

Optimizing Delivery Routes for Newspapers and Magazines Using Vehicle Routing Problem

Media24 Newspaper and Magazine Routes

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The current market of media in the form of newspapers and magazines is facing one of the greatest challenges of their existence. New media's such as television and the internet, have replaced the need for newspapers and magazines, lowering circulations and increasing unit costs. This research aims to investigate the role of logistics in newspaper and magazine delivery routes, to find how they can be optimized. The results should assist media companies to cut the cost of logistics and to have a more effective delivery system. By using the Vehicle Routing Method, this study aims to develop a universal algorithm to apply to the routes currently used by Media 24 in Gauteng. Once the algorithm is created, a feasibility study will be performed to indicate how to program the problem. It will improve the efficiency of the delivery process. This may make a significant difference in not only the media company's logistics costs, but also in their unit costs, thus earning a greater profit for each copy sold.

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Introduction and Background

In today's fast-paced world, individuals and organizations have access to an infinite amount of information via the internet. Search engines such as Google have made it possible to gather the information that is needed in a timely manner. Today's society has been described by some individuals as the 'click here' generation. Individuals are no longer dependent on the media to obtain information, but can gather the appropriate information when needed (Langley, Coyle, Gibson, Novack, & Bardi, 2009, p. 9). Newspapers and magazines all over the world are confronted by the most serious situation in their history. A decline in circulation has occurred in almost all newspapers and magazines worldwide; the reason being that they now have to compete with other media such as television, radio and, more recently, the internet. Currently, readers prefer to consume news from websites and search engines. As a result of the sudden decline in circulation, many media publishers are now carrying much larger distribution cost per copy than previously (Boonkleaw, Suthikarnnarunai, & Sriron, 2010). Because of the increased distribution costs, as well as the increased transport costs, the average price of most magazines and newspapers are greater now than ever before.

South Africa was not left unaffected by this occurrence in the media. Media 24, the leading publishing group on the African continent, is known for its work in magazines, newspapers, book publishing, internet business, printing plants and distribution companies (Company Information: Media24). One of these distribution companies is On the Dot: Magazines and Newspapers, which is a local subsidiary of Media24 and is the largest distributor of newspapers and magazines in South Africa. On the Dot was established in 1975 and operates from fourteen branches across South Africa (About Us, Our History: On the Dot). Because of the abovementioned obstacles that media companies have had to overcome, Media 24 hired a company called GP Retail to change and optimize the newspaper and magazine delivery routes of On the Dot. They wish to optimize the routes by not only combining magazine and newspaper delivery into one trip, but also formulating an algorithm for the ideal system (Stevens, 2012).

Few companies consider it important to concentrate on their logistics department as a sector that needs to be greatly improved and optimized. Although supply chain management has captured the interest of many high-level executives, logistics is usually misunderstood and overlooked. With the excitement surrounding supply chain management and all of the related technology that has been developed to support the supply chain, little time has been spent on logistics. The fascination with the e-supply chain and e-business seems to outshine the critical importance of logistics in an

organization and the need for effective logistics support in a supply chain. Logistics may be regarded by most organizations as routine and dull when compared to other supply chain initiatives, however, experienced managers realize that logistics is one of the most important aspects of any successful business. In spite of all the attention that the internet has received, successful businesses have to manage order fulfillment to their clients effectively and efficiently to establish and maintain competitive advantage and productivity (Langley, Coyle, Gibson, Novack, & Bardi, 2009, p. 32).

James Tomkins once said in a speech presented at the Warehouse of the Future Conference that: *'Change is inevitable, but growth and improvement are optional'*. As a result of the change in the circulation of newspapers and magazines, the media industry has been forced to rethink the products and services that they are offering. Being aware that particularly in the logistics approach, the optimal use of the capacity available to the organization has emerged as one of the prime reasons for success (Dorer & Calisti, 2005). The often quoted line: *'Good logistics is business power'* is very important in building an advantage over competitors. If a firm cannot effectively deliver its products to clients, it will not remain a firm for very long. This is not to say that quality products and effective marketing are not important. Both are obviously very important, but they must be combined with effective and efficient logistics systems for long term success and financial viability (Langley, Coyle, Gibson, Novack, & Bardi, 2009, p. 33).

Road users have increased dramatically over the last two decades across the globe. This is as a result of two important factors:

1. A large increase in the number of companies and private road users using the public roads for logistics.
2. An increase in the length of the average distance travelled by these companies or individuals during transportation.

South Africa's national roads are busier now than ever before as a result of the ever-increasing private road users, leading to traffic congestion, which in turn leads to a sharp decrease in the delivery speeds. The country's public transportation is becoming more expensive as a result of this, resulting in more people using their own transport, unknowingly contributing to the already hyper congested roads (Joubert, 2006).

To achieve good logistics, an organization has to turn to the field of operations research. After World War II, operations research was changed to fit the needs of the general industry, and the field of management science emerged. Techniques such as simulation, forecasting, decision analysis, and linear programming were implemented by industries in the 1960's and 1970's to solve problems in

manufacturing, marketing, and finance (Savage, 2003, p. 2). One of the techniques that received much attention is linear programming. Linear programming (LP) is a tool for solving optimization problems. 'In 1947, George Dantzig developed an efficient method called the simplex algorithm for solving linear programming problems. Since the development of the simplex algorithm, LP has been used to solve optimization problems in industries as diverse as banking, education, forestry, petroleum, and trucking. According to a survey of Fortune 500 firms, 85% of the respondents said they used linear programming' (Winston & Venkataramanan, 2003, p. 49).

This study will focus on researching a way in which the delivery routes of Media24 can be optimized, using the Transportation Methods of linear programming, and the Vehicle Routing Problem. The Transportation Method is a unique linear programming method. The name originates from its application in problems involving transporting goods from different sources to different clients. The two most commonly known goals of such problems are either to; reduce the transportation cost to a minimum, or to maximize the economic gain of shipping a number of units to different destinations (Jacobs, Chase, & Aquilano, 2009, p. 390). The findings of this research are expected to show that it is feasible to minimize the cost of delivery for Media 24, using the Vehicle Routing Problem.

This paper has five parts. First it discusses the project aim followed by the project scope. Then extant literature relevant to this problem is reviewed. Finally the data analysis is performed and the programming of the model is discussed.

Project Aim

The current layout of On the Dot's logistical services for Media 24 starts at a single printing plant in Johannesburg. From this plant the newspapers are moved to 20 different branches, where they are divided into smaller shipments and shipped to different retailers. As the newspapers are delivered early in the morning before any of the retailers are open, they are placed in front of the retail outlets to be on time for early morning sales. Later the trucks return to the printing plant to pick up the magazines, which can only be delivered after the retail outlets have opened. New magazines are offloaded and racked at the outlets, old magazines and newspapers are gathered and fees are collected before the truck can continue on its route (Stevens, 2012).

The aim of this study is to:

1. Generate a universal algorithm, using linear programming, for the optimal route each delivery truck of Media 24 must take from the printing plant in Johannesburg to all the different branches.

2. Study the feasibility of programming such an algorithm to use and apply daily.

Project Scope

Linear programming refers to a number of mathematical techniques used to distribute limited resources amongst demand points in an optimal way. Due to the growing interest of companies in optimizing processes, LP is the most widely used of all the approaches falling under the general category of Mathematical Optimization Techniques. LP has been applied to a variety of different operations management problems, and is often referred to as the advanced planning option, synchronized planning or process optimization (Jacobs, Chase, & Aquilano, 2009, p. 37).

