

Determining Optimum City Size Based On Cost Effective and Efficient Public Service Delivery

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Executive Summary

This project deals with the problem that cities and/or towns in South Africa are expanding very rapidly and public services can't keep up with this growth. It is also becoming increasingly difficult to provide public services at a reasonable cost to these expanding residential and commercial areas. Obviously the costs of providing public services and the growth of a city share a relationship. It is from these issues that the need for a model to determine optimum city size, based on public service delivery, arises.

The project consists of two phases. The first phase was to establish a model to determine what drives public service costs and the second phase was to establish a model to determine the maximum size of a city based on minimizing public service costs.

The initial scope of this project was to be able to establish a model to be able to calculate optimum city size with regards to and driven by public service delivery, but a generic cost model was created to calculate public service costs to help answer the initial scope. This was done because of the lack of data and certain restrictions. The cost function will be based on the cost of completing a "trip" of distance t . A "trip" being defined as the distance traveled to provide a single instance of the specific service and this had to start with establishing the fixed and variable costs involved. The specific public services that will be focused on are police department services, ambulance services and fire department services.

The vehicle running costs and fixed costs are combined and reconciled into:
 $j = ((Ap + B + C)tz + i(h) + l + g + v + e + d + sn)m$. Running costs per kilometer, Fuel (petrol/diesel) price, Tire costs per kilometer, License fees and Vehicle depreciation form part of this equation.

The relationship between the costs and serviceable area of a service office/station are directly proportionate to each other in the sense that if you want to cover a larger area, more costs will be incurred and a larger budget is needed. A service office/station could basically cater for an infinite area if the money is available. Time (24 hours in a day) is the only real constraint. Later on it was found that traffic conditions and desired response time truly govern a service office/station's serviceable area. Traffic conditions dictate the speed at which the vehicles can travel and the desired response time together with that will determine the serviceable area.

To determine optimum city size was not fully realised during the project, but great steps were made towards reaching this goal. The geographical layout and infrastructure were identified as the main variables that determine optimum city size. The geographical layout is recognised as the primary driver and infrastructure as the secondary driver. More study is needed to fully understand the impact of traffic conditions, desired response time, geographical layout, infrastructure, incident severity and amount of incidents on the total scope of the project.

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1. Introduction

This project deals with rapidly expanding cities in South Africa. This is mostly because of people migrating from rural areas to cities as well as all the residential areas that are expanding further away from the city centers. This can be attributed to people's need for better jobs and businesses and commercial areas also moving further away from the city centers that results in a continuous process of businesses driving the residential areas further and further away.

Because of this phenomenon public services can't keep up with the growth of the cities which results in some individuals ending up without basic public services or very bad service delivery. It is also becoming increasingly difficult to provide public services at a reasonable cost to these expanding residential and commercial areas. Obviously the costs of providing public services and the growth of a city share a relationship, but this relationship needs to be determined. It will eventually indicate a threshold of where the current public services cannot cater for all the inhabitants because they are just too far away and the associated costs are too high. For providing public services, a city has to have a threshold that defines its maximum size that ensures the costs of public services are kept to a minimum or if you will an optimum city size.

The project will investigate the driving force behind the costs of public services as well as how to determine the maximum size of a city based on public service costs. It will deal with questions like: "How will one go about calculating the maximum size of a city in order for public services to be cost effective and efficient?", As well as, "How do the costs of public services fit into these calculations?"

Addressing this problem will consist of building an algorithm or a model to determine the maximum size of a city or town so that its public services can service all the inhabitants, whilst keeping the costs to a minimum.

In order to be able to get to the eventual goal of determining optimum city size, we need to establish cost functions for the public services that are being considered. Determining these functions will be the first and foremost goal of the project and the model for determining optimum city size will be a secondary goal.

The focus of this project will be on the costs only and no scheduling problems will be addressed.

1.1. Background

1.1.1. Definition of Public Services

Public services is a term usually used to describe services provided by government to its citizens, either directly (through the public sector) or by financing private provision of services. The term is associated with a social consensus (usually expressed through democratic elections) that certain services should be available to all, regardless of income. Even where public services are neither publicly provided nor publicly financed, for social and political reasons they are usually subject to regulation going beyond that applying to most economic sectors. [1]

Public services tend to be those considered so essential to modern life that for moral reasons their universal provision should be guaranteed, and they may be associated with fundamental human rights (such as the right to water). In modern, developed countries the term public services often include the following: [1]

- Broadcasting

- Education
- Electricity
- Fire service
- Gas
- Health Care (Ambulance)
- Military
- Police Service
- Public Transportation
- Social Housing
- Telecommunications
- Town Planning
- Waste Management (Sanitation and refuse removal)
- Water Services

1.1.2. The State of Public Service Delivery In South Africa

The state of public service delivery in South Africa can only be described as lacking in most aspects. Although a lot of the wealthier South African citizens receive good service delivery and pay for the services they receive, a large portion of the country cannot afford to pay for services, if they are so lucky to have access to basic services. These residents fall within the poor to very poor class of citizens.

In the article "The Bell Tolls For Thee: Cost Recovery, Cutoffs, and the Affordability of Municipal Services in South Africa" by David A McDonald these claims can be seen through the presented statistics. They offer a picture of post-apartheid service delivery that is at best plagued by affordability problems and overly aggressive bureaucrats bent on recovering costs, and at worst a deep failure on the part of government (both local and national) to ensure an affordable supply of essential services to all. That government has not been closely monitoring and evaluating the scale and character of service cutoffs and affordability is itself deeply concerning. [2], page 21

Perhaps the most important conclusion to draw from this survey is that there is an urgent need to debunk the myth of a "culture of non-payment". If, as I

have argued here, ability to pay is more important than willingness to pay, then no amount of moralizing or threatening is going to alleviate the payments crisis in the country. You cannot squeeze blood from a stone. [2], page 21

Central government has committed itself to providing access to “basic supplies” of water and electricity to all of these remaining households by 2008 and 2012 respectively, but the bulk of the remaining water and electricity connections will be in difficult to access rural areas where capital and operating costs per unit are significantly higher than urban areas due to lower population densities and longer distances from water and electricity sources. These service extensions will therefore take longer to complete, will be significantly more costly to install, and could result in substantially higher per unit costs for consumers if direct cost recovery principles are applied. [2], page 4

Access to basic municipal services, therefore, is still a major concern in South Africa, and will remain so for many years to come. But it is to the more vexing question of affordability that we now turn. Access to services is of little consequence if households are unable to afford the costs of using them. [2], page 5

Apart from the clear lack of service delivery with regards to the basics of water and electricity, the next most essential services to ones survival are medical and security services, security of self and of one’s possessions. The services that cater towards these needs are police, fire and health (ambulance) services. The availability of these services is just as bad as the water and electricity supply and will play the biggest role within this project.

The fact of the matter is that in South Africa the wealthier citizens will have to pay more for their services to subsidize the poorer citizens who cannot

afford to pay and this will have a great influence on the cost models that will be created in this project. Whether it is by paying for water and electricity directly to the municipality or the paying of taxes to sustain police, fire and health services; this trend will continue to exist in South Africa for many years to come, until all citizens at least have access to basic services.

1.1.3. City Growth And The Need For Public Service Delivery

Urban populations and city growth have a very large impact on the need for service delivery. Mostly because the more residents that are located in an area, the more service infrastructure and service delivery is needed. Migration and urbanisation both influences urban populations tremendously.

Migration can theoretically and operationally be defined as the crossing of the boundary of a predefined spatial unit by persons involved in a change of residence. [3], page 7

Urbanisation can therefore be defined formally as the increase in the urban population of a country or area due to the following components of urban population growth: (a) urban natural increase, (b) urban net migration, and (c) the reclassification of parts of the rural population into the category 'urban' (due to the sprawl of existing urban areas into their rural surroundings or the development of new towns in former rural areas). [3], page 17

1.2. Problem Statement

One of the biggest challenges for municipalities and city planners in this day and age is the growth, expansion and urbanization of cities in the twenty first century. One of the most important factors that influence their decision making is the provision of public services to the city's residents.

