traveled due to the current set-up should be significantly greater than the distance traveled due to Model 3, Experiment 1, and therefore an improvement is achieved.

- The total cash in circulation increases due to the cash being ordered in bulk for the week and held in a float at the count house, whereas currently there is no float.

- The maximum end-of-day cash in circulation increases, also because of a float being held at the count house.

- The opportunity cost increases, as there is more cash in circulation due to the float at the count house.

- The vehicle cost decreases, from R519,231 to R472,260 (9%), as only two dedicated vehicles are utilized.

- It is not possible to quantify the improvement of the delivery cost from the count house to the ATM, as it appears that the cost has increased, but fewer deliveries were made.

- The delivery cost from the bulk cash supplier to the count house is reduced by 74%, from R375,500 to R97,894.

- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

Both the monthly and interval reorder points appear to be feasible options to pursue. What is of interest, is that there is no significant cost difference between monthly reorder points for the region as a whole and interval reorder points per ATM. One might have expected that the more detailed interval reorder points per ATM should have produced better operational and costing results than the higher level monthly reorder points for the whole area.

6.5.2 Experiment 2 - Forecasting and Time

Model 3, Experiment 2 simulates a weekly forecast for cash to be delivered to the count house. At noon a report is generated, highlighting ATMs below their reorder points per month (Mthatha area) or per interval (individual ATMs). Instead of using the traveling salesman problem to determine the route of the delivery vehicles, the sequence of delivery is determined by the time that an ATM will run empty. The ATM cash levels at noon are subtracted from the daily dispensing forecast per ATM for that day, to determine the cash levels of the ATMs. The cash levels are then ranked from lowest value to highest value to determine the sequence of delivery the next day. If an ATM reaches its reorder point after the delivery vehicle has been dispatched, the ATM becomes part of the next cycle of deliveries. The results of the simulation are shown in Table 6.18.

Referring to Table 6.18 the results of Model 3, Experiment 1 in comparison with the current set-up is discussed below:

- ATM shortages occur regardless of the reorder point method used. The ATM shortages are less when making use of the interval reorder point

	Monthly Reorder Points	Interval Reorder Points	Current Set-up
ATM Shortages (R)	18,786,660	15,977,340	0
Count House Shortage (R)	783,082	1,480,000	0
Deliveries - Count House to ATM	450	459	742
Deliveries - Bulk Cash Supplier to Count House	13	13	57
Total Distance Traveled (km)	43,396	41,288	25,530
Total Cash in Circulation (R)	2,575,384,862	2,565,248,059	2,038,830,110
Max End-of-Day Cash in Circulation (R)	52,028,633	52,295,913	33,369,210
COSTS			
Opportunity Cost	423,351	421,685	335,150
Vehicle Cost	472,260	472,260	519,231
Count House to ATM Cost	109,379	102,675	59,925
Bulk Cash Supplier to Count House Cost	97,894	97,894	375,500
Rebanking Cost (R)	0	0	231,293

Table 6.18: Simulation Results for Model 3, Experiment 2

method. The ATM shortages are slightly higher than Model 3, Experiment 1.

- There are times when an ATM will request cash from the count house while the count house will not have enough cash available. This can be the result of the weekly forecast accuracy. The count house shortage increases with the interval reorder point method. The count house shortages are similar to Model 3, Experiment 1.

- The number of deliveries from the count house to the ATM lead to a reduction of over 35%. With the monthly reorder point method a reduction of 39% is achieved, from 742 to 450 deliveries and with the interval reorder point method - 38%, from 742 to 459 deliveries. The monthly reorder point deliveries are slightly higher than Model 3, Experiment 1 and the interval reorder points are slightly lower than Model 3, Experiment 1. This can be due to the timing of the deliveries, e.g. it can happen that an ATM can be filled sooner, when cash levels in the ATM are still high, than with TSP, resulting in more deliveries.

