DETERMINING THE OPTIMAL LOCATIONS FOR CVD CLINICS: A MATHEMATICAL PROGRAMMING APPROACH

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RESEARCH SUMMARY

Introduction

The development of developing and underdeveloped countries is a topic discussed at the highest level of the United Nations. Although for this topic to become a reality, several economic and social situations are of high importance and need to be contained. To contain such situations, the working class and manpower of the state is needed to be active in economical and social activities. It is estimated that untimely deaths due to cardiovascular disease (CVD) in people of working age 35 - 64 years are expected to increase by 41% between 2007 and 2030. The economic impact is expected to be negatively enormous. This study investigates using a mathematical programming approach for selecting optimal locations for new specialized CVD clinics, and/ or improvements to current clinics within optimal locations in remote regions.

Research Problem, Scope and Objective

Most African states and developing countries have failed to provide an impetus to eradicate CVD as it mostly affects the poor. Even in some countries where CVD specialized clinics exist access to these facilities is severely limited. The objective of this research is to utilize a model to determine the optimal locations of specialized CVD treatment facilities to deal with the epidemic of the disease. In order to accurately evaluate our model, we select the Western Cape of South Africa as a case study because it excels at bringing us to an understanding of the complex issue being tackled. This will also provide a potential insight into the effectiveness of designing a system to deal with CVD at locations for maximum population coverage.

Research Approach

This research is initiated by analyzing the current state of CVD treatment, location of clinics and demographics of the Province of the Western Cape (Chapter 2). Based on the information we executed a stakeholder mapping and established performance measures (Chapter 2). We followed with a literature review on location theory (Chapter 3). We developed our models based on p-Median models and variants of the model (Chapter 4) and executed computational experiments (Chapter 5) and an extensive sensitivity analysis to verify the feasibility of our model and to test how sensitive our models are to changes that may occur. In (Chapter 6) we present the conclusions and recommendations to successfully implement our solutions.

Findings

The mathematical model presented in this research is a tool for the location of specialized CVD clinics. Our developed model is applied to the case of the Western Cape, utilizing demographical data, such as, population groups, age distribution, disease occurrence rate etc. that was provided by the ministry of health and private organizations and NGOS partaking in creating awareness for heart disease. We proceed by estimating the population using a uniform distribution within each municipality and its density. The traveling distances are computed as the straight line distances between each population ***i*** and potential clinic ***j***. The distance between point ***i*** (1...309) and ***j*** (1...309) are computed and inputted into the Advanced Interactive Multidimensional Modeling System (AIMMS) software used for computational experiments to obtain the optimal locations (co-ordinates) for CVD clinics. An analysis carried out on the current situation showed that the current location of the hospitals do not effectively cover over 36% of the population. Using the mathematical models in this research, we maximized the total population of the Western Cape being covered within specific distance limit. We also minimized the distance traveled and also minimized the number of clinics required to cover the whole population. We obtained different configurations for which maximum population coverage is possible (**See Table 1**). Comparing the current situation of coverage of 64% with 16 CVD clinics, it can be seen from Table 1 that re-locating these clinics to appropriate co-ordinates as in Chapter 5 of this research leads to maximum coverage of the population in the Western Cape given a specific distance limit as seen in the table below.

Table 1: Configuration for maximum population coverage

Number of Clinics *(p)*	12	14	16
Distance Limit (D)	55	45	45

Conclusions

In this research, we propose different mathematical programming models to solve the location problem for specialized CVD clinics. The models are based on p-Median models and are objective techniques to identify population not being covered and to identify potential new CVD specialist treatment facilities. Our findings may also be applicable to patients with other kinds of diseases that require specialist care. The methods utilized in this research can also be applied to other types of facilities or resource networks, such as government buildings, schools, businesses and other service related networks. This can be done with very little adaptations or changes to the constraints or parameters, such as the population, distance between facilities and population or other facilities.

Acknowledgements

To God be the Glory, who has been my source of health and strength.

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Finally, I wish to thank my parents and siblings for their continuous support and encouragement throughout my study and pursuit of my dreams.

This thesis is dedicated to my brother who passed away just before the commencement of my thesis, your spirit lives on.

Eugene C.X. Ikejemba (Enschede, the Netherlands. 2014)

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CHAPTER 1
INTRODUCTION

Habitants in rural areas and low socioeconomic groups often live far away from healthcare facilities. This may compromise their abilities to attain a high level of care when sick especially when it requires an immediate expert attention such as the cardiovascular disease (CVD). This paper develops a mathematical model for selecting optimal locations for new specialized CVD clinics and tries to suggest improvements to current clinics within optimal locations in remote regions.