It is from these issues that the need for a model to determine optimum city size, based on public service delivery, arises. This specific project will focus on building the first part needed to complete the eventual goal of the project. It will focus on determining a cost function for providing a public service. The cost function will be based on the cost of completing a "trip" of distance t . A "trip" being defined as the distance traveled to provide a single instance of the specific service.

The specific public services that will be focused on are:

- Police Department Services
- Ambulance Emergency Services
- Fire Department Services

*Each of the above mentioned services will be comprehensively discussed and defined in section 5.

These services were identified because of their significant use of vehicles for delivering their service and this forms part of the scope of the project.

1.3. Project Scope

The project research and data collection will be done at and based on cities located in South Africa. This will only be done if co-operation is received from the municipalities in these regions, otherwise data and information that is generally available will be utilised. In the end no such cooperation was received from municipalities or government organizations and generally available information was utilized.

Because the various municipalities and government organisations were not willing to give access to their resources, certain assumptions will have to be made with respect to the models discussed. These assumptions will obviously be thoroughly researched and documented to prove their relevancy to the project.

The entire project will mainly consist of two phases. The first phase will be the establishing of the first model to determine what drives public service costs and the second phase will be the establishing of the second model to determine the maximum size of city based on minimizing public service costs. The second phase will only be attempted if it is perceived as feasible within the given time frame. The time frame will be taken as 30 January 2008 to end October 2008. The second phase of the project was found to be unfeasible to be attempted within the given time frame and can be addressed in a future project to further study and investigate its relevance and importance.

This project was proposed by Dr. PJ Jacobs from the Department of Industrial Engineering at the University of Pretoria and is not to be done for a specific company. It may benefit the public services (fire, ambulance etc.) sector and/or municipalities in South Africa and may assist them in the planning of new or existing towns and municipalities as well as provide some assistance with budgeting for public service costs.

The project will involve the use of statistical and economic industrial engineering principals taught during the Industrial Engineering course at the University of Pretoria.

1.4. Project Aim

The aim and goal of this project is to firstly determine the context and area of focus for the intended cost functions. It needs to be determined what items are included and form a part of each of the cost functions. For example, determining if the salaries of the employees form a part of the fixed costs component of the cost function.

The next goal is to create a model to determine how costs are calculated with respect to each of the identified public services. A second model needs

to be created and will consist of a combination of the cost models established in the first phase. The aim of the second model will be to determine the maximum size or threshold of a city based on the provision of public services to all of its residents at the lowest possible cost.

Both models will require specific inputs from the user and these inputs will be based on the public service that the model was created around. These inputs can be described as the key drivers of the model. With respect to the cost models, it will be the factors that drive the total cost of that specific public service. The model that will be used to determine the maximum size of a city based on its public service costs will use inputs that are specific to the type of area or city that is being evaluated. This can consist of residential, commercial or rural areas.

The aim of the project is merely a goal set at the beginning of the project and it may change during the course of the project due to further investigation into the subject. This may be as a result of the complexity of the project and the creation of certain aspects or parts of the project may be placed on hold for the time being and could be addressed with in a future project.

1.5. Project Deliverables

1.5.1. University of Pretoria Deliverables

According to the study manual provided for the BPJ410 and BPJ420 modules as presented by the University of Pretoria, the following deliverables are needed:

1. Project proposal
2. Interim project report
3. Final project report draft
4. Final project report
5. Final project presentation, poster and oral examination

1.5.2. Project Deliverables

The deliverables as required by Dr. PJ Jacobs have not been fully discussed yet, but the following deliverables are proposed:

1. An excel based cost model relating to each public service identified for this project.
2. An excel based model or algorithm to determine a city's maximum size relating to its public services.
3. An example of how the above mentioned models work for an existing and fictional city.

2. Literature Review

The research conducted for this project shows that no other projects have been attempted specifically to determine optimum city size based on public service delivery. This fact makes the project very exciting and difficult at the same time due to the novel ideas behind it. Although no literature on this exact subject could be found, a large number of articles, websites and books can be found on similar subjects and subjects that can be applied on the ideas behind this project.

The information that follows is only a small portion of the literature that was reviewed, but contains some of the most relevant information found. Further more a list of all the articles, websites and books that was reviewed but not referenced can be found in the Appendices at the back of the document.

2.1. The Sizes and Types of Cities by J.V. Henderson

This paper presents a general equilibrium model of an economy where production and consumption occur in cities. The paper solves for equilibrium and optimum city sizes, discussing under what situations the equilibrium size differs from the optimum. Optimum city sizes are defined as those which maximize potential welfare of participants in the economy. Equilibrium city sizes are determined by the location or investment decisions

of laborers and capital owners, each attempting to maximize their own perceived welfare. [4], page 640

Some of the basic concepts underlying the model are contained in the following propositions. We observe population agglomeration or cities because there are technological economies of scale in production or consumption and because these activities are not space or land intensive (relative to agriculture). [4], page 640

This study deals mainly with an economy where there is only one type of city. Each city produces and exports the same traded good at a fixed price to other regions or countries. In return the cities import another consumption good at a fixed price. [4], page 641

From these abstracts from the article "The Sizes and Types of Cities" by J.V. Henderson it can be seen that this article focuses on cities by determining equations for production, consumption and importing. After these equations have been determined, the city equilibrium and optimum size can be determined, but this is not the same approach that is going to be followed in this project. Our aim is to determine equations based on the expenses that are incurred to deliver public services, specifically focusing on the costs and time of traveling by vehicle when providing these services.

2.2. Market Choices and Optimum City Size by Edwin S. Mills and David M. De Ferranti

To do so it is necessary to start with some basic notions as to what cities are for. Two complementary ideas dominate the literature. First, scale and other agglomeration economies make it advantageous to concentrate production in certain central places where goods and services are produced for their inhabitants and those of the surrounding country-side. [5], page 340

Second, regional comparative advantage makes it economical for each region to specialize in production to some extent and to trade with other regions of the country. It is then advantageous to locate the production of a region's exports and related goods at ports, railheads, and highways where interregional transportation costs are low. [5], page 340

Within the framework of the previous paragraph, there is no general theorem that the resulting urban areas are too large. In fact, Martin Beckmann has shown in a pure central-place framework that competition may produce excessively small urban areas. Of course, those who claim that some urban areas are too big have in mind considerations that are excluded from most central-place models. Pollution and congestion are most frequently identified as culprits. On the most abstract level, both can be subsumed under a general divergence between private and social costs as a function of city size. In an important paper, George Tolley has shown that such externalities do indeed produce cities of inappropriate size, but that they may be too large or too small depending on specific details of the model. [5], page 340

We do not have a detailed analysis of all the important issues related to optimum city size. In the next section we present a classification of alleged causes of excessive size, and some brief comments on each. The rest of the paper is devoted to an analysis of congestion, which seems to us to be the most important and interesting of the alleged causes of excessive city size. [5], page 340

An extensive sampling of the urban economics literature suggests that most of the factors that can plausibly be claimed to distort city sizes can be classified under three headings: the provision and financing of local public services, pollution, and congestion. [5], page 340

From the above mentioned paragraphs it can be confirmed that most other models focus on cities' production and consumption to determine a relationship for optimum, equilibrium and maximum city size. It can also be seen that people who regard cities as too big consider other things like pollution and congestion and these factors must be taken into account and will determine if a city can be regarded as too big. In the last paragraph from the mentioned article they clearly indicate that provision and financing of local public services are one of the key issues that distort city sizes. This is a good indication that this project has validity and purpose in what it is trying to achieve, because no one else has previously done a study like this one.

2.3. Engineering Economy, 6th Edition by Leland Blank and Anthony Tarquin

Fundamentally, engineering economy involves formulating, estimating, and evaluating the economic outcomes when alternatives to accomplish a defined purpose are available. Another way to define engineering economy is as a collection of mathematical techniques that simplify economic comparison. [6], page 6

Chapter 9 of Engineering Economy entitled "Benefit/Cost Analysis and Public Sector Economics" is the most appropriate part of the textbook to research for this project. The concepts conveyed in this chapter will be applied and integrated with the information gained from the researched background information.