To construct a linear program, a structured approach must be taken consisting of various steps. Donald Knuth, a Stanford computer scientist, discovered that computer program development generally goes through five stages of development. According to Decision Making with Insight (Savage, 2003, p. 14), these five stages can be rephrased and applied to LP's. The five stages are illustrated in the figure below:

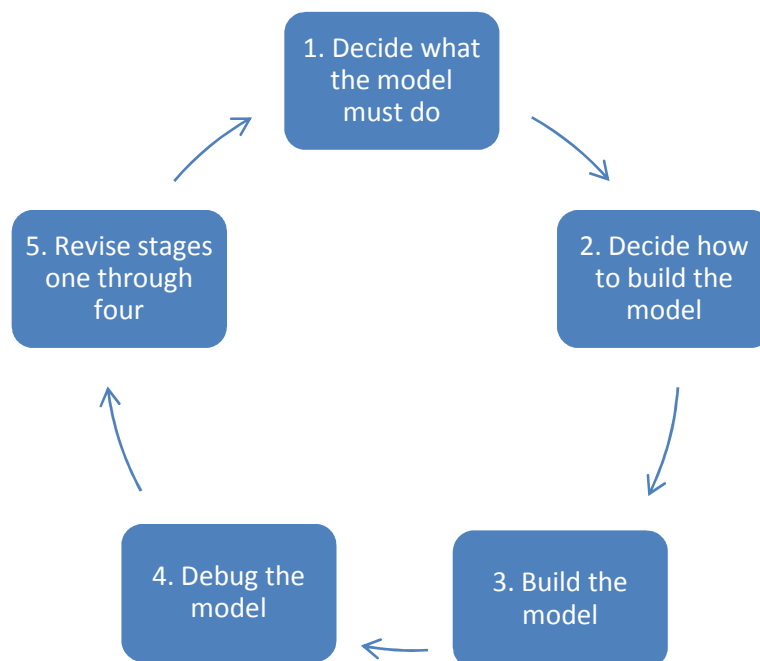


Figure 1: Five Stages of Developing a Model

Decide What the Model Must Do

In order to decide what it is that the model must do, information has to be gathered from Media 24 and their subsidiary company, On the Dot. This information can fall into one of four categories and is essential in deciding what the model is capable of. The four categories are summarized in the table below:

		<u>Information Quality</u>	
		Deterministic knowledge of input data	Stochastic knowledge of input data
<u>Information Evolution</u>	Input is known beforehand	Static Deterministic	Static Stochastic
	Input changes over time	Dynamic Deterministic	Dynamic Stochastic

Figure 2: Table of Taxonomy of Vehicle Routing Problems by Information Evolution and Quality

In static and deterministic cases all input is known beforehand and no change can be applied to the routing plan. This problem includes the classical vehicle routing problem and its variations. For instance, the driver knows exactly where and how much to deliver at each station.

Static and stochastic problems are characterized by input partially known as random variables, of which the realization is only revealed to the planner during the execution of the routing. Applications falling into this category do not require any technological support by the truck drivers. For example, although there could be changes in the quantities delivered, the stations are known.

In dynamic and deterministic problems the plan can be completely redefined while the truck is en route. Applications falling into this category do require technological support by the truck drivers. For example, if a company picks fruit and loads it onto a truck, the truck must set off because the fruit has only a limited time before it will decay. While the truck is driving in a direction, the fruit can be sold by the decision makers, and the final destination communicated to the driver of the truck.

Similarly, dynamic and stochastic problems have part or their entire input unknown and revealed dynamically during the execution of the plan. But in this case, usable stochastic knowledge is available on the dynamically revealed information. Applications falling into this category also require technological support. For example, a truck can be loaded with fruit and be en route to Johannesburg. While the truck is driving, the fruit should be sold to a company in Johannesburg, and the destination sent to the driver (Pillac, Gueret, & Medaglia, 2010).

In order to decide what the model can do, information must be gathered on the characteristics and constraints of orders, trucks and the costs of Media 24 that are involved.

Characteristics of the orders include:

- Order Type
- Volume
- Weight
- Pickup Time Window
- Time it takes to Load
- Location of Deliveries
- Delivery Time Window
- Time it takes to Unload

Characteristics of the trucks include:

- The Type of Truck
- Volume of the Truck
- Maximum Weight of the Truck
- Special Equipment Needs
- Start Location
- Time of Availability
- Cost

Characteristics of costs include both the fixed and the variable costs. Fixed costs are the costs which must be paid regardless of deliveries, and variable costs vary according to the quantities of deliveries made (Dorer & Calisti, 2005, pp. 4-5). In this paper the goal of the model is to minimize the delivery costs.

Decide How to Build the Model

In Introduction to Mathematical Programming (Winston & Venkataramanan, 2003, pp. 5-6), it is argued that the following seven steps must be followed to build a model:

- *Step 1: Formulate the problem.* Media 24's problem must first be clearly defined. Describing the problem takes into account Media 24's objectives and the parts of the business that have to be studied before the problem can be solved.

- *Step 2: Observe the System.* After this, information is collected to determine the value of constraints that affects Media 24's situation. These estimates are used to build and assess a mathematical model of Media 24's situation.
- *Step 3: Formulate a Mathematical Model of the Problem.* In this step, the mathematical model of the problem is developed.
- *Step 4: Verify the Model and Use the Model for Prediction.* Decide whether the mathematical model built in the previous step accurately represents reality.
- *Step 5: Select a Suitable Alternative.* Looking at the model and also some appropriate alternatives, the alternative that best meets Media 24's objective must be chosen.
- *Step 6: Present the Results and Conclusion of the Study to the Organization.* Finally, the model and recommendation from the previous step is presented to the individual responsible for making the decision from GP Retail. Sometimes several alternatives might be presented and GP Retail has to decide on the one that best meets Media 24's needs.
- *Step 7: Implement and Evaluate Recommendations.* If Media 24 accepts the study, then the recommendations will be implemented.

Build the Model

A Linear Programming Problem consists of 3 parts:

1. A linear function (the objective function) of decision variables (say X_1, X_2, \dots, X_n) that is to be maximized or minimized.
2. A set of constraints (which could either be linear or nonlinear) that restrict the values that must be assumed by the decision variables.
3. The sign restrictions, which specify for each decision variable X_j either variable X_j has to be nonnegative ($X_j \geq 0$); or variable X_j must be positive, zero or negative.

(Winston & Venkataramanan, 2003, p. 112)

General Description of a Transportation Problem

Usually, the transportation problem can be specified by the information that follows:

1. A set of m supply points from which newspapers and magazines are shipped. Supply point i can supply at most s_i units.
2. A set of n demand points to which the newspapers and magazines are shipped. Demand point j must receive at least d_j units of the shipped goods.
3. Each unit produced at supply point i and shipped to demand point j incurs a variable cost of C_{ij} .

Let:

x_{ij} = number of units shipped from supply point i to demand point j

Then the general formulation of a transportation problem is:

$$MIN \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} c_{ij} x_{ij}$$

Subject to:

$$\sum_{j=1}^{j=n} x_{ij} \leq s_i \quad (\text{Supply Constraints})$$

$$\sum_{i=1}^{i=m} x_{ij} \geq d_j \quad (\text{Demand Constraints})$$

$$x_{ij} \geq 0 \quad \forall i = [1, m) \text{ and } j = [1, n)$$

(Winston & Venkataramanan, 2003, pp. 362-363)

Debug the Model

There are a number of problems that are likely to occur in the building of this model, some of them are listed below:

Large number of constraints

Many LP's solved in real world applications contain a large number of constraints and decision variables. Few users of linear programming would want to input the constraints and objective function each time such a LP is to be solved. For this reason, almost all real world applications of LP's utilize a matrix generator to simplify the inputting of the LP. A matrix generator allows the user to input the relevant parameters that determine the LP's objective function and constraints; it then generates the LP formulation from such data (Winston & Venkataramanan, 2003, p. 163). Another problem with a large number of constraints is that it is extremely time consuming to run the algorithm in order to receive an answer. This problem can be solved by the use of Meta Heuristics, which will be explained later in this research.

The Flaw of Averages and Integer Programming

In this problem a number of average values of uncertain inputs will be used in the functions. This is as a result of the variability in demand that is constantly experienced by media companies. In order to avoid a stock out, media companies have to make an approximation of the demand needed. A stock out is when the desired products are not available when and where a customer needs them

(Langley, Coyle, Gibson, Novack, & Bardi, 2009). In the case of media companies, a trade-off exists between carrying stock to satisfy demand and the costs resulting from stock out (Jacobs, Chase, & Aquilano, 2009, p. 549). If a company is not able to satisfy a customer's demand with existing inventory, one of four possible things might happen:

- (1) The customer waits until the product is available
- (2) The customer back orders the product
- (3) The seller loses a sale
- (4) The seller loses a customer.

These four outcomes are listed from best to worst in terms of the cost impact on the company. In the media industry scenario 2 does not exist for newspapers. Theoretically, scenario 1 (customer waits) should cost the company nothing; this situation is more likely to occur where product substitutability is very low (Langley, Coyle, Gibson, Novack, & Bardi, 2009). However, in the case of a newspaper, a customer usually does not want to wait for a product and will buy a different newspaper as product substitutability is very high. When there are no products available to the customer, the customer will buy from another company; this is known as a lost sale. A lost customer is when a customer permanently switches to another supplier. If a company loses a customer they do not only lose the sale, but also all future sales of that customer. Estimating the customer loss that stock outs can cause is difficult.

If the problem is merely viewed from a media company's perspective, a daily decision has to be made about how many newspapers to put on a certain newsstand. If the company does not put enough papers on the stand, certain customers will not be able to procure a paper and potential profit to the company will be lost. On the other hand, if too many papers are placed on the stand, the company will have printed papers that were not sold during the day and have to be scrapped, lowering profit for the day. The only way to solve this problem is to study how much risk the company is willing to take for running out of newspapers every day.