- The number of deliveries from the bulk cash supplier to the count house are reduced by 77%, from 57 to 13 deliveries. This is due to deliveries, in the current set-up, being made when cash is required, whereas with Model 3, Experiment 2, bulk cash is delivered in a more structured manner, once a week.

- The total distance traveled due to the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled for Model 3, Experiment 2 is between 41,000 km and 43,000 km for less than 460 deliveries. It is evident that the total distance traveled due to the current set-up should be significantly greater than the distance traveled by Model 3, Experiment 2, and therefore an improvement is achieved. The total distance traveled is greater than Model 3, Experiment 1 because the routes being traveled by the vehicles do not represent the minimum distance.

- The total cash in circulation increases due to the cash being ordered in bulk for the week and held in a float at the count house, whereas currently there is no float.

- The maximum end-of-day cash in circulation increases, also because of a float being held at the count house.

- The opportunity cost increases, as there is more cash in circulation due to the float at the count house.

- The vehicle cost decreases, from R519,231 to R472,260 (9%), as only two dedicated vehicles are utilized.

- It is not possible to quantify the improvement of the delivery cost from the count house to the ATM, as it appears that the cost has increased, but fewer deliveries were made. The delivery cost is greater than Model 3, Experiment 1 because the route being traveled by the vehicles do not represent the minimum distance.

- The delivery cost from the bulk cash supplier to the count house is reduced by 74%, from R375,500 to R97,894.

- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

It was expected and was the case that the ATM shortages, the total distance traveled and the cost of deliveries from the count house to ATM would have increased with the time routing when comparing it to the TSP routing as the time routing is not optimal in its traveling.

6.5.3 Experiment 3 - Forecasting and TSP with current vehicle set-up

Experiment 3 simulates a weekly forecast for cash to be delivered to the count house. At noon a report is generated, highlighting ATMs below their reorder points per month (Mthatha area). Three CIT vehicles are used: two dedicated vehicles and one CIT managed vehicle. The two dedicated vehicles are divided into two geographical areas, see Table 6.19 and Table 6.20. The CIT managed vehicle's set-up is displayed in Table 6.21. The allocation of ATMs to the vehicles are set-up the same way that the bank currently does it. The traveling salesman problem is applied to determine the shortest route for delivery. For this experiment only the monthly reorder points were used to demonstrate what impact three vehicles will have compared to two.

ATM	19	2	15	3	4	13	7	16	8	17	12
19	0	12	12	10	8	15	80	80	116	116	50
2		0	1	14	15	9	80	80	116	116	50
15			0	14	15	9	80	80	116	116	50
3				0	8	7	80	80	116	116	50
4					0	11	80	80	116	116	50
13						0	80	80	116	116	50
7							0	1	35	35	45
16								0	35	35	45
8									0	1	75
17										0	75
12											0

Table 6.19: Symmetrical distance matrix for Geographical Section 1 for one of the dedicated vehicles (kilometers)

The results of the simulation are shown in Table 6.22.

ATM	19	1	6	10	18	11
19	0	96	82	96	96	118
1		0	85	106	106	81
6			0	167	167	162
10				0	1	37
18					0	37
11						0

Table 6.20: Symmetrical distance matrix for Geographical Section 2 for one of the dedicated vehicles (kilometers)

ATM	19	5	9	14
19	0	173	85	144
5		0	88	53
9			0	59
14				0

Table 6.21: Symmetrical distance matrix for Geographical Section 3 for the CIT managed vehicle (kilometers)

	Monthly Reorder Point	**Current Set-up**
ATM Shortages (R)	16,811,980	0
Count House Shortage (R)	486,480	0
Deliveries - Count House to ATM	452	742
Deliveries - Bulk Cash Supplier to Count House	13	57
Total Distance Traveled(*excl Scheduled vehicle*) (km)	28,857	25,530
Total Cash in Circulation (R)	2,559,729,769	2,038,830,110
Max End-of-Day Cash in Circulation (R)	52,002,633	33,369,210
COSTS		
Opportunity Cost	420,777	335,150
Vehicle Cost (*excl Scheduled vehicle*)	519,231	519,231
Count House to ATM Cost	63,145	59,925
Bulk Cash Supplier to Count House Cost	97,894	375,500
Rebanking Cost (R)	0	231,293