Section 1.1 discusses CVD and its social and economic consequences in developing states. Section 1.2 outlines the strategy utilized to execute this research.

1.1. CARDIOVASCULAR DISEASE

1.1.1. The Disease

Cardiovascular Disease (CVD) refers to any disease of the heart and blood vessels. The most common CVD are strokes, heart attacks, heart failure and heart disease caused by high blood pressure. According to the World Health Organization, in 2008 an estimated 17.3 million people died of CVDs and by 2030, at least 23.3 million people will die annually from CVDs (WHO, 2013). The plague of CVD is a global phenomenon as shown in Fig 1.1. In the contemporary habitat, the magnitude of this increase in incidence and prevalence in the developing world is visible (Gersh, Sliwa, Mayosi, & Yusuf, 2012). Contrary to popular belief, 4 out of 5 of these deaths occurred in low- and middle-income countries, and men and women were equally affected.

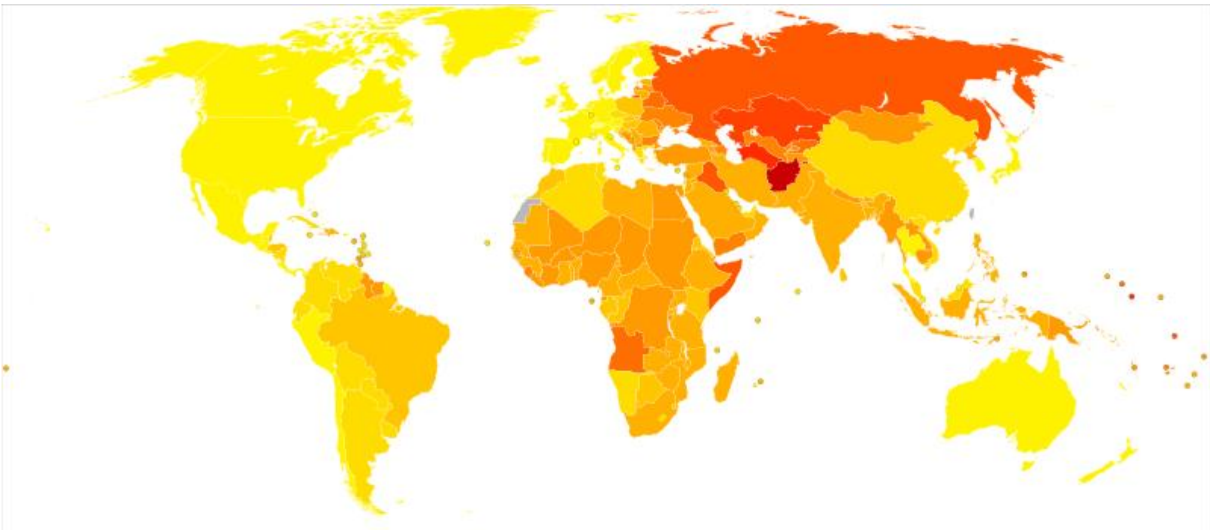

Fig 1.1: Map of Cardiovascular diseases incidence around the world. Darker colors signify larger percentage of diseased population (A. John Camm, 2009).

The facts are unequivocal and alarming. CVD remains the major cause of death in the world, far outpacing deaths due to malaria, HIV/AIDS, and tuberculosis (Fuster & Voute, 2005). Roughly 80% of the 35 million deaths annually are attributed to chronic disease and a corresponding proportion of the 16.7 million deaths caused by cardiovascular disease occur in low and middle-income countries (Lopez, Mathers, Jamison, & Murray, 2006). A number of risk elements for heart disease include: age, gender, high blood pressure, high serum cholesterol levels, tobacco smoking, excessive alcohol consumption, sugar consumption (Wylie-Rosett, 2002) family history, obesity, lack of physical activity, psychosocial factors, diabetes mellitus, air pollution (Bridget & Fuster, 2010). Some of these risk elements, such as age, gender or family history, are permanent; however, multiple important cardiovascular threat factors are changeable by modifying lifestyle, medical treatment and social change.

1.1.2. The Social and Economic Consequences of Cardiovascular Disease in Developing States

Industrialization, urbanization, economic change and globalization introduce lifestyle changes that advocate heart disease. These risk factors as explained in the preceding page include the use of tobacco, physical inactivity, and unhealthy diet. Life expectancy in developing countries is ascending exponentially and people are exposed to these risk factors for lengthy periods. Research shows that emerging cardiovascular disease risk factors like low birth weight, foliate deficiency and infections are also more frequent among the poorest in low and middle-income countries around the world (WHO CVD Report). India is a striking example of a country with contrasting burdens of disease. In spite of the surge in the Indian economy over the last two decades, in 1999-2001 the Federal Agricultural Organization reported that roughly 213.7 million people were considered undernourished (UNICEF Report, 2011).