If the media company has collected data about sales over a few months, it could for example find that a certain newsstand sells 90 papers every Friday with a standard deviation of 10 papers (this assumes that the papers have never run out). Using the data that was gathered over a number of months, the company can simply decide on a service rate that they consider being tolerable. For example, the media company might merely decide that they wish to be 80% sure of not running out of newspapers on a Friday. Assuming that the probability distribution associated with the sales of newspapers is normal; the probability of running out of papers if the company stocked exactly 90 papers on a Friday would be 50%. To be 80% sure of not stocking out, they would need to carry a

few more papers. A quick way to find the exact number of standard deviations needed for a given probability of stocking out is with the NORMINV function of Microsoft Excel. Given the Excel result (which is more accurate than that of normal distribution tables) the number of extra papers would be (Jacobs, Chase, & Aquilano, 2009, p. 551):

$0.84162 \times 10 = 8.4162$, or 9 papers.

This leads to a problem when the model is programmed as an integer program is much harder to formulate and run. The problem that this uncertainty brings forth is that demand, amount of trucks available and a lot of other variables are not certain and averages are used. When averages are used instead of real or integer numbers, mistakes are always going to occur. Considering the problem mathematically, it is usually written as:

$$F(E(x)) \neq E(F(x))$$

Unless F is linear (where x is the uncertain number) F is the function, and E is the expected or average value. A more detailed version of this statement is known as Jensen's inequality (Savage, 2003).

An example that is usually used to explain the flaw of averages is the sobering example. In this problem the fate of a drunk walking back and forth on a highway is decided. The input to the problem in this case is the drunk's position on the highway, and the output is the expected fate of the drunk.

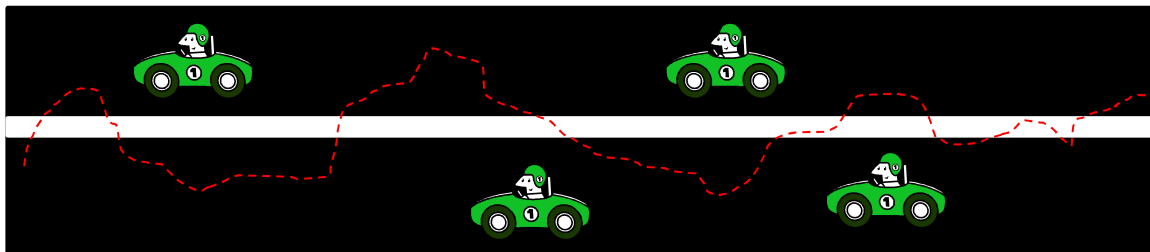


Figure 3: Flaw of Averages Example

If the red dotted line portrays the path which the drunk walked on the busy road one can clearly see that on average he is on the center line where he is safe. However, a better guess would be that he was hit by a car (Savage, 2003, p. 67). This example illustrates that even though something might work on average, it doesn't mean that it is acceptable. When working with algorithms to optimally solve a problem, working with averages can have a major effect on the solution. Even though this problem cannot be avoided by media companies, it is important to take it into account when the programming part of this project starts.

Transport Methods and Capacities

Dr. Michael Hammer argues that collaboration between two companies allows both to perform better than they do separately (Langley, Coyle, Gibson, Novack, & Bardi, 2009, p. 116). While collaboration between companies contributes to a more synergistic business environment, it does tend to pose some problems. From a logistics point of view, these problems can be overcome through the effective and efficient management of a partnership in third party logistics. Media24 and On the Dot collaborate with each other in precisely such a manner as third party logistics firms. Third party logistics can be described as an external firm that performs all or some of another firm's logistics services (Langley, Coyle, Gibson, Novack, & Bardi, 2009). Currently there is a significant increase in the number of companies offering third party logistics services. Examples of the latter include UPS Supply Chain Solutions, Ryder, DHL- Excel, FedEx Supply Chain Services, and IBM Supply Chain Management Services (Langley, Coyle, Gibson, Novack, & Bardi, 2009, pp. 119 - 121). This is not only a very profitable collaboration for Media 24 and On the Dot, but is used by a number of companies worldwide as mentioned in the table below (Stoughton, 2006).

Top Buyers of Third Party Logistics Services		
Rank	Shippers	Number of Third Party Logistics Services Used
1	General Motors	43
2	DaimlerChrysler	32
3	Ford Motor Company, Wal-Mart	30
4	Volkswagen	28
5	Hewlett-Packard	26
6	Unilever	24
7	Procter & Gamble	22
8	General Electric	21
9	Siemens	19
10	BMW	17
11	Georgia-Pacific, IBM, Nestle, Royal Philips Electronics, Toyota Motor	16
12	Home Depot, Sara Lee	15

Figure 4: Third Party Logistics Market Overview

Today the private motor truck carrier is the preferred method of transport by most logistics companies, and On the Dot: Newspapers and Magazines is no exception. The increase in the number of logistics firms using motor truck carriers is due to the relatively low capital required to enter this trade when compared to other modes of transport. There are numerous positive aspects of using trucks; including its high availability and accessibility. Some of the major setbacks of using trucks include the way that weather and traffic can disrupt the motor service industry (Langley, Coyle, Gibson, Novack, & Bardi, 2009, pp. 280-283).

This in turn affects the dependability and reliability of all data collected from the motor carriers. The delivery times to various nodes on the route can change dramatically, having a huge effect on the results obtained by the algorithm. If the delivery times are changed, major constraints are changed and the algorithm could give the wrong solution. The high availability of trucks also leads to a firm owning a dissimilar fleet of trucks, which is not how the basic VRP works. The VRP will have to be adapted to fit a fleet of various trucks. High variable cost and low fixed cost characterize the cost structure as illustrated on the graph below (Langley, Coyle, Gibson, Novack, & Bardi, 2009, p. 328). To optimally solve a routing problem the cost has to be minimized.

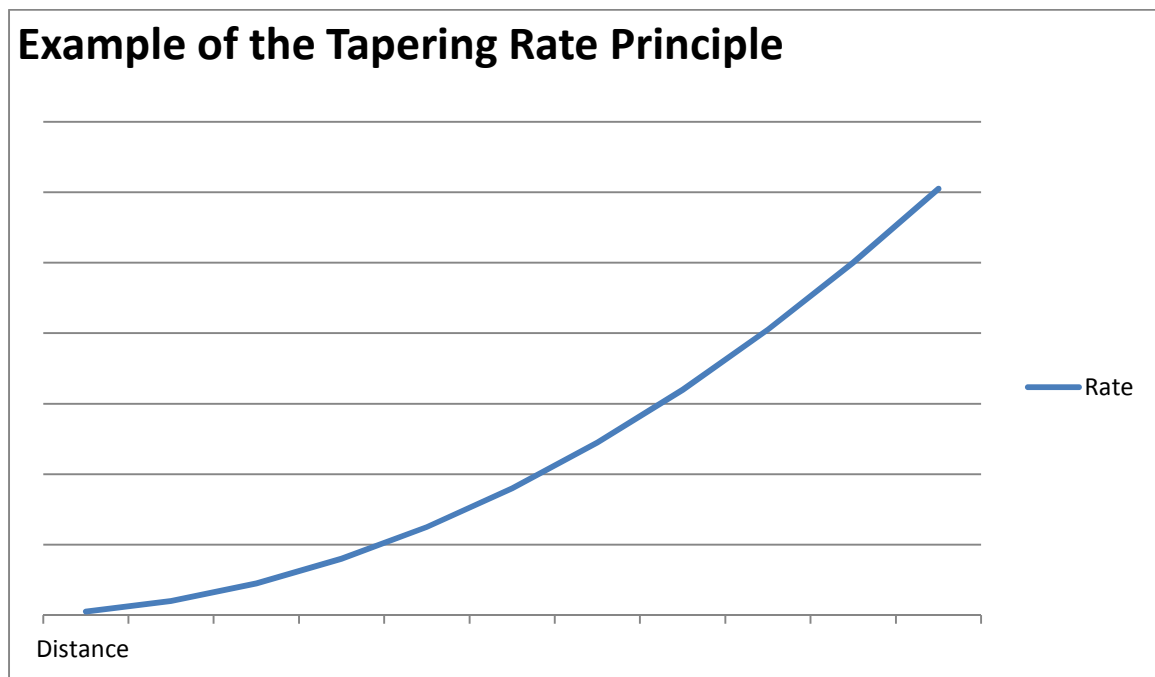


Figure 5: The Tapering Rate Principle

These possible problems can have major effects on the solution of the algorithm, and must be avoided as far as possible.