2.4. The AA Rate Tables

The AA Rate tables have been devised to provide users with a fair and equitable rate against which to assess vehicle performance or alternatively to enable the user to determine or exercise a fair claim for vehicle usage. The

AA Rates are not intended to provide a specific or detailed rate for individual specific vehicles. [7]

Each year the AA (Automobile Association of South Africa) compiles a rates table to determine the fixed and operating cost components for vehicles. The AA is a widely recognised institution and great care is put into developing these rates.

Table 1: AA Fixed Cost Table [7]

| Fixed Costs Table | | | | | | | | |
|---|---------------------------|----------------|----------------|---------------|----------------|----------------|----------------|-------|
| Averaged Fixed Cost (C/Km) – All Costs Inclusive Of VAT | | | | | | | | |
| Purchase Price (VAT incl) | Annual Distance Travelled | | | | | | | |
| | <10000 | 10001 To 15000 | 15001 To 20000 | 2001 To 25000 | 25001 To 30000 | 30001 To 35000 | 35001 To 40000 | >4001 |
| up to R30,000 | 103 | 69 | 52 | 42 | 35 | 31 | 27 | 24 |
| R30,001 - R50,000 | 173 | 115 | 87 | 70 | 59 | 51 | 45 | 41 |
| R50,001 - R75,000 | 261 | 174 | 131 | 105 | 88 | 77 | 68 | 62 |
| R75,001 - R100,000 | 350 | 233 | 175 | 141 | 119 | 104 | 92 | 83 |
| R100,001 - R125,000 | 383 | 256 | 192 | 155 | 130 | 114 | 101 | 91 |
| R125,001 - R150,000 | 461 | 308 | 232 | 187 | 157 | 137 | 122 | 110 |
| R150,001 - R175,000 | 541 | 361 | 272 | 219 | 184 | 161 | 142 | 129 |
| R175,001 - R200,000 | 621 | 414 | 311 | 251 | 211 | 185 | 163 | 148 |
| R200,001 - R250,000 | 779 | 520 | 391 | 316 | 265 | 232 | 205 | 185 |
| R250,001 - R300,000 | 878 | 586 | 441 | 356 | 299 | 262 | 232 | 210 |
| R300,001 - R350,000 | 1030 | 688 | 517 | 417 | 351 | 307 | 272 | 246 |
| R350,001 - R400,000 | 1184 | 790 | 595 | 480 | 403 | 353 | 313 | 283 |
| more than R400,001 | 1313 | 876 | 659 | 532 | 447 | 392 | 347 | 314 |

The rates are used to calculate an operating cost (R/km) figure for a vehicle based on the vehicle type, engine size and fuel type (Petrol or diesel). The fixed cost component of the rates tables are determined by the vehicle's purchase price and the estimated amount of km's traveled per year. The problem is that the fixed cost component is also returned as a Rand per Kilometer value and this is not how fixed cost is defined for this project. Using the same principles that is utilised by the AA, another means of

determining the fixed cost component of the vehicle operating cost will be determined and used in this project.

Table 2: AA Running Cost Table [7]

| Running Costs Table – Petrol Vehicles | | | |
|---|---------------|--------------------------|-------------|
| Averaged Running Cost (C/Km) – All Costs Inclusive Of VAT | | | |
| Engine Capacity (cc) | Fuel | | Maintenance |
| | Petrol Factor | Service And Repair Costs | |
| | | (in cents) | |
| | A | B | C |
| <1300 | 7.67 | 15.14 | 6.55 |
| 1301 - 1500 | 8.18 | 15.87 | 8.29 |
| 1501 - 1800 | 8.98 | 16.71 | 11.26 |
| 1801 - 2000 | 9.01 | 23.48 | 17.65 |
| 2001 - 2500 | 10.67 | 27.62 | 18.81 |
| 2501 - 3000 | 11.22 | 28.86 | 20.55 |
| 3001 - 4000 | 12.38 | 31.97 | 24.18 |
| >4001 | 14.44 | 41.01 | 34.16 |

Running Costs calculation (c/km) = (A multiplied by petrol price in R/litre) + B + C

| Running Costs Table – Diesel Vehicles | | | |
|---|---------------|--------------------------|-------------|
| Averaged Running Cost (C/Km) – All Costs Inclusive Of VAT | | | |
| Engine Capacity (cc) | Fuel | | Maintenance |
| | Diesel Factor | Service And Repair Costs | |
| | | (in cents) | |
| | A | B | C |
| < 2000 | 6.82 | 22.68 | 17.65 |
| 2001 - 2500 | 8.32 | 33.392 | 18.81 |
| 2501 - 3000 | 8.61 | 35.15 | 20.55 |
| 3001 - 4000 | 9.10 | 34.42 | 24.18 |
| >4001 | 13.99 | 57.77 | 34.16 |

Running Costs calculation (c/km) = (A multiplied by diesel price in R/litre) + B + C

Table 3: AA Running Cost Table [7]

| Running Costs Table – Petrol LCVs | | | |
|---|---------------|--------------------------|-------------|
| Averaged Running Cost (C/Km) – All Costs Inclusive Of VAT | | | |
| Engine Capacity (cc) | Fuel | | Maintenance |
| | Petrol Factor | Service And Repair Costs | |
| | | (in cents) | |
| | A | B | C |
| <2000 | 9.59 | 17.20 | 8.72 |
| 2001 - 2500 | 13.56 | 17.47 | 10.89 |
| 2501 - 3000 | 15.02 | 18.01 | 11.59 |
| 3001 - 4000 | 15.13 | 23.11 | 13.75 |
| >4001 | 15.77 | 28.24 | 20.71 |

Running Costs calculation (c/km) = (A multiplied by petrol price in R/litre) + B + C

| Running Costs Table – Diesel LCVs | | | |
|---|---------------|--------------------------|-------------|
| Averaged Running Cost (C/Km) – All Costs Inclusive Of VAT | | | |
| Engine Capacity (cc) | Fuel | | Maintenance |
| | Petrol Factor | Service And Repair Costs | |
| | | (in cents) | |
| | A | B | C |
| <2000 | 8.30 | 20.23 | 8.72 |
| 2001 - 2500 | 10.82 | 22.15 | 11.23 |
| 2501 - 3000 | 11.62 | 25.82 | 11.59 |
| >3001 | 14.70 | 27.11 | 17.67 |

Running Costs calculation (c/km) = (A multiplied by petrol price in R/litre) + B + C

Table 4: AA Running Cost Table [7]

| Running Costs Table – Petrol SUVs | | | |
|---|---------------|--|--------------------------|
| Averaged Running Cost (C/Km) – All Costs Inclusive Of VAT | | | |
| Engine Capacity (cc) | Fuel | Maintenance | |
| | Petrol Factor | Service And Repair Costs (in cents) | Tyre Costs (in cents) |
| | A | B | C |
| <2000 | 9.89 | 30.82 | 17.65 |
| 2001 – 2500 | 11.18 | 32.04 | 18.81 |
| 2501 - 3000 | 13.14 | 32.38 | 20.55 |
| 3001 - 4000 | 13.56 | 33.42 | 24.18 |
| >4001 | 16.58 | 36.20 | 34.16 |

Running Costs calculation (c/km) = (A multiplied by petrol price in R/litre) + B + C

| Running Costs Table – Diesel SUVs | | | |
|---|---------------|--|--------------------------|
| Averaged Running Cost (C/Km) – All Costs Inclusive Of VAT | | | |
| Engine Capacity (cc) | Fuel | Maintenance | |
| | Diesel Factor | Service And Repair Costs (in cents) | Tyre Costs (in cents) |
| | A | B | C |
| <2000 | 7.78 | 31.04 | 17.65 |
| 2001 – 2500 | 10.75 | 33.16 | 18.81 |
| 2501 - 3000 | 11.51 | 32.095 | 20.55 |
| 3001 - 4000 | 12.05 | 34.62 | 24.18 |
| >4001 | 14.22 | 37.55 | 34.16 |

Running Costs calculation (c/km) = (A multiplied by diesel price in R/litre) + B + C

2.5. Economics of Automobile Usage

Public costs related to the automobile are several; effects related to emissions have received a lot of attention, however the impact of discarded autos is far from well-understood since many are recycled. [8]

The benefits of using a car differ by many factors, in regard to location and culture. One general benefit is availability of use which, when coupled with public support via infrastructure (such as roads or fuel stations), can allow highly flexible movement and transportation.