Table 6.22: Simulation Results for Model 3, Experiment 3

Referring to Table 6.22 the results of Model 3, Experiment 1 in comparison with the current set-up are discussed below:

- ATM shortages still occur with the extra vehicle utilized. Compared to Model 3, Experiment 1, which also makes use of TSP, the ATM shortages are slightly more. This might have something to do with the way the vehicles are allocated to ATMs, which might not be optimal.

- There are times when an ATM will request cash from the count house and where the count house will not have enough cash available. This can be the result of the weekly forecast accuracy. The count house shortage is similar to that of Model 3, Experiment 1.

- The number of deliveries from the count house to the ATM is reduced by 39%, from 742 to 452 deliveries. The monthly reorder point deliveries are similar to Model 3, Experiment 1, as the same type of routing method is used, but with this experiment employing one more vehicle.

- The number of deliveries from the bulk cash supplier to the count house is reduced by 77%, from 57 to 13 deliveries. This is due to deliveries, in the current set-up, being made when cash is required, whereas with Model 3, Experiment 3, bulk cash is delivered in a more structured manner, once a week.

- The total distance traveled due to the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled for Model 3, Experiment 3 is 28,857 km for 452 deliveries. It is evident that the total distance traveled due to the current set-up should be significantly greater than the distance traveled by Model 3, Experiment 3, and therefore an improvement is achieved. The total distance traveled is greater than Model 3, Experiment 1 because the routes being traveled by the vehicles do not represent the minimum distance.

- The total cash in circulation increases due to the cash being ordered in bulk for the week and held in a float at the count house, whereas currently there is no float. The total cash in circulation is similar to Model 3, Experiment 1.

- The maximum end-of-day cash in circulation increases, also because of a float being held at the count house. The maximum end-of-day cash in circulation is similar to Model 3, Experiment 1.

- The opportunity cost increases, as there is more cash in circulation due to the float at the count house. The opportunity cost is similar to Model 3, Experiment 1.
- The vehicle cost is the same as in the current set-up, R519,231, but with one CIT managed vehicle more than Model 3, Experiment 1.
- It is not possible to quantify the improvement of the delivery cost from the count house to the ATM, as it appears that the cost has increased, but fewer deliveries were made. The delivery cost is less than Model 3, Experiment 1 because only dedicated vehicles are taken into consideration for the variable traveling cost. CIT managed vehicles have a fixed cost regardless of the distance traveled.
- The delivery cost from the bulk cash supplier to the count house is reduced by 74%, from R375,500 to R97,894.
- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

What is of interest is that there is not a significant difference in the results between using three vehicles with the current allocation versus two vehicles with the geographically proposed set-up.

6.6 Model Four - No Forecasting and TSP

This model does not make use of any forecasting. A (t, s, Q) inventory policy is followed for the replenishment of the ATMs. At noon a report is generated, highlighting ATMs below their reorder points per month (Mthatha area) or per interval (individual ATMs). An order, for these ATMs, is placed at the count house for replenishment the next day. At the same time an order is placed at the bulk cash supplier, for an amount equal to the total ATM replenishment values the previous day, to be delivered to the count house. It takes three days for the

	Forecasting			No Forecasting	
Model	**DR**	**TSP**	**Time**	**DR**	**TSP**
Model 1					
Experiment 1	•				
Experiment 2	•				
Experiment 3	•				
Model 2					
Experiment 1				•	
Experiment 2				•	
Experiment 3				•	
Model 3					
Experiment 1		•			
Experiment 2			•		
Experiment 3		•			
Model 4					•

Table 6.23: Perspective of Experiments - Model 4

bulk cash to be delivered from the bulk cash supplier to the count house. Two dedicated vehicles are utilized with the same set-up as in Table 6.15 and Table 6.16. The traveling salesman problem is applied to determine the shortest route for delivery. The results of the simulation are shown in Table 6.24.