Literature Review

Linear Programming

Logistics processes are known as different ways which material can be moved. If material is moved into manufacturing it is known as 'inbound logistics', and if material is moved out of a manufacturing process to an outlet, it is known as 'outbound logistics' (Jacobs, Chase, & Aquilano, 2009, p. 10).

Over the previous two decades the term logistics has become commonly known to the general public. Television, radio, and print have stressed the importance of logistics. Transportation firms,

such as UPS, DHL and FedEx, frequently refer to their organizations as logistics companies (Langley, Coyle, Gibson, Novack, & Bardi, 2009, p. 34). Logistics provides three different types of utility to products:

1. Place Utility
2. Time Utility
3. Quantity Utility

Place utility is added to materials by moving them from the manufacturing point, to a place where they can be utilized by customers. Time utility adds utility to the material by having it at the time it is needed by a customer. And finally, quantity utility is added if the right amount is available at the right time and at the right place to the user (Langley, Coyle, Gibson, Novack, & Bardi, 2009, pp. 36-39).

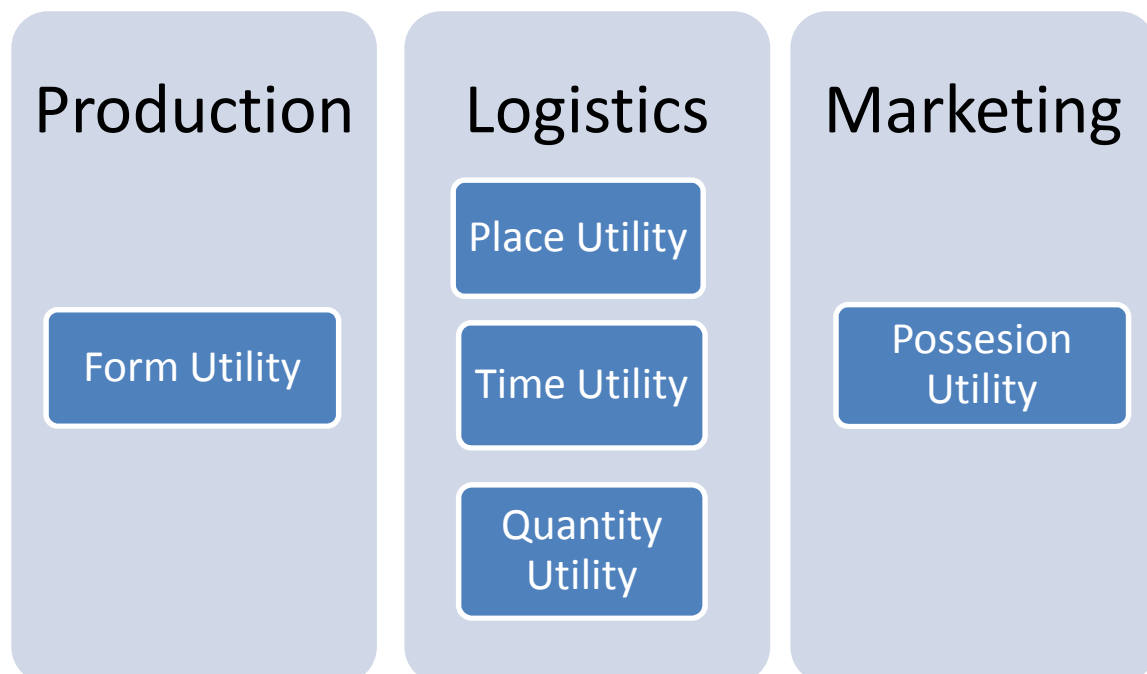


Figure 6: Different Utilities Added to Products

Customers demand products and services at the point of utilization. The point where a product is used or utilized is usually in another geographic area than the point where it is supplied from or manufactured. This problem can usually only be bridged with transportation (Joubert, 2006). There are large benefits for motor carrying companies in implementing advanced vehicle routing systems. It also benefits the general public by addressing traffic congestion, lowering energy consumption and impacting the environment in a positive manner (Joubert, 2006). According to *Managing Supply Chains: A Logistics Approach* (Langley, Coyle, Gibson, Novack, & Bardi, 2009), this can be achieved by one of two methods:

1. **Reducing the Number of Carriers:** By reducing the number of trucks it uses, On the Dot can increase the cargo volume and cargo profit of the truck, thereby increasing its capability to

have the truck providing the rates and services that On the Dot needs (Langley, Coyle, Gibson, Novack, & Bardi, 2009, p. 308).

2. **Consolidating Shipments:** By consolidating shipments, On the Dot can reap the benefits of the lower rates carriers charge for larger shipment volumes. Generally, carriers charge lower rates for shipping larger volumes (Langley, Coyle, Gibson, Novack, & Bardi, 2009, p. 310).

The scheduling and routing of transportation, using the vehicle routing problem or other algorithms, are at the heart of many service operations. Routing and scheduling algorithms are inherently problem specific, meaning that there is not any single algorithm that provides a solution to all problems (Joubert, 2006). In a competitive business environment, logistics operators often use refined vehicle routing and scheduling algorithms to improve the usage of trucks and cut the costs of meeting customer demands (Joubert, 2006). For certain transportation services such as school buses or repair businesses, service delivery is very important in measuring the performance. For other services like taxi's or trucking firms, timely delivery is the most important measure of performance. In either case the optimization of a routing schedule is of the utmost importance in delivering quality service. Optimization means determining the best way to accomplish an objective given the limited resources under one's control (Savage, 2003, p. 223).

The single objective of any routing or scheduling problem is to minimize the total cost of the transportation. The field of mathematics used to optimize routing or scheduling problems are known as mathematical programming. Certain subtopics of mathematical programming include linear programming (LP), nonlinear programming, multi objective programming, goal programming, dynamic programming and multilevel programming (Joubert, 2006). The following are typical applications of LP's (Jacobs, Chase, & Aquilano, 2009):

- Total sales and operations planning
- Analysis of Service or Manufacturing productivity
- Planning of Products
- Routing of Products
- Vehicle or crew schedules
- Process control
- Inventory control
- Distribution Scheduling

- Plant location studies
- Materials handling

The benefits of using linear programming for optimization are endless. Some of the most important benefits are listed below (Savage, 2003, pp. 3-4):

- **The model can show you mistakes in a much cheaper way than implementing in the real world:** The first airplane was built by the Wright brothers. Before the Wright brothers built the airplane and risked their lives in it, they first designed a series of kites, which were modeled to the real aircraft, to do tests on. They could identify crucial mistakes in a much cheaper way than trial and error with a real airplane.
- **A model can result in surprising outcomes to the real world problem:** The absentminded twisting of a bicycle inner tube box supposedly inspired the Wright brothers' unique wing warping system that allowed their plane to bank. Without this finding it would have been impossible to control their plane once in the air, and again this could be dealt with on the ground, and not in the air at the risk of losing their lives.
- **A model allows one to apply analytical tools not available in the real world:** In the case of the Wright brothers, they used a type of a wind tunnel on small scale airplanes which allowed them to test different wingspans and geometries until they found an optimal design.
- **The act of building a model forces one to better understand the relationships being modeled and the data required for analysis:** The Wright brothers built a series of three gliders over three years. Each of these was designed to address a problem they were already aware of, but each illuminated a new problem that they were unaware of. In this way they became aware of new problems that occurred because the model forced them to understand new ideas or theories of aerodynamics.
- **A model serves as a means of communication.** The Wright brothers were exploring new phenomena for which no words existed at the time, but since they both observed the behavior of the same models, they shared the same perception of reality.

Although the abovementioned benefits are very important, in linear programming as in anything in life, it is not perfect. There are certain shortcomings to linear programming.

'All models are wrong, some models are useful' – W. Edwards Deming

Deming, a man that can be described as the father of modern quality control, argues that perfect rationality in modeling is mostly impossible to achieve due to too high computational demands when looking for exact solutions (Savage, 2003, p. 15). It is very important to keep models as simple as possible. Routing and scheduling problems of transportation is almost impossible to solve precisely. The use of solution algorithms to solve these problems will only provide an estimated solution; the algorithm is usually not solved optimally but close to it (Joubert, 2006). George Dantzig, who is considered to be the father of linear programming, contends in the preface of his book, *Linear Programming and Extensions*, that:

'The final test for a theory is its capacity to solve the problems which originated it'.