Institutional care of CVD is costly and a lengthy process as it greatly affects both families and developing nations. CVD disrupts the future of families that are impacted by the disease when it affects individuals that are in their peak mid-life years. This will then affect their families which will further diminish manpower and hence affects the development of a country. In developed nations, groups beneath the average socioeconomic groups have greater prevalence of risk factors, higher occurrence of disease and higher mortality. In developing countries, as the CVD epidemic matures the encumbrance will shift to the lower socioeconomic groups (WHO Report, 2011).

1.1.3. Impediments for CVD in Developing and Underdeveloped Countries

The World Health Organization (WHO) has been very active in industrialized states. The observance of World Heart Day and World Non-Smoking Day has increased awareness among the people. However, due to the lack of government commitment and bureaucracy, prevention on the disease is not taking seriously. This leads to limited recognition and available data on CVD (Dodani, 2013). Governments, especially in the developing countries, can bring about change by way of legislation against the use of tobacco for and the labeling of processed foods to declare their fat and sodium content. The government must enforce its political will in eradicating the disease by proper transfer of technology to the states. Most African states and developing countries have failed to provide an impetus to eradicate CVD. For example, The John Taolo Gaetsewe district in South Africa's Northern Cape Province faces serious health challenges. The area has the highest infant mortality and maternal death rate in the country, and one of the highest rates of HIV/AIDS infection and Ischaemic Heart Disease. Despite the urgent need, access to healthcare is severely limited. For those who can afford it, there is a taxi prepared to drive patients along the 130km of dirt road to the nearest hospital. The rest must make the journey by donkey cart, if at all (Health, 2013).

1.1.4. World Health Organization

The WHO Programme (WHO Report, 2011) works on prevention, management and monitoring of CVD globally. It aims to develop global strategies to reduce the incidence, morbidity and mortality of CVD by:

- Effectively reducing CVD risk factors and their determinants;
- Developing cost-effective and equitable health care innovations for management of CVD;
- Monitoring trends of CVD and their risk factors.

1.2. RESEARCH STRATEGY

1.2.1. Problem Description

In Africa, it is without doubt that patients with CVD, especially in rural areas depend on cultural herbs and traditional walk-ins to hospitals to get treatment. Furthermore, hospitals within rural areas lack the ability and settings to deal with this problem, which unfortunately leads to death and patients having to travel long distances to get treatments. This follows from the fact that specialized clinics that deal with this disease are not in close proximity to the rural areas and low socioeconomic groups that contract the disease. This geographical barrier adversely influences the health outcomes of patients.

1.2.2. Research Objective

The goal of this paper is to determine the optimal locations of specialized CVD clinics taking into account current specialized hospital locations, emergency services, and geographical and demographical characteristics.

1.2.3. Research Set-up and Scope

As the main objective of WHO is focused on the prevention, monitoring and treatment of the disease, the focus of this paper is not on prevention of the disease, rather on the principal problem of locating CVD clinics at locations not too distant from patients most especially in the rural areas where the disease affects mostly the low socioeconomic groups. To effectively test and validate the model to be developed, a series of activities need to be executed that includes selecting a region. Using the Western Cape of South Africa as a case study provides a potential insight on the effectiveness of designing a system to deal with CVD at locations that disperses between the low-socioeconomic groups and the elites.

1.2.4. Research Questions and Thesis Outline

Based on the exploration of the research problem and objective, the following questions are developed as a structure to the study. In Chapter 2, the initial measure of the research is to comprehend the process necessary to determine the optimal locations of centers specialized for the treatment of CVD. Therefore, at this stage, it is important to be acquainted with the locations of current hospitals, clinics and centers that deal with CVD if at all any exist.

RQ1. Present Situation (I) - *What are the locations of the existing centers? What population or county do these centers cover?*

RQ2. Present Situation (II) - *What are the current performance indicators and what measures are used to consider an existing centre state-of-the-art?*

As identified in the research objective on how geographical barrier can adversely influence health outcomes, decision makers must choose where to locate new facilities to maximize coverage and clinical benefits. However, the best method to locate potential new clinics for these facilities has not been identified. Such decisions are often based on political factors or guesswork, and an objective method would be useful. As a result the following questions corresponding to each chapter are outlined below:

In Chapter 3, analysis of previous research is carried out. As such the following question is formulated:

RQ3 - *What modeling approach can be utilized to solve the location problem?*

In Chapter 4, the mathematical models are presented and the following question is formulated:

RQ4 - *Which mathematical models can be successfully utilized to solve the problem taking into account different situations such as minimum distance, population and distance limit?*

In Chapter 5, Computational Experiments of the models are executed. In addition, sensitivity analysis is also performed. Therefore the following questions are formulated:

RQ5 – *Where should the specialized centers be located based on the solutions?*

RQ6 – *How robust are the solutions provided by the mathematical models?*

RQ7 - *What new centers may be required?*

In Chapter 6, conclusions and recommendations and the possibilities for future research are presented and the following questions are formulated:

RQ10 - *What advantages do the model generated solutions have on patients with Cardiovascular Disease and the current system?*

RQ11 - *How should the outcomes be successfully implemented?*

In the remainder of the paper, the Appendix contains data utilized, supplementary data and diagrams used in the research process.

CHAPTER 2
ANALYSIS OF THE CURRENT STATE

In this chapter, analysis is carried out on the existing state of the system taking into account all geographical and demographical factors. The chapter starts with a brief introduction of the current state of specialized CVD clinics and the medical equipments utilized by these centers for the treatment of patients. Section 2.2 describes the situation in which the model is to be tested and verified by taking into account the current clinic locations, discerning of residence locale habitants suffering from CVD. This section is concluded with Mapping of CVD. In section 2.3, a stakeholder analysis is carried out to identify the measurable properties to be utilized in the model.

2.1. INTRODUCTION

As previously mentioned, CVD is traceable to eight risk factors: physical inactivity, smoking, excess bodyweight, drinking, high cholesterol, high blood pressure, low fruit and vegetable intake and diabetes. The joint effect of these factors increases an individual's chance of developing CVD by 65% (SA Health Report). Although dispensing good quality health-care for the poor is a moral necessity, due to delicate health systems and insufficient healthcare expenditure to many states, low socio-economic groups receive third-rate services or do not have access to it at all. WHO forecasts that over the next 10 years, a substantial rise in deaths from CVD will occur in developing countries such as South Africa (WHO, 2008).

Extensive study is done to understand the current condition on the treatment and containment of CVD in the province of the Western Cape. It was found that although numerous clinics exist within the great Cape Town area, these clinics do not cover over 36% of the habitants who live away from the metropolitan (see Section 2.2.4. CVD Mapping). We also took into consideration the time needed for emergency services to drive patients needing emergency treatment to the closest specialized CVD clinic for treatment. This research solely focuses on location-allocation problem that deals with the determination of the optimal locations for specialized CVD clinics as this can help keep fixed and overhead costs low and at the same offer a higher accessibility. The treatment section and clinic process optimization will be considered for future research. Ascertaining the necessary equipments needed by clinics to deal with CVD vary based on the context of state-of-the-art. This situation would be analyzed in Section 2.3: Stakeholder Analyses and applied in Chapter 4 and 5 in determining the locations for specialized CVD treatment facilities.

2.2. CASE STUDY

The main criterion for choosing the case study is its ability to bring a deep understanding of the subject at hand. The chosen case study extends experience and adds strength to what is already known through previous research (Yin, 1984). The methodology as described in the preceding chapter is applied in the province of the Western Cape of South Africa which consists of 6 district municipalities including West Coast, Cape Winelands, Overberg, Eden, Central Karoo and the City of Cape Town. Western Cape, which includes built-up urban areas, agricultural farms and rural townships, is of high interest because it is the most diverse province in the country.

2.2.1. Discerning of Residence Locale

According to Statistics South Africa, in 2001[1] the Western Cape Province accommodates about 10.1% of the population of South Africa. Measured by its total current income, the Western Cape is the second richest province in South Africa after Gauteng. In spite of these comparable fortunes, the province is still affected by high poverty rates, high income gap between the rich and the poor, and unemployment, though not as worse as compared to the other regions in South Africa (Pauw, 2005). In order to envision the geographical distribution of specialized CVD clinics and their associated potentials, data from Statistics South Africa was utilized to demarcate the province of the Western Cape into municipalities/clusters (see Fig. 2.2 and Table 2.1). In addition, Western Cape is divided into one metropolitan municipality (City of Cape Town) and five district municipalities which are further subdivided into 24 local municipalities. A complete list of all 24 local municipalities with relevant statistics can be found in Appendix 1.