	Monthly Reorder Points	Interval Reorder Points	Current Set-up
ATM Shortages (R)	16,374,130	14,536,100	0
Count House Shortage (R)	0	0	0
Deliveries - Count House to ATM	452	490	742
Deliveries - Bulk Cash Supplier to Count House	51	53	57
Total Distance Traveled (km)	37,145	37,370	25,530
Total Cash in Circulation (R)	5,156,619,240	5,902,397,900	2,038,830,110
Max End-of-day Cash in Circulation (R)	88,783,350	103,552,530	33,369,210
COSTS			
Opportunity Cost	847,663	970,257	335,150
Vehicle Cost	472,260	472,260	519,231
Count House to ATM Cost	89,501	90,217	59,925
Rebanking Cost (R)	0	0	231,293

Table 6.24: Simulation Results for Model 4

Referring to Table 6.24 the results of Model 4, Experiment 1 in comparison with the current set-up is discussed below:

- ATM shortages occur regardless of the reorder point method used. The ATM shortages are less when making use of the interval reorder point method. The accuracy of the weekly forecast will also play a part in the ATM shortages. The ATM shortages are similar to Model 3, Experiment 1, which also makes use of the TSP routing.

- The count house shortage is zero due to safety stock being held at the count house float and cash being delivered from the bulk cash supplier in East London to the Mthatha count house in short intervals.

- The number of deliveries from the count house to the ATM lead to an improvement of over 30%. With the monthly reorder point method a reduction of 39% is achieved, from 742 to 452 deliveries and with the interval reorder point method - 34%, from 742 to 490 deliveries.

- The number of deliveries from the bulk cash supplier to the count house is nearly the same as in the current set-up, due to cash being ordered from the bulk cash supplier when required, which is the same principle followed in the current set-up.

- The total distance traveled due to the current set-up is 25,530 km for a total of 742 deliveries, whereas the total distance traveled for Model 4 is around 37,000 km for fewer then 490 deliveries. It is evident that the total distance traveled due the current set-up should be significantly greater than the distance traveled due to Model 4, and therefore an improvement is achieved. The total distance traveled is similar to Model 3, Experiment 1.

- The total cash in circulation is greater than Model 3, Experiment 1, due to the cash being ordered from the bulk cash supplier when required as opposed to cash being ordered for a week, thus in total more bulk cash will be ordered than when weekly orders are placed.

- The maximum end-of-day cash in circulation increases as more bulk cash is held at the count house float, and is greater than that of Model 3, Experiment 1.

- The opportunity cost increases, as there is more cash in circulation due to the float at the count house.
- The vehicle cost, R472,260, is less than in the current set-up, R519,231.
- It is not possible to quantify the improvement of the delivery cost from the count house to the ATM, as it appears that the cost has increased, but fewer deliveries were made.
- The rebanking cost is eliminated with the float at the count house, as all the cash is 'recycled', whereas with the current set-up the cash returned to the count house is rebanked. This change on its own brings about a saving of R231,293.

This model is not a viable option and does not compare well with Model 3, Experiment 1, which uses forecasting and TSP.

6.7 Evaluation of Simulation Models

To make a decision on which experiment produces the best result and should be further pursued, the 10 experiments were compared against each other based on cost, which is driven by the operational performances. The experiment with the smallest cost or biggest saving, with satisfactory operational performances, is considered best.

Models 1 and 2 can be ignored from the start, because they resulted in large amounts of ATM shortages and count house shortages when two vehicles are utilized and when more vehicles are utilized the vehicle costs become too large. Whether forecasting is used or not the operational and financial impact of these two models are not viable and do not come close to improving on the current set-up.