The technique of linear programming was developed in 1947 by George Dantzig. He first came up with a simple characterization that brought a great class of problems under a single roof. He also devised the simplex algorithm that solved all these problems (Savage, 2003). Applying these linear programs to real-world problems adds new complications for which the theory of optimization has been extended (Savage, 2003, p. 254):

- Optimization might not give integer answers. For example, when producing goods, it is not possible to produce 5.75 cars, even if the model says it is optimal.
- Real-world problems are seldom solved in isolation. For example, a model is not only needed to optimally produce cars in one month, but for the whole year.
- Many aspects of the problem might be uncertain. Optimizing for 'average' conditions might not be optimal under any real life conditions (as mentioned earlier in the flaw of averages example).
- For certain important problems, particularly those in the financial sector, optimization is not linear and requires nonlinear programming. This problem will not use linear programming; it will focus on integer programming.
- Traditionally, optimization models have required rigid mathematical formulation, which was foreign to most managers. The latest versions of Excel Solver and What's Best! go a long way toward relaxing this requirement (Savage, 2003).

Routing and scheduling problems can most easily be understood and visualized if it is looked at graphically as networks. For example, consider the figure below. This figure has four squares which are called nodes. The first node represents the depot, and the rest of the nodes the delivery points. The depot node is where the delivery trip starts and ends. Each node is connected to the next by a

line segment, called arcs. Each arc has a distance that represents the distance that needs to be travelled between two nodes. Any algorithm that has to do with routing and scheduling can be illustrated in this way. There are many different classifications of algorithms used for routing and scheduling, this research will only mention a few applicable examples.

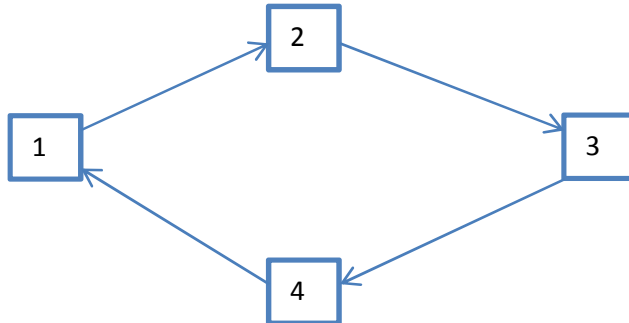


Figure 7: Graphical Example of a Trip

Type	Demand	Number of Depots	Number of Vehicles	Vehicle Capacity
Travelling Salesman Problem	At the nodes	1	=1	Unlimited
Multiple Travelling Salesman Problem	At the nodes	1	> 1	Unlimited
Vehicle Routing Problem	At the nodes	1	> 1	Limited

Figure 8: Different Classifications of Routing Algorithms

The Travelling Salesman Problem

The Travelling Salesman Problem (TSP) is in all probability the most studied routing problem by researchers (Joubert, 2006). It can be described as a set of nodes that needs to be visited by a single vehicle. The order in which the nodes are to be visited can vary, and there is no priority between the nodes. The costs of travelling between the nodes are the same irrespective of the direction travelled. There are no time barriers. The trip starts and ends at the depot node. The only objective of the TSP is to minimize the distance travelled, which will in turn minimize the total cost of the trip (Joubert, 2006).

In reality it is almost impossible and time consuming to try and solve these problems optimally. The only way to get a very good approximation of an optimal solution is by using heuristics, which will be discussed later in the literature review.

To solve a TSP first, a decision variable needs to be defined (Joubert, 2006):

$$X_{ij} \in [0,1]$$

Thus, X_{ij} will be 1 if a truck moves from node i to node j and 0 if it does not. Furthermore a cost variable also needs to be defined, which leads to the objective function of:

$$\text{Min } Z = \sum_{i=1}^N \sum_{j=1}^N X_{ij} \cdot C_{ij}$$

Thus if the minimum of the abovementioned formula is obtained, the TSP will be solved subject to certain constraints (Joubert, 2006). The problem that this research finds with using the TSP is that only one vehicle is used and not a fleet. And although there are many variants of the TSP available, for the purposes of this study, the Multiple Travelling Salesman Problem is the most appropriate.

Multiple Travelling Salesman Problem

The Multiple Travelling Salesman Problem (MTSP) is another form of the TSP. As the name states, it uses multiple vehicles and still a single depot. In the MTSP trips for a number of trucks are determined instead of only one. The MTSP is more difficult to solve than the TSP since it requires assigning different nodes to different salespersons or nodes (Joubert, 2006). The MTSP consists of finding a number of trips, N, for salesmen, each starting and ending at the depot. Each node is visited exactly once by a single salesman and all trips have to be completed by a certain time. Again the objective is to minimize the cost of all the trips combined (Joubert, 2006). The problem must be condensed to N single truck Travelling Salesman Problems, and must once again be solved with the help of heuristics. The objective function remains as:

$$\text{Min } Z = \sum_{i=1}^N \sum_{j=1}^N X_{ij} \cdot C_{ij}$$

The shortcoming of the MTSP is that the vehicle has no limited capacity and the demand at various nodes must be the same. The next type of algorithm will be another step closer to being able to solve the problem as stated in this paper. These shortcomings can be solved by the Vehicle Routing Problem (Moolman, 2004).

The Vehicle Routing Problem

In 1959 Dantzig introduced the Vehicle Routing Problem (VRP). Since then the VRP and its variants have been used to solve numerous problems because of the importance of mobility in logistics and supply chain management (Dantzig & Ramser, 1959). Vehicle routing can be seen in many every day examples where delivery per truck happens from a depot to the retailer (Moolman, 2004). The VRP has been seen as one of the greatest success stories of mathematical programming since the early sixties. Whilst being a close derivative of the TSP, the VRP is more complicated and much more difficult to solve.

The VRP is known as a distribution problem in which trucks start and end their trips from a single depot and visit various nodes to fulfill demand during a given time frame (Joubert, 2006). This

means that the total demand of a trip cannot exceed the total capacity of all the trucks (Moolman, 2004). This is the same type of problem that Media 24 has encountered. The main objective of the VRP, as in the case of the MTSP, is to minimize the cost of transporting certain goods to all the various nodes. The problem is to assign optimal delivery routes from a depot, to several nodes located in different geographic areas, these are subject to constraints.

The basic VRP is to route the trucks, one route per truck, each starting and finishing at the warehouse as illustrated below (Boading, 2009).

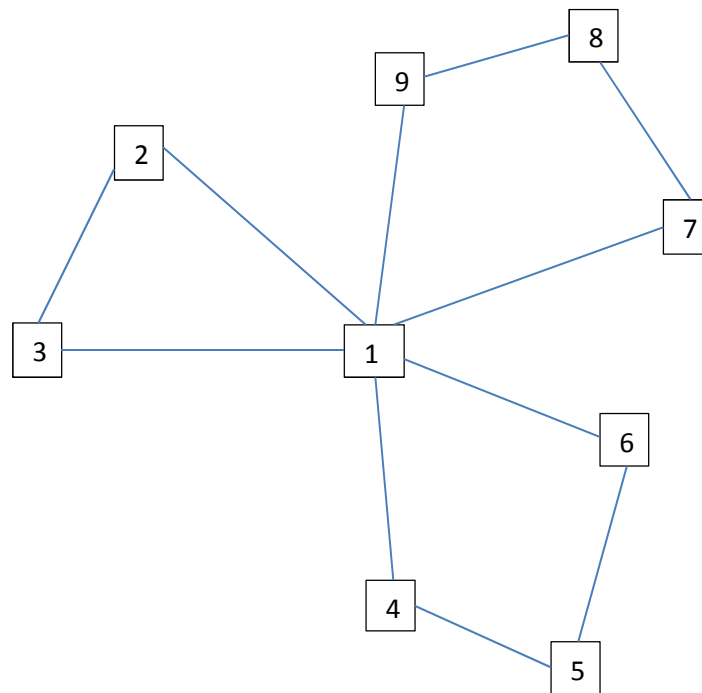


Figure 9: Vehicle Routing Graph

Due to the number of different ways that VRP can be applied, and its profitability, VRP has been studied broadly. In practice, there are factors that are not definite in VRP, such as demands of customers, travel times between customers, the number of customers to be visited, the locations of customers, the capacities of vehicles, and the number of vehicles available. This fact motivates a study of uncertain factors in VRP not only for Media 24, but for most organizations (Boading, 2009).

An extension of the VRP that has been researched and studied extensively is the time window. A time window is the period of time during which deliveries can be made to a specific customer i , and has three main characteristics (Joubert, 2006):

- Earliest allowed arrival time, e_i , also referred to as opening time
- Latest allowed arrival time, l_i , also referred to as closing time

- Whether the time window is considered soft or hard.

For example:



Figure 10: Double Sided Hard Time Window



Figure 11: Soft Sided Time Window

These time windows will be very important issues in this project as the newspapers can only be delivered early in the mornings and the magazines can only be delivered later in the days, after the outlets have opened.