According to the RAC motorists in the UK spend an average of GBP 5,000 (US\$ 9,000) per year on their car, or roughly 1/3 of the average net wage; while the RACV suggests roughly AUD10,000 per year, compared to AUD26,000 median income among all Australian adults or AUD66,000 median income among all Australian households. This situation is reflected

in most other Western nations. For the average car owner, depreciation constitutes about half the cost of running a car. The typical motorist underestimates this fixed cost by big margin, or even ignores it altogether, according to a survey by the RAC. [8]

The costs of running a car can be broken down as follows (in no particular order): [8]

- Depreciation
- Fuel (including fuel tax)
- Repairs
- Maintenance, regular
- Maintenance, for car longevity
- Financing
- Insurance
- Parking
- Tolls on Roads, Bridges and Tunnels
- Vehicle tax
- Vehicle inspection
- Registration
- Car Washes
- Accessories
- Opportunity cost
- Part replacement, including:
 - Tire replacement
 - Break Pad Replacement
 - Battery Replacement
 - Light Replacement
 - Filters (Cabin Air and Motor Oil)
 - Fluid Replacement (Wind shield washer, Motor Oil, Antifreeze, Power Steering)

Despite rising oil prices, car travel has steadily become cheaper over the past five decades. According to the Department for Transport, the real cost of running a car in the UK has dropped by 9% between 1980 and 2007. This development is in part due to better manufacturing technologies, and in part due to engines becoming more fuel-efficient.

Of the annual running costs of an automobile for the average person, 70–75% are fixed costs (with respect to distance travelled): a 10% increase or decrease in usage should result in a 2.5–3% increase or decrease in annual running costs.[8]

3. Industrial Engineering Methods, Tools and Techniques

The following Industrial Engineering Methods, Tools and Techniques will be considered and applied during this project:

- Cost modeling
- Data fitting and Trend analysis
- Regression analysis
- Sensitivity analysis

These techniques were selected because they are the most appropriate tools for this problem. This project focuses on cost and must not be seen as a scheduling or simulation project. The mentioned techniques are the most appropriate tools for this project. The Microsoft Excel software package will be used to produce all the necessary calculations, graphs and analysis for the project.

With regards to regression and sensitivity analysis, it was found that it would not be possible to incorporate these tools fully within the project. This can be attributed to the fact that no data sets were found to be useful for manipulation within this project. Without having datasets, the use of

regression modeling would be redundant. Sensitivity analysis could still be applied in future in order to measure different scenarios and situations, but a more generic approach was followed in this phase of the project.

4. Data and Information Gathering

Data collection and research will consist of finding similar models or projects previously attempted and finding relevant data that can be used for the proposed models.

Data collection and research will be done using the internet, textbooks and articles, the University of Pretoria's library services, Statistics South Africa's Website and Archives as well as the co-operation of the various municipalities. The project will only look at the costs involved with each public service and no scheduling issues will be taken into account.

Internet research will form the largest part of all the research that is conducted. A company with the name Quantec Research (Pty) Ltd was also approached as a source of obtaining useful data. Quantec is a member of EIU (Economist Intelligence Unit) City Data, they collect data about cities from across the world, including Johannesburg, Paris and Tokyo. Quantec was approached and contacted and they clearly stated that they do not have such detailed information as what is needed within this project. It would indeed be possible to utilise Quantec for future projects or project phases that arise from this study.

The main ideas for developing this project will come from the articles and specifically the textbook mentioned above. The articles will mainly be used for gaining background knowledge on how others have quantified optimum city size. It will also give insight into how others found the equilibrium and optimum values of the equations they used to determine city size.

The textbook, *Engineering Economy*, will be used to ensure that the equations that will be developed are correct and as accurate as possible. It will also help ensure that the optimum and equilibrium values derived from these equations are determined correctly.

The example that follows will illustrate the basic concept that will be used to formulate the intended model. Assume that Public Service 1 and Public Service 2 represent specific services that are provided to citizens that live within our city. The costs associated with Public Service 1 can be quantified by the following equation: $C = A + B(q)$ where C is the total cost of providing the service to the people, A is the fixed cost portion and $B(q)$ is the variable cost portion. q can only be described as a variable relating to some measure of city size, be it in length (m) or area (m²). Using this equation, different scenarios of service delivery using different vehicles can be determined. It can be used to generate a data-set for delivering the specific public service. From this data set, containing different service delivery scenarios, an overall service delivery equation can be derived. Lastly, a maximum data point can be found where the cost of delivering the service is at its highest or the change in cost is insignificant.

Another very important factor to consider is the different types of people that use the service that is delivered to them. There will be users or consumers, if you will, with different monthly incomes and therefore with different abilities to pay for the services. The "richer" consumer will have to pay enough for their services to cover the costs of delivering the service to them as well as the other users who do not pay, but still use the service. This creates a very difficult situation because there has to be a minimum ratio of users who are unable to pay and users who are able to pay.

Research Methodology

To accomplish the defined objectives and deliverables, the following procedure is followed: [9], page 9

1. Selection of the project
2. Get and present the data
3. Analyze the data
4. Develop the ideal method/technique
5. Present and install method

Last but not least, most available data found applies to personal vehicle use and ownership. The data surrounding government vehicles and public services is not widely available. This fact does not mean that the data is not applicable. The data that was collected can just as easily be applied to other vehicles owned by government or other institutions. The overall principles stay exactly the same.

5. Design and Problem Solving

To start with the design and problem solving segment of this project it is necessary to fully understand what areas of the specific public service form part of the cost model.

It was decided to focus on the police, ambulance and fire services when attempting this project. The reasoning behind this is the initial scope that was defined for the project. It stated that the cost function that needs to be determined should first and foremost be a function of distance and cost. After which other elements can be incorporated into the baseline function. Some of the other elements that are being considered are elements that will have a significant influence, like the time of day and traffic conditions and density as well as population density and different emergency situations.

The police, ambulance and fire services in South Africa consist of many different functions like visible policing in police services and administrative functions involved in all services. For this project the services that we will be focusing on is any service provided with the use of a vehicle. Administrative type of services will not be considered because distance does not form a part of the costs. This also applies to fire and ambulance services. Only the services they supply by means of using a vehicle will be taken into account. These services can be summed up in any emergency response situation for police, fire and ambulance service and normal patrolling for police services only.

If one looks at the basics behind creating a cost function, the following will probably come to mind. There are many different approaches to formulating a function. Firstly one can use a data set and try to plot the data on a chart and by adding a trend line, you can determine a function that quite accurately predicts and describes your data. Secondly one can try to build a function from different scenarios and variables and construct the function without any data available initially. Because no data sets containing information about traveling distances and costs could be found for the applicable public services, it was decided that the best way to approach the project is to try and establish a cost function by first determining all the required inputs and then building the function from there. The starting point of the function was to first establish the fixed and variable costs involved when traveling in a motor vehicle.

What is fixed cost? - Costs that do not vary over time and are not dependant on the distance traveled, in this case.

What is variable cost? - Costs that are volume sensitive and that are dependant on the distance traveled, in this case.

For this project Vehicle Running Costs (Variable Costs) will be defined as follows:

- Fuel Costs
- Service & Repair Costs
- Tire Costs

The vehicle running costs will be determined by using the following tables' principles and these costs are dependant on the type of car (vehicle, LCV, SUV), the fuel type (Petrol/Diesel) and the vehicle's engine capacity.

The variables are defined as follows:

- Running costs per kilometer (R/km) $\rightarrow x$
- Fuel factor $\rightarrow A$
- Fuel (petrol/diesel) price (R) $\rightarrow p$
- Service and repair costs per kilometer (c/km) $\rightarrow B$
- Tire costs per kilometer (c/km) $\rightarrow C$
- Average total cost per trip (R) $\rightarrow U$
- Average trip traveling distance (km) $\rightarrow t$

Thus $x = f(A, B, C)$, $x = (Ap + B + C) \div 100$ and $U = xt$.