2.2.2. Current Clinic Locations

A list of all existing hospital in the Western Cape was obtained from the provincial department of health. Since the focus and interest of the research is on CVD, extracting the clinics that provide specialist cardiac care from the list is deemed important. We also consider the numerous clinics and physicians around the province that provide services but do not possess the necessary equipment for specialized care. The SA Heart Organization[2] and the Heart and Stroke Foundation South Africa[3] provided a list of specialized CVD clinics within the region of the Western Cape that provide emergency services and quality care to patients affected by the disease. Analysis was carried out and a list of 16 clinics was obtained and over 80% of these are within the $2{,}460\ \mathrm{km}^2$ of the Metropolitan City of Cape Town.

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[1] Stats SA (http://www.statssa.gov.za) (Retrieved 10 Oct. 2013)

[2] The Heart and Stroke Foundation South Africa (HSF) plays a leading role in the fight against preventable heart disease and stroke, with the aim of seeing fewer South Africans suffer premature deaths and disabilities. The HSF was established in 1980 is a non-governmental non-profit organization and has NPO and section 21 status.- See more at: (http://www.heartfoundation.co.za/about-you/about-us#sthash.vWARwqFZ.dpuf) 12 Oct. 2013

[3] More Information at: http://www.saheart.org/ (Retrieved 12 Oct. 2013)

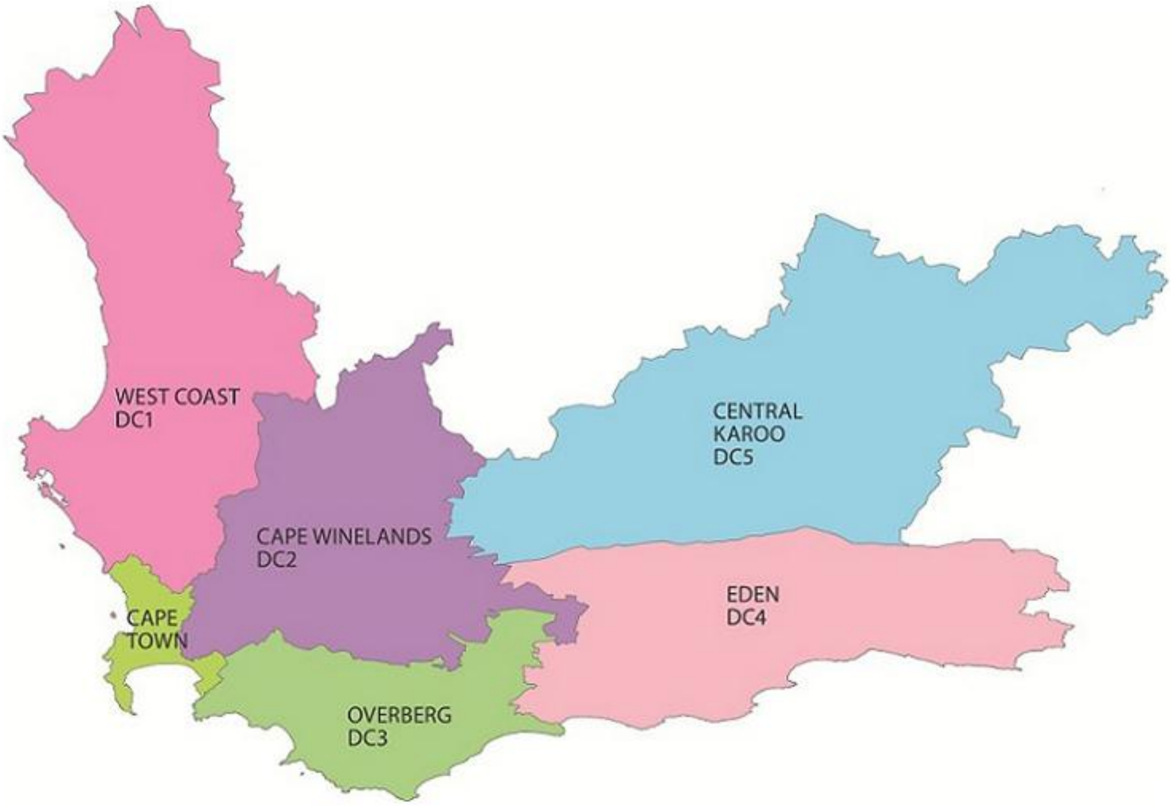

Fig. 2.2 The study regions of the Western Cape (2011)

Table 2.1
Description of the study region (2011, StatSA)

Name	**Code**	**Area** (km²)	**Population** (2011)[4]	**Pop. density** (per km²)
West Coast District	DC1	31,104	391,766	12.6
Cape Winelands District	DC2	22,309	787,490	35.3
Overberg District	DC3	11,405	258,176	22.6
Eden District Municipality	DC4	23,331	574,265	24.6
Central Karoo District	DC5	38,854	71,011	1.8
City of Cape Town Metropolitan	CPT	2,460	3,740,026	1,5

Mapping the clinics to the necessary locations by GPS systems, findings indicating communities which are underserved are greatly visible on the outskirt of the municipality of Cape Town. Using the following information, it is the onus of this research to utilize appropriate measures to determine appropriate locations for municipalities without specialized CVD clinics. A representative map of existing specialized systems can be seen in Fig. 2.3.