The objective function as it was stated in the MTSP now changes as the trucks are no longer necessarily the same. The decision variable now becomes:

$$X_{ijk} \in [0,1]$$

And the objective function changes to (Joubert, 2006):

$$Min Z = \sum_{i=1}^N \sum_{j=1}^N \sum_{k=1}^K X_{ijk} \cdot C_{ij}$$

Heuristics

If an algorithm produces the best mathematical solution possible for a certain problem it is called the optimal solution. If an algorithm produces a close to optimal solution, it is called a heuristic (Moolman, 2004). Heuristics techniques are usually applied to solve algorithms that take a long time to solve optimally. Heuristics do not necessarily solve a problem optimally, but rather give an informed estimate of an optimal answer (Winston & Venkataramanan, 2003). The TSP is a classic example of where heuristics are useful in achieving a close to optimal result because it is a nondeterministic problem. Nondeterministic problems are a certain class of problems that require

an excessive amount of computational time. Heuristic algorithms are usually used to solve nondeterministic problems (Winston & Venkataramanan, 2003).

Heuristic methods are excellent tools to use when solving a VRP (Moolman, 2004). Meta-heuristics, or global optimization heuristics, all have a the same form; they all use a concept derived from nature, artificial intelligence, physics or biology to guide the heuristic to improve the performance close to optimal (Moolman, 2004). For example certain heuristics use the evolution theory from nature to make an intelligent choice of what the next node should be.

Currently there are six groups of Meta-heuristics that have been used to solve the VRP (Moolman, 2004):

1. Simulated Annealing
2. Deterministic Annealing
3. Tabu Search
4. Genetic Algorithms
5. Ant Systems
6. Neural Networks

If the problem is to be programmed, one of these heuristics would be used by the programmer.

Data Analysis

The Basic VRP

The VRP at its most basic form is a problem with a single depot, with a number of nodes or customers to be visited, a number of arcs connecting the nodes to each other and a fleet of homogeneous trucks. A route is defined as a single trip of a truck to a number of nodes, and back to the depot. Each arc connecting two consecutive nodes has a distance and travel time associated with it (Moolman, 2004). If it is assumed that the number of Trucks (T) is K, and the number of Customers (C) or nodes is N, it can be written as:

$$T = \{1, 2, 3, 4, 5, 6, \dots, K\}$$

And

$$C = \{0, 1, 2, 3, 4, 5, 6, \dots, N\}$$

With C_0 being the Depot

The VRP must be formulated in such a way that the objective function is minimized. The objective of the problem can be anything that is related to the transportation costs. After the objective function is formulated, the following constraints need to be applied to the problem:

- Only a single truck can service a customer per day.
- There are only as many trucks as there are routes. A truck can only take one route once a day.
- The customers' demand is known beforehand
- The sum of all the customers' demand for a single route cannot exceed the capacity of the truck servicing the route.
- The distance between customers i and j should be the same as the distance between customers j and i .
- The trucks in the fleet must have the same capacity. (This is not true in practice but will be assumed at this stage to try and solve the VRP in its most basic form)
- The trucks must complete their routes before a certain time.
- The route of each truck ends at the depot.
- A cost C_{ij} and a time T_{ij} are assigned to every arc connecting two nodes.

There are 2 types of decision variables (Moolman, 2004):

- The variable X_{ijk} is 1 if a truck, k , move from a node i to j , and 0 if it does not.
- The variable T_i is the time at which the truck leaves the node i .

The goal of this objective function is to minimize the transportation cost, subject to all of the above mentioned constraints.

To solve this problem mathematically, the correct notation must first be chosen and applied throughout.

Notation:

- K is the number of trucks.
- N states the total number of customers.
- C_{ij} is the cost of travelling between node i and node j .
- C_0 is the depot.
- T_{ij} is the time that it takes a truck to travel from node i to node j .
- D_i is the demand at node i . Demand is measured in kilogram. The reason for is that the weight and thickness of newspapers changes each day. If the amount of papers is multiplied by the weight per paper each day, demand is in kilogram. It is easier to work with demand in kilogram as the capacity of a truck is also measured in kilogram.
- Z_k is the maximum capacity that a truck k can handle in kilogram.
- e_i is the time that deliveries to node i can start.
- l_i is the time at which deliveries at node i must be completed.
- S_i is the time it takes to service node i .
- T_i is the time at which the truck arrives at node i .
- b_k is the total time allowed on the route for truck k .

The objective function consequently becomes:

$$MIN \sum_{i=0}^N \sum_{j=0}^N \sum_{k=0}^K X_{ijk} \cdot C_{ij}$$

To recapitulate what this equation means, if a truck k moves from node i to j the variable X_{ijk} will be equal to 1, if it does not move, X_{ijk} is equal to 0. This means that only the routes that are taken will be summated and that is why X_{ijk} is called a decision variable. The routes taken will now be equal to 1, which is in turn multiplied by the cost of moving between node i and node j . The sum of all these costs will then be equal to the total cost of transporting newspapers from the depot in Johannesburg to all the various nodes. If this cost is minimized, an optimal solution to the delivery routes will be obtained.

This objective function is subject to the following constraints:

$$\sum_{j=1}^N X_{ijk} = \sum_{j=1}^N X_{jik} \leq 1 \text{ for } i = 0; k \in [0, K] \quad (1)$$

This means that each truck leaving the depot must return to the depot.

$$\sum_{k=0}^K \sum_{j=1}^N X_{ijk} = 1 \text{ for } i = 1, 2, \dots, N \quad (2)$$

This means that every node must be serviced exactly once.

$$\sum_{k=0}^K \sum_{j=1}^N X_{ijk} = K \text{ for } i = 0 \quad (3)$$

This means that there are only as many trucks as there are routes.

$$\sum_{i=0}^N X_{ihk} - \sum_{j=1}^N X_{hjk} = 0 \quad \forall h \in [0, N]; k \in [0, K] \quad (4)$$

This means that every node must be serviced by one truck only.

$$\sum_{i=1}^N \sum_{j=1}^N X_{ij} \leq (N - 1) \quad (5)$$

This means that every route must at some point pass through the depot.

$$\sum_{i=0}^N D_i \cdot \sum_{j=0, j \neq i}^N X_{ijk} \leq Z_k \quad \forall k \in [0, K] \quad (6)$$

This means that the total demand of a certain route cannot exceed the total capacity of a truck on that route.

$$\sum_{i=0}^N \sum_{j=0, j \neq i}^N X_{ijk} \cdot (T_{ij} + S_i) \leq b_k \quad \forall k \in [0, K] \quad (7)$$

This means that an absolute maximum travel time of a route for each truck is fixed.

Constraints of the Problem

The above model is a model for a basic VRP. In the problem discussed in this research, additional constraints need to be added to the model. The constraints must relate to the following characteristics as set by Media24:

1. The demand of newspapers differs from day to day. The demand is known before the trucks leave the depot, but the demand changes every day. The most newspapers that need to be delivered per day are approximately 800 000, and the least will be on a Saturday when it is about 90 000. Magazines amount to about 10 000 per day.

2. Time windows needs to be added to the above mentioned constraints for the time available to load the trucks. The time windows in which the newspapers can be loaded onto the trucks are from 22:00 to 4:00.
3. A loading time for the trucks needs to be added to the above mentioned constraints. The time that it takes to load a truck can vary from 15 minutes to an hour depending on the quantity being loaded, and the capacity of a truck.
4. Delivery time windows also need to be added to the constraints. The delivery time windows are broken up into three categories:
 - 4.1. Subscribers must receive their papers at the latest at 6:00
 - 4.2. Agents or retailers must receive their papers at the latest at 8:00
 - 4.3. Kwazulu Natal retailers or agents can receive their papers at the latest at 12:00
5. An unloading time also needs to be added at every customer or node. The time it takes a truck to unload at every delivery point is between 20 minutes and an hour.
6. The fleet is not a homogeneous fleet of trucks and thus this constraint also needs to be changed. There are four different types of delivery vehicles for which the capacities vary:
 - 6.1. Passenger cars can handle up to half a ton
 - 6.2. Bakkies can handle up to 1.3 tons
 - 6.3. Sprinters can handle up to 3.5 tons
 - 6.4. Trucks can handle up to 10 tons
7. The starting location or depot is situated in Johannesburg and is named City Deep Printers
8. Costs of the contractors that operate the vehicles are fixed per kilometer.
9. The weights of the newspapers differ from newspaper to newspaper and are illustrated in the table below:

Newspapers:	Mass per Bundle:
Beeld	8 – 12 kg
Daily Sun	24 – 40 kg
Laduma	70 – 80 kg
Vaalweekblad	100 kg
Potchefstroom en Carltonville Herald	40 – 80 kg
Raport	12 – 20 kg
Sondag	80 kg
City Press	12 – 20 kg
Sunday Sun	80 kg

Figure 12: Weights per Bundle of Various Newspapers

This research focuses on formulating a VRP that fits all the constraints as mentioned. The VRP could then be solved using various heuristics and programming skills by a programmer. Once a solution is found mathematically, the program should be written in such a fashion that the VRP can be adapted by Media24 should any changes occur to their current setup.