Table 5: AA Running Cost Table [7]

| Running Costs Table – Petrol Vehicles | | | |
|---|---------------|--------------------------|-------------|
| Averaged Running Cost (C/Km) – All Costs Inclusive Of VAT | | | |
| Engine Capacity (cc) | Fuel | | Maintenance |
| | Petrol Factor | Service And Repair Costs | |
| | | (in cents) | |
| | A | B | C |
| <1300 | 7.67 | 15.14 | 6.55 |
| 1301 - 1500 | 8.18 | 15.87 | 8.29 |
| 1501 - 1800 | 8.98 | 16.71 | 11.26 |
| 1801 - 2000 | 9.01 | 23.48 | 17.65 |
| 2001 - 2500 | 10.67 | 27.62 | 18.81 |
| 2501 - 3000 | 11.22 | 28.86 | 20.55 |
| 3001 - 4000 | 12.38 | 31.97 | 24.18 |
| >4001 | 14.44 | 41.01 | 34.16 |

Running Costs calculation (c/km) = (A multiplied by petrol price in R/litre) + B + C

| Running Costs Table – Diesel Vehicles | | | |
|---|---------------|--------------------------|-------------|
| Averaged Running Cost (C/Km) – All Costs Inclusive Of VAT | | | |
| Engine Capacity (cc) | Fuel | | Maintenance |
| | Diesel Factor | Service And Repair Costs | |
| | | (in cents) | |
| | A | B | C |
| < 2000 | 6.82 | 22.68 | 17.65 |
| 2001 - 2500 | 8.32 | 33.392 | 18.81 |
| 2501 - 3000 | 8.61 | 35.15 | 20.55 |
| 3001 - 4000 | 9.10 | 34.42 | 24.18 |
| >4001 | 13.99 | 57.77 | 34.16 |

Running Costs calculation (c/km) = (A multiplied by diesel price in R/litre) + B + C

Vehicle Fixed Costs will consist of the following:

- Comprehensive Insurance, dependant on
 - Driver Age
- License & Registration Fees, dependant on
 - Vehicle Tare Mass
- Vehicle Financing Costs
- Depreciation
- Equipment Costs, consisting of
 - Equipment financing and depreciation
- Salaries of occupants

The fixed costs consist of adding all the above mentioned items together and the variables are defined as follows:

- Yearly fixed costs (R) → y
- Comprehensive insurance (R) → i

- Driver's age $\rightarrow h$
- License fees (R) $\rightarrow l$
- Vehicle financing costs (R) $\rightarrow g$
- Vehicle depreciation (R) $\rightarrow v$
- Equipment financing costs (R) $\rightarrow e$
- Equipment depreciation (R) $\rightarrow d$
- Average salary (R) $\rightarrow s$
- Average number of people in vehicle $\rightarrow n$

*All of the values are calculated as a value per year

Thus $y = f(i, h, l, g, v, e, d, s, n)$ and $y = i(h) + l + g + v + e + d + sn$.

Equipment costs and salaries of the occupants of the vehicles are included in the fixed cost component because without these components it is not possible to deliver the specific service. A cost function not containing these elements would result in total traveling or transport costs alone and would not result in obtaining the total cost of delivering the service.

Other Variables:

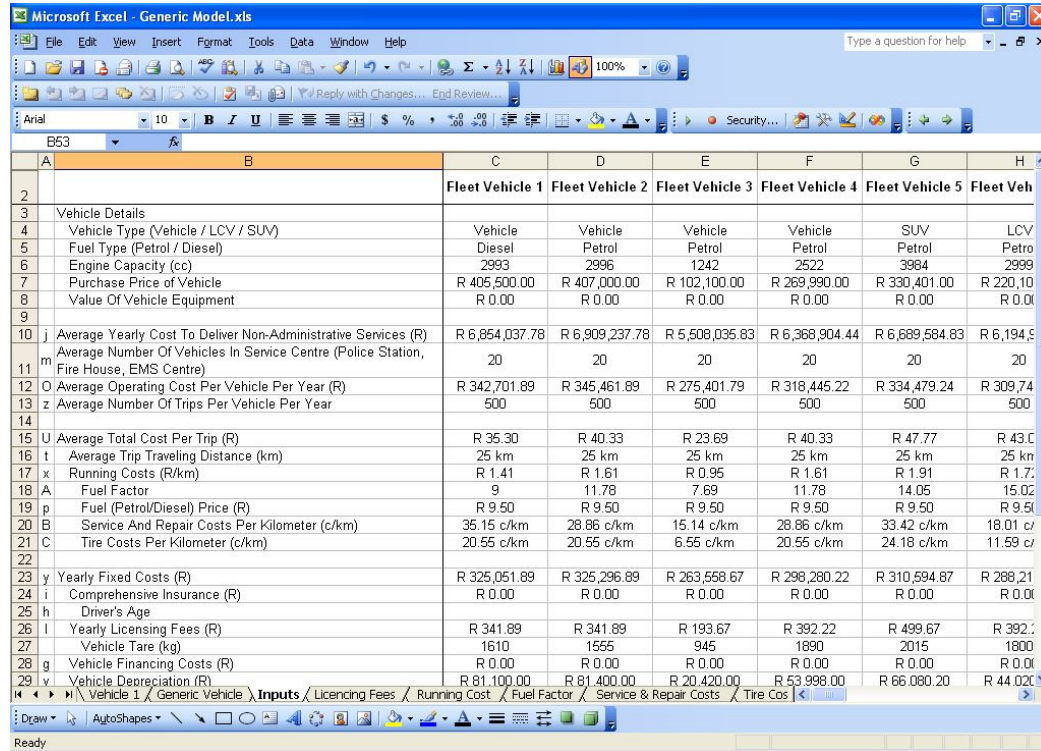
- Average operating cost per vehicle per year (R) $\rightarrow O$
- Average number of trips per vehicle per year $\rightarrow z$
- Average number of vehicles in service centre (police station, fire house, EMS centre) $\rightarrow m$
- Average yearly cost to deliver non-administrative services (R) $\rightarrow j$

Thus $O = Uz + y$ and $j = Om$.

Furthermore when taking all of the above mentioned equations into consideration and then reconsolidating them into one equation, this is the result. $j = ((Ap + B + C)tz + i(h) + l + g + v + e + d + sn)m$

After the reconciliation these equations are used in Microsoft Excel to create a workable generic model that looks as follow:

Figure 1: Generic Model - Example

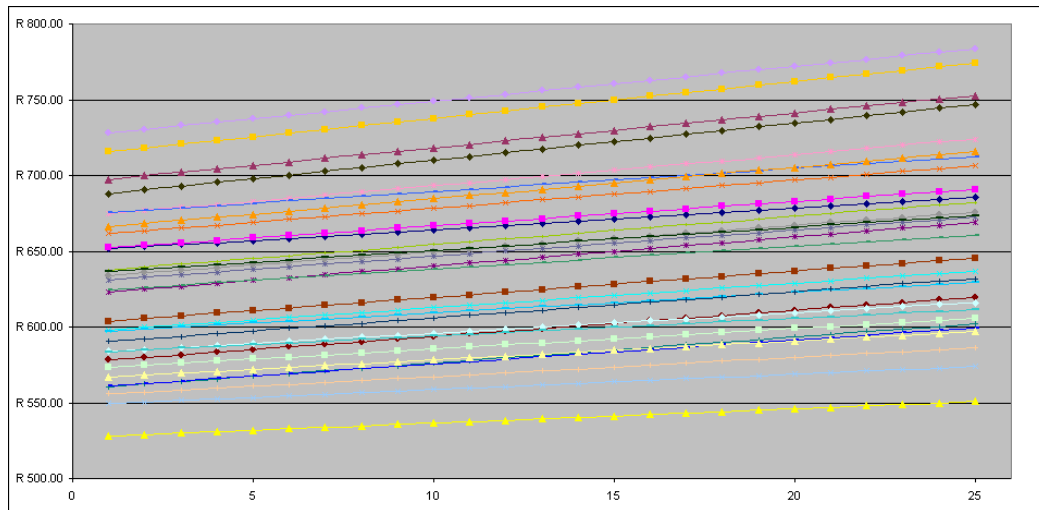


| | Fleet Vehicle 1 | Fleet Vehicle 2 | Fleet Vehicle 3 | Fleet Vehicle 4 | Fleet Vehicle 5 | Fleet Veh |
|----|-----------------|-----------------|-----------------|-----------------|-----------------|-----------|
| 2 | | | | | | |
| 3 | Vehicle Details | | | | | |
| 4 | Vehicle | Vehicle | Vehicle | Vehicle | SUV | LCV |
| 5 | Diesel | Petrol | Petrol | Petrol | Petrol | Petro |
| 6 | 2993 | 2996 | 1242 | 2522 | 3984 | 2999 |
| 7 | R 405,500.00 | R 407,000.00 | R 102,100.00 | R 269,990.00 | R 330,401.00 | R 220,10 |
| 8 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 |
| 9 | | | | | | |
| 10 | R 6,854,037.78 | R 6,909,237.78 | R 5,508,035.83 | R 6,368,904.44 | R 6,689,584.83 | R 6,194.9 |
| 11 | 20 | 20 | 20 | 20 | 20 | 20 |
| 12 | R 342,701.89 | R 345,461.89 | R 275,401.79 | R 318,445.22 | R 334,479.24 | R 309,74 |
| 13 | 500 | 500 | 500 | 500 | 500 | 500 |
| 14 | | | | | | |
| 15 | R 35.30 | R 40.33 | R 23.69 | R 40.33 | R 47.77 | R 43.0 |
| 16 | 25 km | 25 km | 25 km | 25 km | 25 km | 25 km |
| 17 | R 1.41 | R 1.61 | R 0.95 | R 1.61 | R 1.91 | R 1.7 |
| 18 | 9 | 11.78 | 7.69 | 11.78 | 14.05 | 15.02 |
| 19 | R 9.50 | R 9.50 | R 9.50 | R 9.50 | R 9.50 | R 9.50 |
| 20 | 35.15 c/km | 28.86 c/km | 15.14 c/km | 28.86 c/km | 33.42 c/km | 18.01 c/ |
| 21 | 20.55 c/km | 20.55 c/km | 6.55 c/km | 20.55 c/km | 24.18 c/km | 11.59 c/ |
| 22 | | | | | | |
| 23 | R 325,051.89 | R 325,296.89 | R 263,558.67 | R 298,280.22 | R 310,594.87 | R 288,21 |
| 24 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 |
| 25 | | | | | | |
| 26 | R 341.89 | R 341.89 | R 193.67 | R 392.22 | R 499.67 | R 392.1 |
| 27 | 1610 | 1555 | 945 | 1890 | 2015 | 1800 |
| 28 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 | R 0.00 |
| 29 | R 81,100.00 | R 81,400.00 | R 20,420.00 | R 53,998.00 | R 66,080.20 | R 44,020 |

From this generic model one can derive functions for the following:

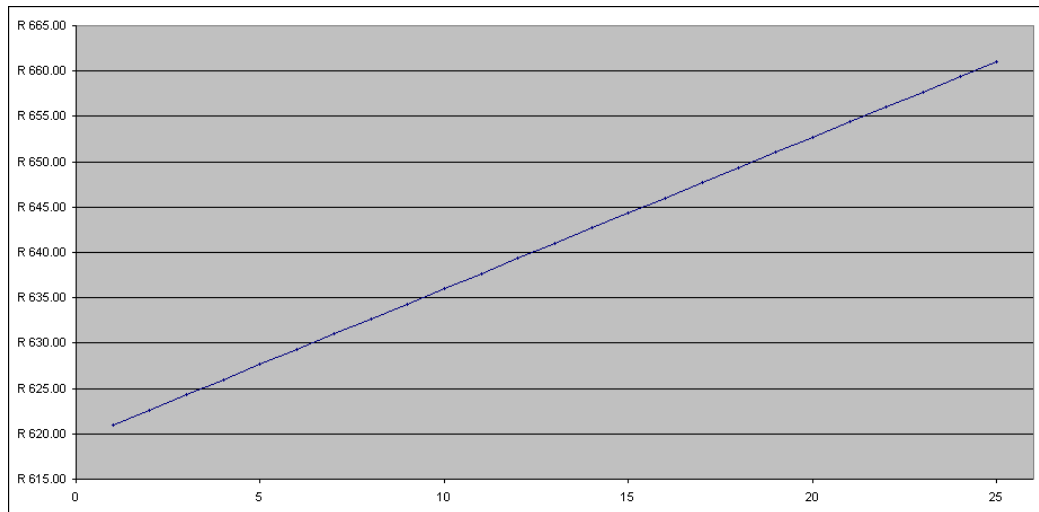
- Cost function for each of the vehicles that are specified

Figure 2: Cost Functions For Each Vehicle - Example



- Cost function for the average vehicle between the specified vehicles

Figure 3: Cost Function For The Average Vehicle - Example



6. Design / Solution Evaluation

In section 5 a generic model was introduced and it was shown how certain functions and figures could be derived from it. In this section a world scenario will be implemented using the given model and the results will be discussed.

Scenario Description:

Let's say for instance we are analysing the Garsfontein police station in Pretoria.

At this police station they have the following vehicles that are used for visible policing and responding to emergency situations. In the table one can see the Running costs per kilometer (R/km) and the Yearly fixed costs (R) for each of these vehicles.

Table 6: Vehicle Details At Garsfontein Police Station - Example

| Vehicle | Vehicle Type | Fuel Type | Engine Capacity | Purchase Price of Vehicle | Equipment Value | Quantity | Running Costs Per Kilometer (R/km) | Yearly Fixed Costs (R) |
|--------------------------------------|--------------|-----------|-----------------|---------------------------|-----------------|----------|------------------------------------|------------------------|
| BMW 330i | Vehicle | Petrol | 2996 | R407,000.00 | R40,000 | 2 | R1.61 | R335,255.00 |
| Ford Territory 4.0 TX AT RWD | SUV | Petrol | 3984 | R330,401.00 | R40,000 | 2 | R1.91 | R320,539.20 |
| Nissan Hardbody 2700D Double Cab LWB | LCV | Petrol | 2663 | R177,950.00 | R40,000 | 2 | R1.72 | R289,408.00 |
| Volkswagen Jetta 5 2.0 FSI Sportline | Vehicle | Petrol | 1984 | R238,100.00 | R40,000 | 2 | R1.35 | R301,196.00 |
| Toyota Hilux 2.5 D-4D SRX | LCV | Petrol | 2494 | R179,600.00 | R40,000 | 5 | R1.59 | R289,750.00 |

Taking the above mentioned items into account and implementing them within the model, you can determine the cost per kilometer of travel for one trip of delivering the specific service. The following information applies to the calculation of the running costs and fixed costs:

- The South African Police Service does not insure their vehicles.
- The vehicles are not financed, they are bought in cash.
- The average value of equipment used together with these vehicles are R40,000 per vehicle. Radios etc.
- The police station is situated in the Gauteng province, so the Gauteng licensing fees will apply.
- These vehicles form 80% of the police stations' total vehicles, the other 20% are vehicles used by administrative personnel.
- Equipment depreciation is 25% per year.
- The employees operating the vehicle receive a yearly salary of R121,000 per employee.

The depreciation & average amount of trips for the vehicles and equipment are as follows:

Table 7: Depreciation Details Of Vehicle At Garsfontein Police Station - Example

| # | Vehicle | Purchase Price of Vehicle | Depreciation at 20% per year | # of trips per year |
|---|-------------------------------------|---------------------------|------------------------------|---------------------|
| 1 | BMW 330i | R407,000 | R81,400 | 500 |
| 2 | BMW 330i | R407,000 | R81,400 | 500 |
| 3 | Ford Territory 4.0 TX AT RWD | R330,401 | R66,080.20 | 500 |
| 4 | Ford Territory 4.0 TX AT RWD | R330,401 | R66,080.20 | 500 |
| 5 | Nissan Hardbody 2700D Double Cab | R177,950 | R35,590 | 500 |

| | | | | |
|----|--|----------|---------|-----|
| | LWB | | | |
| 6 | Nissan Hardbody 2700D Double Cab LWB | R177,950 | R35,590 | 500 |
| 7 | Volkswagen Jetta 5 2.0 FSI Sportline | R238,100 | R47,620 | 500 |
| 8 | Volkswagen Jetta 5 2.0 FSI Sportline | R238,100 | R47,620 | 500 |
| 9 | Toyota Hilux 2.5 D- 4D SRX | R179,600 | R35,920 | 500 |
| 10 | Toyota Hilux 2.5 D- 4D SRX | R179,600 | R35,920 | 500 |
| 11 | Toyota Hilux 2.5 D- 4D SRX | R179,600 | R35,920 | 500 |
| 12 | Toyota Hilux 2.5 D- 4D SRX | R179,600 | R35,920 | 500 |
| 13 | Toyota Hilux 2.5 D- 4D SRX | R179,600 | R35,920 | 500 |

The budget for this specific police station for the year looks as follows:

Table 8: Budget Of Garsfontein Police Station - Example

| Item | Amount | Contributes To |
|---------------------|----------------------|-----------------------|
| Depreciation | R840,000.00 | Fixed Costs |
| Salaries | R3,146,000.00 | Fixed Costs |
| Licensing fees | R3,500.00 | Fixed Costs |
| Total | R3,989,500.00 | Fixed Costs |
| | | |
| Fuel | R160,000.00 | Variable Cost |
| Vehicle Maintenance | R200,000.00 | Variable Cost |
| Total | R360,000.00 | Variable Cost |

From the total budget the money is distributed and allocated to each vehicle depending on their fixed and variable costs as a percentage of the total value.