[4] http://www.statssa.gov.za/Census2011/Products/Census_2011_Municipal_fact_sheet.pdf (Retrieved Oct 12, 2013)

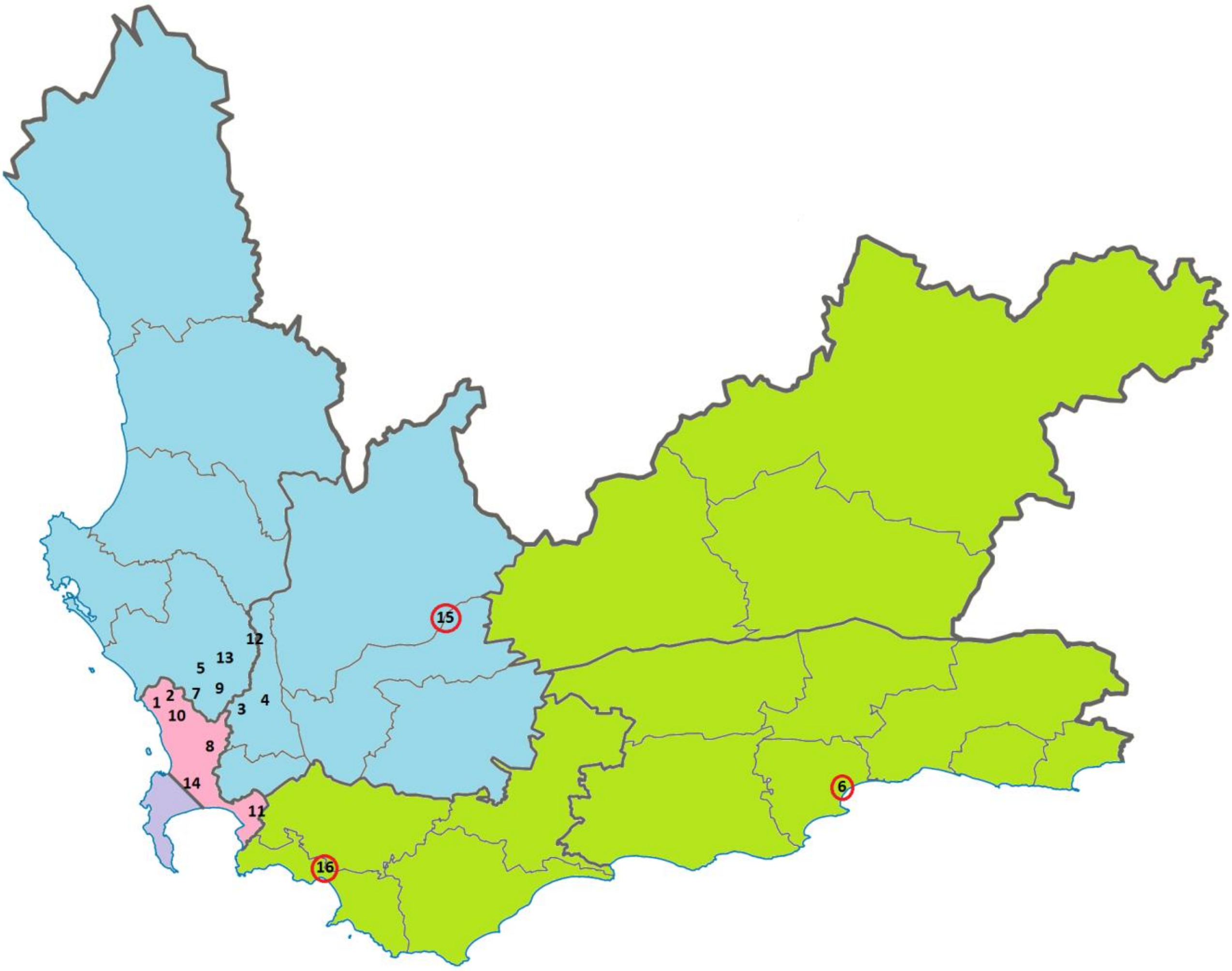

Fig. 2.3 The 16 existing specialized CVD clinics in the Western Cape[5] (2013)

2.2.3. Discerning of CVD Statistics

Across the globe the phenomenon of cardiovascular disease affects every habitant and does not discriminate against age, race and sexual orientation. As reported in a recent article (Steyn, 2007), the incidence of heart disease is growing amongst teenagers and young adults. Getting the disease is directly related to one's lifestyle and we can notice that CVDs are more widespread in countries such as the United States (Steyn, 2007). In addition, South Africa is not excluded from this problem and the numbers from tells us that this is the most eminent killer in the country.