Only models 3 and 4 were compared to aid the decision-making process, as these are the only simulation models that are able to improve on the current set-up. Table 6.25 illustrates the operational comparison between the experiments of models 3 and 4.

Table 6.26 illustrates the cost comparison between the experiments of models 3 and 4.

From Table 6.26 one can conclude that Model 3, Experiment 1 - Monthly Reorder Points, is the most cost effective of the experiments. The model does have ATM shortages of R15,864,440. This shortage will reduce if the ATMs follow their normal dispensing patterns, which is not the case with the data used for this research, due a total of 19 days when ATMs did not dispense and led to unusual demands on certain days. The total shortages (ATM and count house) can also be reduced by fine-tuning the forecasting of the cash demand.

The major enabler of the cost saving is the change in the ordering policy from ordering cash 5 days in advanced for a future forecasted ATM cash demand, to a weekly bulk cash order for the Mthatha area as a whole, and keeping it in a float at the count house. This change led to:

- an increase in the opportunity cost of over R75,000 over the three month period, or R25,000 per month.
- a decrease in the delivery cost from the bulk cash supplier in East London to the count house in Mthatha of R277,606 over the three month period, or R92,535 per month.

By bringing in a more scientific vehicle routing method (TSP) the number of deliveries reduced from 742 to 450. It is expected that this will translate into cost savings, but the data received from the ATM Management department is either not complete or incorrect.

From the experiments performed and evaluated it is clear that significant savings can be achieved when standard practical industrial engineering techniques are applied. Savings in excess of R400,000 over a three month period are achievable. The R400,000 can not be seen as a clear cut saving as a holding cost to

Operational Factors	Current	Model 3					Model 4	
		Experiment 1		Experiment 2		Experiment 3		
		Monthly Reorder Points	Interval Reorder Points	Monthly Reorder Points	Interval Reorder Points	Monthly Reorder Points	Monthly Reorder Points	Interval Reorder Points
ATM Shortage (R)	0	15,864,440	14,624,980	18,786,660	15,977,340	16,811,980	16,374,130	14,536,100
Count House Shortage (R)	0	494,422	1,480,000	783,082	1,480,000	486,480	0	0
Deliveries - Count House to ATM	742	444	466	450	459	452	452	490
Deliveries - Bulk Cash Supplier to Count House	57	13	13	13	13	13	51	53
Total Distance Travelled to ATMs (km)	25,530	36,338	36,840	43,396	41,288	28,857	37,145	37,370
Total Cash in Circulation (R)	2,038,830,110	2,499,590,032	2,539,407,069	2,575,384,862	2,565,248,059	2,559,729,769	5,156,619,240	5,902,397,900
Max End-of-Day Cash in Circulation	33,369,210	50,910,423	43,960,133	52,028,633	52,295,913	52,002,633	88,783,350	103,552,530

Table 6.25: Operational comparison between Model 3 and 4 experiments

Cost Factors	Current	Model 3					Model 4	
		Experiment 1		Experiment 2		Experiment 3		
		Monthly Reorder Points	Interval Reorder Points	Monthly Reorder Points	Interval Reorder Points	Monthly Reorder Points	Monthly Reorder Points	Interval Reorder Points
Scheduled CIT Vehicle	25,124	0	0	0	0	25,124	0	0
Dedicated CIT Vehicle	472,260	472,260	472,260	472,260	472,260	472,260	472,260	472,260
Count house to ATM	59,925	86,935	88,532	109,379	102,675	63,145	89,501	90,217
Bulk cash supplier to count house	375,500	97,894	97,894	97,894	97,894	97,894	Unknown	Unknown
Rebanking cost	231,293	0	0	0	0	0	0	0
Opportunity cost	335,150	410,892	417,437	423,351	421,685	420,777	847,663	970,257
Total Cost	1,499,252	1,067,981	1,076,123	1,102,884	1,094,514	1,079,200	1,409,424[1]	1,630,628[1]
Saving		**431,271**	**423,129**	**396,368**	**404,738**	**420,052**		

[1]This total cost excludes the cost of delivery from the bulk cash supplier to the count house.