*The information and data in this scenario is fictional and some assumptions are made. This scenario is an example of how the model could be used, but an in depth study would be needed to be really accurate with the figures.

Then by taking the budgeted figures and inputting those into the model one can determine the average distance per trip per vehicle.

Figure 4: Results From Modeled Budget Figures - Example

| | | BMW 330i |
|-----------------|---|------------------------|
| | | Fleet Vehicle 1 |
| Vehicle Details | | |
| | Vehicle Type (Vehicle / LCV / SUV) | Vehicle |
| | Fuel Type (Petrol / Diesel) | Petrol |
| | Engine Capacity (cc) | 2996 |
| | Purchase Price of Vehicle | R 407,000.00 |
| | Equipment Value | R 40,000.00 |
| | | |
| z | Average Number Of Trips Per Vehicle Per Year | 500 |
| | | |
| x | Running Costs (R/km) | R 1.61 |
| A | Fuel Factor | 11.78 |
| p | Fuel (Petrol/Diesel) Price (R) | R 9.50 |
| B | Service And Repair Costs Per Kilometer (c/km) | 28.86 c/km |
| C | Tire Costs Per Kilometer (c/km) | 20.55 c/km |
| | | |
| y | Yearly Fixed Costs (R) | R 335,255.00 |
| i | Comprehensive Insurance (R) | R 0.00 |
| h | Driver's Age | |
| l | Yearly Licensing Fees (R) | R 300.00 |
| | Vehicle Tare (kg) | 1555 |
| g | Vehicle Financing Costs (R) | R 0.00 |
| v | Vehicle Depreciation (R) | R 81,400.00 |
| e | Equipment Financing Costs (R) | R 0.00 |
| d | Equipment Depreciation (R) | R 10,000.00 |
| s | Average Salary (R) | R 121,000.00 |
| n | Average Number Of People In Vehicle | 2 |
| | | |
| | Running Cost As % of Total | 7.49% |
| | Fixed Cost As % of Total | 8.51% |
| | Amount of Budget | |
| | Running Cost | R 26,948.05 |
| | Fixed Cost | R 339,333.78 |
| | | |
| | Average Trip Travelling Distance | 38 km |

Here we can see that with the given budget constraints that this vehicle can do 500 trips with an average of 38km per trip in a year.

The other vehicles' values are calculated using the same principles.

From the model introduced in section 5 it is stated that $j = Om$, but in this specific case we only have one vehicle that we are using so $m = 1$. So $j = O$ and $j = xtz + y$, because $O = Uz + y$ and $U = xt$. This all results in the following function to determine the average trip traveling distance (km), namely t .

$$t = \frac{j - y}{zx}$$

The results show that on average the vehicles at the Garsfontein police station can only deliver their service within a 19km (38 divided by 2) radius of the police station. This is the average distance so they can have certain cases where the traveling distance is further or even shorter.

From the previously mentioned examples one can see that this model is able to assist when budgeting needs to be done with regards to determining the cost of delivering your vehicle based service as well as in determining what average distance your vehicles can cover if you are constrained by a budget. Some may ask the question "What does this matter?". Well, this tells us that if this specific station's budget increases without increasing costs they will be able to provide a service to a wider area and if you think about it, they will be able to provide the service across an infinite distance if their budget increases infinitely. According to the costs this may be true but it is not practically possible.

While working with this model and seemingly coming to a quite confusing conclusion it was realized that the main drivers behind the determining the optimum service area is not cost based. The main drivers behind it are traffic conditions of the area where the station is situated and the desired response time of the vehicles. The reasoning behind this is that the area's traffic conditions influences the speed at which the vehicles can travel. Together with the desired response time of the vehicle this governs the serviceable area.

For example:

The response time is a variable that needs to be as close to 0 as possible. Let's say the Garsfontein police station wants their average response time to

be 15 minutes and the average traveling speed that they are able to achieve, based on their traffic conditions, is 60km/h. This then results in an average traveling distance of 15 kilometers. So they will be able to service an area with a radius of 15 kilometers of the police station within 15 minutes. So for budgeting purposes an average trip distance of 30 kilometers could be used as an input in the model.

Some other aspects that need to be taken into account are that there are a lot of other factors that influence these two variables. Some of them are:

- Time of day – Traveling speed during the day is a lot less than in the evening and the difference in traveling speed at 7h00 in the morning and 16h00 in the afternoon versus other times of the day.
- What can be regarded as an acceptable response time?
- An area with more incidents require a quicker response time than others.
- The severity of an incident will also influence the acceptable response time.

Basically to determine an acceptable average serviceable area for stations in general, one would need the following:

- Average traveling speed in area.
- Acceptable response time for an incident, driven by the number of incidents in the area and the nature of the incidents.

These simple two variables can determine the station's serviceable area. Once it has been used it to determine the average distance of a trip, it can be used in the model to assist with budgeting for that specific station.

This figure is an example of how police stations can be distributed, if they have the same desirable response time and traffic conditions. In this figure it can also be seen that some areas are not covered by the 15 minutes

response time. To remedy this one needs to distribute the stations to overlap as seen in the next figure.

Figure 5: Police Station Distribution (Not Overlapping) - Example

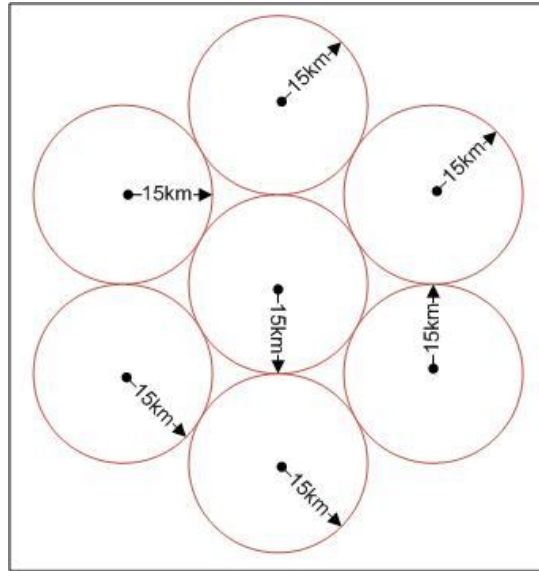
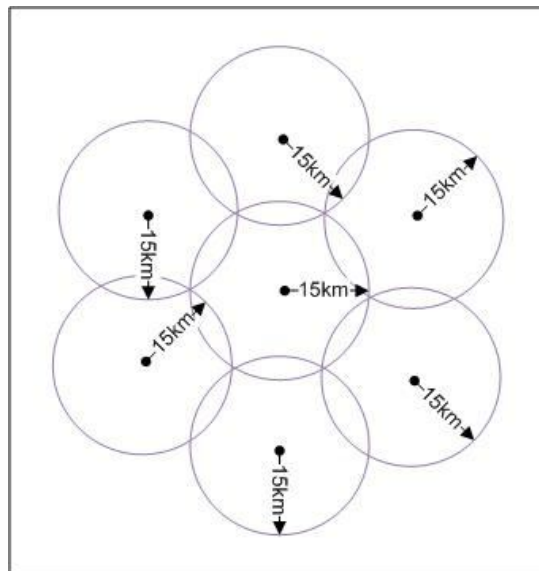