[5] It is important to note that, the list of CVD specialist clinics was obtained from private and public NGO's and that error may occur. Nevertheless, according to StatSA, over 80% of the CVD specialist clinics are within the great Cape Town area. The numbers on the map represents each hospital which can be found in appendix 2 of this research. In addition, the numbers circled in red indicates the clinics that are most likely to serve other population not within the Cape Town municipality.

The ‘Heart Disease in South Africa’ report commissioned by The Heart and Stroke Foundation SA (HSFSA) revealed the following:

- More than 195 people perished per day due to some form of CVD between 1997 and 2004 in South Africa.
- In a day, approximately 33 people die due to heart attacks.
- The incidence in males is approximately twice as high as for females.
- In a day approximately 37 people die due to heart failure.
- Despite the death caused by AIDS at high rates in South Africa actuarial projections suggest that CVD, including heart disease, is also set to increase by 2010 and beyond.
- Approximately more than half of the deaths related to CVD occur before the age of 65 years. These are untimely deaths that affect the workforce in the country and have a major impact on its economy.
- Untimely deaths due to CVD in people of working age 35 - 64 years are expected to increase by 41% between 2007 and 2030. The economic impact of this incident is expected to be negatively enormous.

In response to all of these, this paper will seek to determine the optimal locations of specialized CVD treatment/rehabilitation centers in the Western Cape using a mathematical model. As no concrete statistics is available for the province of the Western Cape on CVD occurrence and deaths, overall statistics based on South Africa would be analyzed to develop a representative statistics of the Western Cape based on the population.

2.2.4. CVD Mapping

Utilizing the data in Table 2.2 and 2.3, we generated the shaded density plots of the disease over the province of the Western Cape. Fig. 2.4 is a result of the historical and present reported cases of CVD within the province. We were able to categorize patients according to the provided statistics and based population within the different municipalities. The dark red color represents the higher densities of case patients and light brown represents lower densities of case patients per population grid[6]. Current existing clinics are also displayed on the map. This analysis only represents reported cases and is based on historical data, previous research indicated between 1997 and 2004.

Characteristics (*n =64,042)*	$\sim Proportion$
Distance from closest CVD Clinic, km[7]	
>00 and <100	68.7
>100 and <200	23.4
>200	7.9

Table 2.2 Characteristics of habitants diagnosed or affected by CVD between 1997 and 2004.

[6] See Chapter 4 Model Formulation on population grid.
[7] Estimated based on the current existing clinics