Table 6.26: Cost comparison between Model 3 and 4 experiments

store the bulk cash in a float at the count house will have to be subtracted from this saving. Currently the count house do not store cash in a float, but rebank the cash. The R400,000 saving can be seen as an amount that can be used when negotiating holding cost with the CIT company. The future holding cost is unknown and will still need to be negotiated, but is expected to be less than R50,000 per month or R150,000 for the three month period. Working with these numbers a saving of R250,000 for three months is possible and extrapolating this to a year the potential saving is R1,000,000 per annum.

The bank has 40 count house areas of which Mthatha is one. It is not correct to say that a potential saving of R40,000,000 (R1,000,000 $\times$ 40) per annum is possible, as each count house area will have its own unique challenges and require its own unique set-up, but by studying them and applying the methodology followed in this thesis using standard industrial engineering techniques substantial cost saving opportunities are possible.

Chapter 7

Conclusions

The research focused on three main topics: Forecasting, Inventory Management and Routing within an ATM cash management environment.

The application of the multiplicative Holt-Winters forecasting method together with an improvised method demonstrated the improvements, in relation to the current forecasting method, that can be achieved when making use of known forecasting techniques. It is recommended that more research is done on the forecasting of ATM cash demand. The few articles available about ATM cash management, focus mainly on forecasting, but none address the multiple seasonalities and calendar day effects associated with ATM cash forecasting.

The cash-swap method applied in this research differs from standard inventory models in that the inventory (cash) in stock is removed and replaced by a fixed quantity (amount). Two inventory policies were simulated:

1. A (s, Q) policy, where the point in time at which replenishment orders are triggered, depends on the reorder point s, and the order quantity Q is constant over time. This policy is suited to a direct replenishment set-up.
2. A (t, s, Q) policy, where the points in time at which replenishment orders are released are determined by reorder points and cash levels at a review interval t. At constant intervals a replenishment order is initiated that raises the inventory position to a target level Q. This policy is more suited towards a vehicle routing set-up.

A new ordering policy is proposed whereby the cash supply for a week for the Mthatha area is ordered and stored at the count house and when required a fixed quantity is delivered to the specific ATM. Currently cash is ordered from the bulk cash supplier to be delivered to the ATM five days later. Changing the order policy gives the bank greater ATM replenishment flexibility and reduces the margin for error, i.e. quantities ordered and forecasting demand. Different reordering points were simulated: (1) fixed reorder points throughout the three month period, (2) a reorder point per month for the region as a whole, (2) nine variable reorder points per ATM, divided into three intervals per month. From the simulations it appears that the variable reorder points per month produce the best results. It is however suggested that more work be done on the determination of reorder points and intervals as it is presumed that better results can be achieved by having more reorder points within intervals per ATM.

Three delivery vehicle routing methods were simulated: (1) Direct Replenishment, (2) Traveling Salesman approach and (3) A time-based method where the sequence depends on the ATM that is determined to run empty next. Of the three routing methods the Traveling Salesman approach produced the best results when paired with different configurations.

The research proved that significant savings are achievable if standard practical industrial engineering techniques are applied, i.e. forecasting, inventory management, operational research and simulation. Potential cost savings in excess of R 1,000,000 per annum is possible for the Mthtatha count house area.

Going forward it is proposed than an application be build incorporating the decision making techniques discussed in this thesis, and some more. The application must (1) give the Cash Management department of the bank the capabilities to design What-If scenarios per count house region, (2) it must give suggestions to the operator, i.e. cash to order based on the forecast or sequence of ATMs to replenish, and (3) it must automate the placement of orders with the bulk cash supplier and the count house.

Future research areas that can be pursued for ATM cash management is forecasting, determining optimal reorder points, establishing the optimal inventory policy, cash-add versus cash swap and testing different routing methods.

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