The Revised VRP

More constraints need to be added to the basic VRP, these include:

$$T_o = 0 \quad (8)$$

This means that the time when the truck leaves the depot is 0. In many forms of programming there exists a counter for time and it can easily be coded to fit the problem.

$$T_i + X_{ijk} \cdot (T_{ij} + S_i) \leq T_j \quad i, j \in [1, N]; i \neq j; k \in [0, K] \quad (9)$$

This means that if the arrival time at node i is added to the service time of node i and the travel time between nodes i and j, the answer will be smaller or equal to the arrival time at node j.

$$e_i \leq T_i \leq l_i \quad (10)$$

This means that the arrival time of a truck at node i cannot be earlier than the earliest delivery time of the node, and not later than the latest delivery time of the specific node. The e_i and l_i will be different for newspapers and magazines.

$$S_i = \text{Fixed Time} + (\text{Variable Time} \times D_i) \quad (11)$$

This means that the service time at a node will be equal to a certain fixed time, and also subject to the demand at the specific node multiplied by a variable time. It then states that the larger the demand of a certain node, the longer the service time will take.

$$T_{ij} = \text{Starts at } (T_i + S_i) \quad (12)$$

This means that the travel time between two nodes i and j will only start after the arrival time at i added to the service time at i.

$$C_{ij} = (\text{Variable Cost of Fuel per kilometre} + \text{Variable Cost of operator per kilometre}) \times \text{Distance travelled} \quad (13)$$

A note must be made in the program that the trucks are not of the same size or capacity.

Programming

Integer Programming

Although the possibilities with integer programming (IP) are wide, it does require a certain level of skill to use in an effective manner. Integer programming differs from linear programming in the sense that it can be formulated as an IP, but it takes a long time to solve. If the formulation is not done correctly, it will consume an excessive amount of computational time. Therefore it requires exceptional experience in the field of IP to solve the problem (Schrage, pp. 29-30). IP programs are

difficult to solve. The time it takes to solve an IP may decrease as the number of constraints increase which is in strong contrast with LP's (Schrage, p. 262).

This means that a skilled programmer would have to solve the abovementioned revised VRP. After careful consideration it was found that it would be feasible to solve this type of problem, but that there are certain requirements that the program must fulfill such as an appropriate interface (Fourie, 2012).

Interface

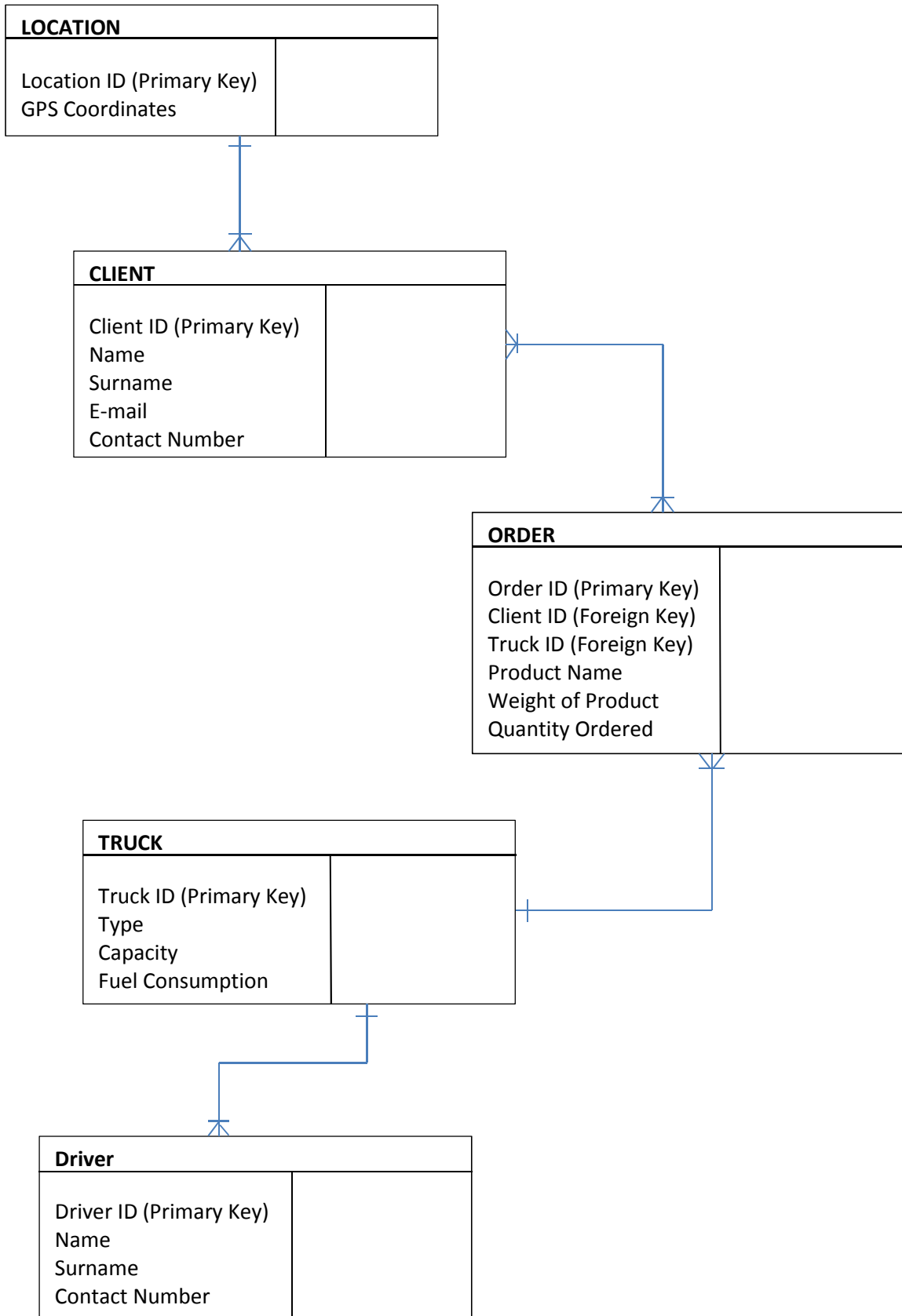
An interface is, according Dictionary.com (2012), a point where two systems, subjects, organizations, etc., meet and interact. The interface will allow anybody to be able to operate the program, even with no training in programming. In contrast to popular believe an interface was designed to protect code from incompetent users, specifically encapsulation (protection of valuable variable) and polymerization (the ability to have multiple different objects of a class).

An interface is a vital part of this program. It is such an important part because changes to the problem occur at a daily basis. The demand varies by a large extend every day. The demand for each day must be entered by the user. The amount of truck drivers can also vary as some do not show up at work every day or, as is common is South Africa, truck drivers that strike almost on a yearly basis. The amount of truck drivers available needs to be entered by the user each day. The trucks can change, as new ones can be bought and old ones sold. The program must allow trucks to be deleted and added to the program. The new trucks capacity and fuel consumption must also be added. Delivery locations can change. All of these variables must be added by the person operating the program, and the interface must be written in such a way that it is easy to do so.

Without an interface allowing certain changes to be made, the model would not be reusable after a while and the whole project would be futile. The form of the interface is discussed in more detail in the appendix.

Entity Relationship Diagram (ERD)

There are a number of different notations that exist for data modeling. The model is commonly referred to as an entity relationship diagram as it depicts data in terms of entities and their relationships (Bentley & Whitten, 2007). For the purposes of the programmer, an ERD was made to show how the problem fits together and how the interface should work once it is programmed. This ERD can be seen on the following page.



Conclusion

This study proves that significant savings can be made by optimizing logistics in an organization. After studying a wide spectrum of both linear and integer programs, the vehicle routing problem was chosen and modified to fit the needs of Media 24 mathematically. This research also went further by showing that experience and knowledge are required to write this problem as a user friendly program the everyday users can use. After careful consideration of the results found by this research it is believed that substantial changes can be made to the delivery routes of Media 24 that will benefit them financially in the future.