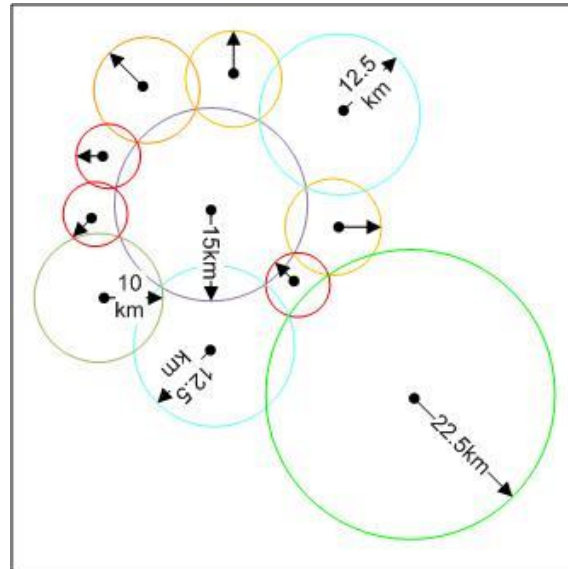
Figure 6: Police Station Distribution (Overlapping) - Example



This figure is an example of how police stations can be distributed, if they have different desirable response times and traffic conditions. In this figure

it can also be seen that all areas in between are covered by the respective response times. The placement and distribution of each station poses a whole new opportunity for problem solving.

Figure 7: Police Station Distribution Varying Response Times - Example



7. Implementation & Future Possibilities

It can be seen from the mentioned model that there is still some room for improvement. A large quantity of detailed information is needed to make this model work and such detailed information isn't always available. An in depth study of specific instances of service delivery offices would be needed to obtain such information. In some instances one would not always be able to find so much data, so the best alternative would be to get information about the typical or average situations, values and equipment used in the specific service delivery offices.

The model, assumptions and relationships defined and created in this project can be applied to service delivery stations/offices in general to determine, using average values, an average service area for any station. It can also be applied to all the offices/stations within a province to determine

the average service area for that province and the same could be done for service offices/stations within a municipality. Lastly it can be used to determine specifics of one nominated service office/station.

For future possibilities, studies or projects one needs to investigate the relationships between the current model, vehicle response times, traffic conditions and incident frequency and severity/importance. Determining these relationships will assist and solve the idea behind calculating the optimal service area of service delivery offices/stations. This can be done as a new study and incorporated with the current information to get the project to a more completed phase.

Lastly, from all the information gathered during this project it can be seen that optimum city size does not conform to service delivery constraints and costs. For instance, according to the cost functions, if you keep building new offices/stations then the city can never stop growing and it is possible to deliver service to an infinite area. The assumption could rather be made that the city depends or grows according to infrastructure, like roads, electricity, water, sanitation etc. Without these items the city cannot grow and expand. But these can also almost be expanded into infinity. The variables that really restrict a city's growth is the layout of the surrounding geographical area, mountains etc, and it is that which limits a city's size.

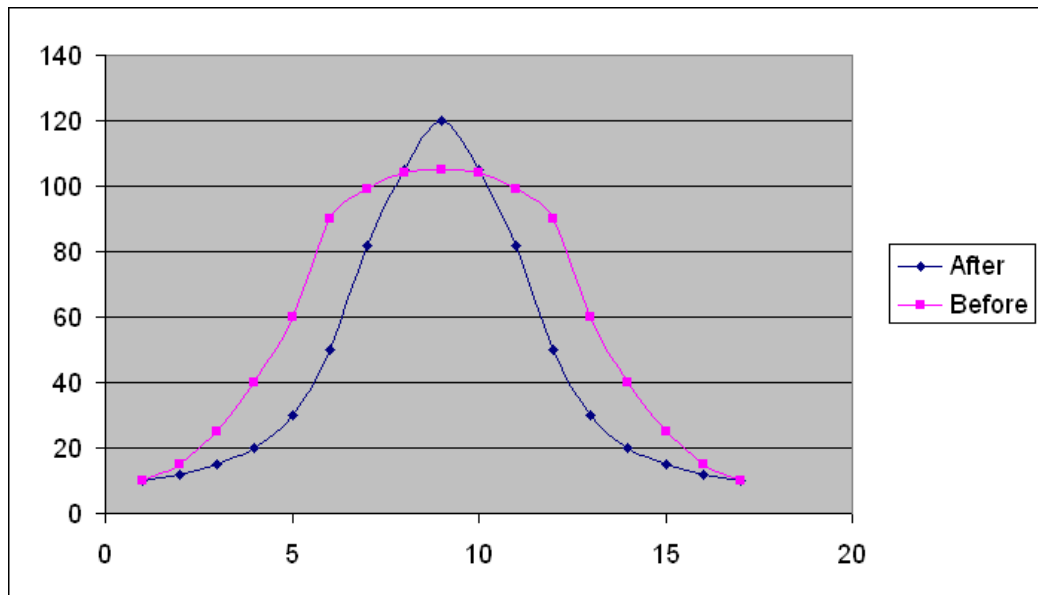
In the end, one can ask the question "What is this worth and what does it mean?". This model and findings that may come from future endeavors is useful to enhance and improve the budgeting abilities of a single service delivery office/station, municipality, provincial and/or national government. It may also be very useful in planning situations where the mapping and planning of service delivery offices/stations, based on vehicle response time, is key to solving the problem. Using this tool to plan the locations of

offices/stations may result in greatly improving service delivery and response times.

With improved budgeting abilities, the municipalities and government reduces their risk profile of over budgeting. The costs saved with better budgeting could be applied elsewhere and would result in better cash flow management.

The bell curve that follows is an example of how the risk profile could be reduced. The "Before" curve shows a wider curve with more room for error and the possibility of your cost predictions not be that accurate. The "After" curve shows a narrower curve with a lowered risk. This illustrates the principle behind managing your costs to lower the risk profile.

Figure 8: Bell Curve (Before & After) - Example



The full future possibilities and implementation opportunities for this project can only be determined and quantified to its greatest extent once the project has reached more detailed results and findings.

8. Conclusion

The initial scope of this project was to be able to establish a model to be able to calculate optimum city size with regards to and driven by public service delivery, but this scope has changed some what during the course of the project.

Firstly, the scope has shifted towards creating a cost function/model for determining the costs associated with vehicles that are used to deliver a service, specifically focusing on police services, fire services and ambulance services. With regards to this goal, a generic model was created that takes into account all the possible costs that play a role with delivering the specific service by using a vehicle. No models/functions were developed for one service, only a generic function was found. This answers the question concerning the costs involved and these principles can be applied to any service in general. The scope of the project also changed in such a way that the focus of the model was to determine the optimum serviceable area for a service office/station and then use this to determine optimum city size. It was established that the relationship between the costs and serviceable area of a service office/station are directly proportionate to each other in the sense that if you want to cover a larger area, more costs will be incurred and a larger budget is needed. So with this in mind one service office/station could basically cater for an infinite area if the money is available. Time (24 hours in a day) would be the only real constraint. In the end it was realized that the variables that truly govern the optimum serviceable area for a service office/station are traffic conditions and desired response time for the service office. The traffic conditions dictate the speed at which the vehicles can travel in that area and the desired response time together with that will then determine the serviceable area for that station within the specified response time. These facts have to be investigated more thoroughly in order

to truly determine the significance of these variables and should be conducted within a next phase of the project.

Secondly, to determine optimum city size is a very difficult task in itself. This goal was not fully realised during the project, but great steps were made towards reaching this goal. From the beginning of the project this was identified as a risk within the project and the other goals that may lead to this solution were achieved. During this project the geographical layout and infrastructure were identified as the main variables that determine optimum city size. The geographical layout of the area is recognised as the primary driver and infrastructure as the secondary driver behind city size.

To conclude, more study is needed to understand the impact of traffic conditions and desired response time on a service office/station's ability to deliver quality service. This can and should be done concurrently with a study of the driving factors behind optimum city size.

Appendices

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