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Appendix

Interface

If it was decided the program would be written, a suitable software package to use would be Visual Studios. Visual Studios links up with SQL Server, from where data tables could be fabricated. The form that would open if the interface were to be used by the user, as explained in the before mentioned ERD, would look like this:

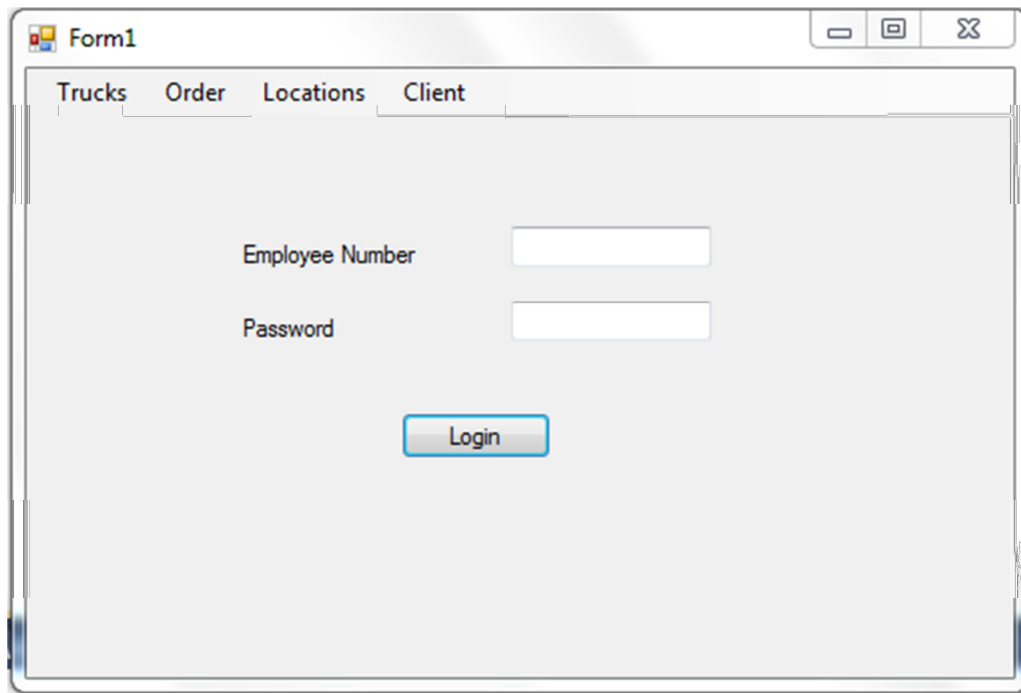
The image shows a Windows-style window titled "Form1". At the top, there are four tabs: "Trucks", "Order", "Locations", and "Client". The "Trucks" tab is currently selected. The main area of the form contains two input fields: "Employee Number" and "Password". Below these fields is a "Login" button. The window has standard minimize, maximize, and close buttons in the top right corner.

Figure 13: Form 1

From this home page, the user will be requested to enter a password or an employee number as illustrated above. After logging in, the four tabs in the left hand corner will be available to use. The first of these could be trucks. The form of trucks:

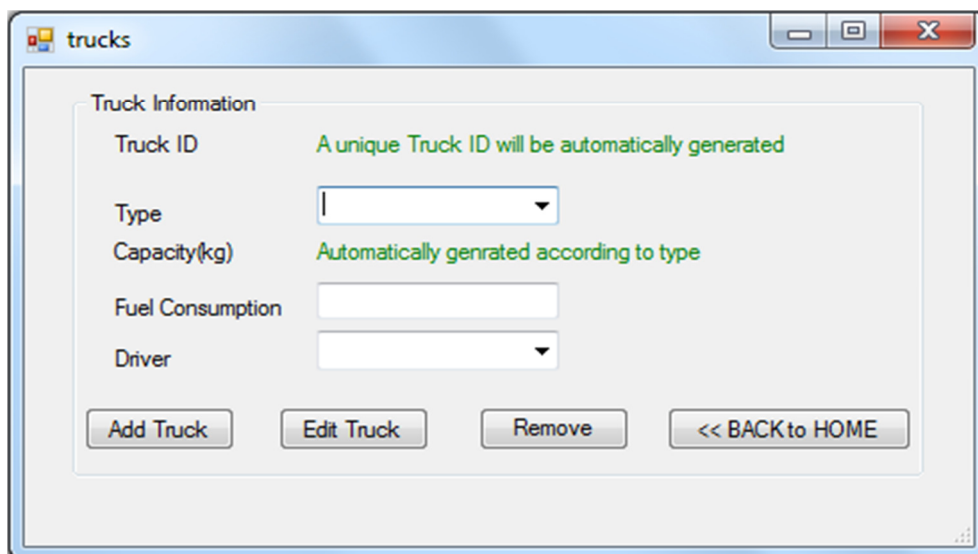
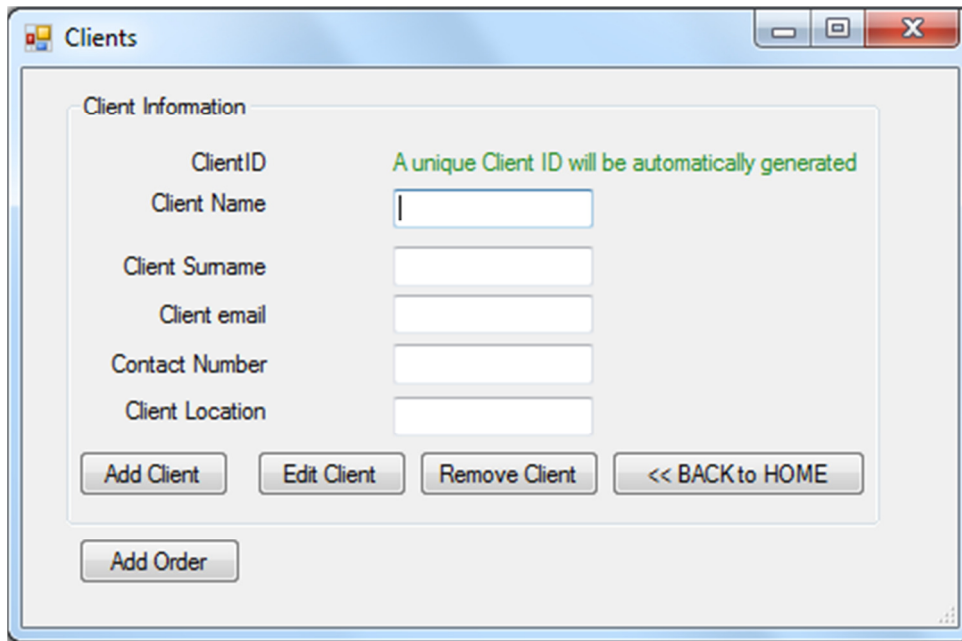
The image shows a Windows-style window titled "trucks". The form is titled "Truck Information" and contains several fields: "Truck ID" with a green note "A unique Truck ID will be automatically generated"; "Type" with a dropdown menu; "Capacity(kg)" with a green note "Automatically generated according to type"; "Fuel Consumption" with an input field; and "Driver" with a dropdown menu. At the bottom of the form, there are four buttons: "Add Truck", "Edit Truck", "Remove", and "<< BACKto HOME". The window has standard minimize, maximize, and close buttons in the top right corner.

Figure 14: Trucks Form

From this form each truck will receive a unique Truck ID which will be the primary key of trucks. The type of truck can be chosen from a dropdown list that has all four types of vehicles to choose from. The capacity will be known according to the type of vehicle chosen. Fuel consumption for each truck should be entered as this may differ. The available driver of the truck can also be chosen from a dropdown list containing all the names of the drivers. Trucks could be added and removed depending on new trucks being purchased.

Another tab will contain the clients:



The screenshot shows a software window titled "Clients". Inside the window, there is a section titled "Client Information". This section contains the following fields and controls:

- ClientID:** A text field with a green message above it stating "A unique Client ID will be automatically generated".
- Client Name:** A text input field.
- Client Surname:** A text input field.
- Client email:** A text input field.
- Contact Number:** A text input field.
- Client Location:** A text input field.

Below the input fields, there are four buttons: "Add Client", "Edit Client", "Remove Client", and "<< BACKto HOME". At the bottom left of the window, there is an "Add Order" button.

Figure 15: Clients Form

From this form the user could choose the applicable client and the details of the client will automatically appear, including a unique client ID. Clients could be added, removed or edited from this form. To add an order to a specific client the user could click on the 'add order' button in the bottom left hand corner. The order form will then automatically open:

Figure 16: Order Form

This form will generate a unique order ID. The description of the order can be entered. The order type can be chosen from a dropdown list containing all of the different products that Media 24 provides. The quantity that will be ordered should also be entered. On the right hand side of the form both the customer and the truck that the program assigns to the order will be displayed.

The final form that should be available should be the location form. On this form a data table of the distances between all of the locations should be added. This form should also contain a button to both add and remove locations.