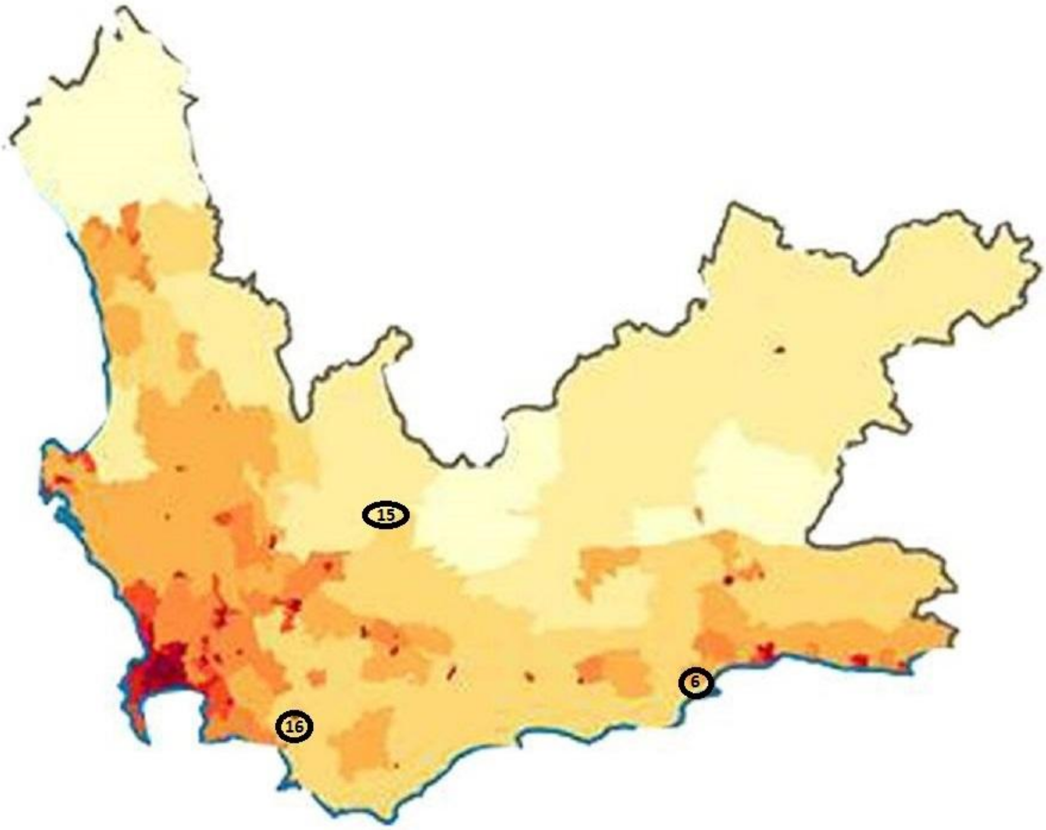

Fig. 2.4 Shaded map representing the distribution of CVD based on population distribution

District	Population 2011	Age Structure			Dependency Ratio		Sex Ratio	Population Growth	
		<15	15-64	65+	Per 100 (15-64)		Males per 100 females	Population Growth (% p.a.)	
		2011	2011	2011	2001	2011		1996-2001	2001-2011
West Coast	391,766	25.5	68.5	6.0	51.4	45.9	98.6	3.70	3.26
Cape Winelands	787,490	25.8	69.0	5.1	50.0	44.9	97.2	2.23	2.23
Overberg	258,176	24.1	67.6	8.3	50.2	47.9	100.4	4.98	2.37
Eden	574,265	25.9	66.3	7.8	53.5	50.7	95.8	3.55	2.33
Central Karoo	71,011	30.5	63.3	6.2	62.9	58,0	95.9	1.50	1.60
City of Cape Town	3,740,026	24.8	69.6	5.5	46.3	43.6	95.9	2.42	2.57

Table 2.3 Demographics of the Province of the Western Cape (2012, StatSA)

However, in some municipalities, there might have been rapid population growth or seasonal movement within the population and unregistered events which may contribute to errors in estimating higher or lower than expected occurrence of the disease burden for the municipalities. Therefore, comparisons should be based on rates rather than case counts (Koepsell & Weiss, 2003).

2.3. STAKEHOLDER MAPPING & PERFORMANCE MEASURES

This section provides an overview of the responsibilities and roles of key stakeholders impacting clinics. The detailed description of each stakeholders assists in identifying the measurable and what data are needed to adequately identify where the priorities for improvement might lie.

2.3.1. Stakeholder Analysis

Customary performance measures for business such as return on investments focus solely on the financial results acquired by an organization over a period of time. While deemed important, virtually little or no insight is provided to why certain results were obtained (Curtice, 2006). Therefore, measuring how favorable the expectations of each of the hospital's stakeholders produces a more unbiased and holistic view of performance that can bestow critical insight and counsel for action. Performing an extensive stakeholder analysis for all clinics in the province of the Western Cape would be tedious. Taking this into consideration as well as the time frame of this research, only two clinics are selected. To conform to the request of these clinics of anonymity, they will be represented in this research as Hospital A[8] and B[9]. Surprisingly, the procedure of establishing a balanced stakeholder-based measurement approach proved to be an opportunity for factual organizational learning, resulting in insights about the fundamental mission and vision of the hospitals.

Identifying all stakeholders in a health care system can be very tricky and difficult. These are individuals or groups of people that can thoroughly influence the performance of clinics. These individuals or groups of people, successively, have certain expectations from the clinics, and evaluating the degree to which these conjecture are currently being satisfied in a balanced method provides a valuable indicator of current and future performance. Following an extensive analysis and interviews using the method outlined in Appendix 3, hospital A and B decided on a list of stakeholders which can be seen respectively in Fig. 2.5 and Fig. 2.6.

One of the doctrines of the balanced approach is that in the long run, satisfying one stakeholder at the expense of another is not acceptable. Of course, patients are very important, but in the long term, if employees are unhappy with their work, they will not provide the necessary care deemed important for patients. As a result, the service levels will drop substantially. The next initiative was determining the gratification attributes of each of the stakeholders. According to (Curtice, 2006) this is the most important step of the analysis and it must be objective and fact-based, not based on pre-conceived judgment or assumptions.

[8] A private hospital in the northern suburb of Cape Town
[9] A public hospital in the great Cape Town area.

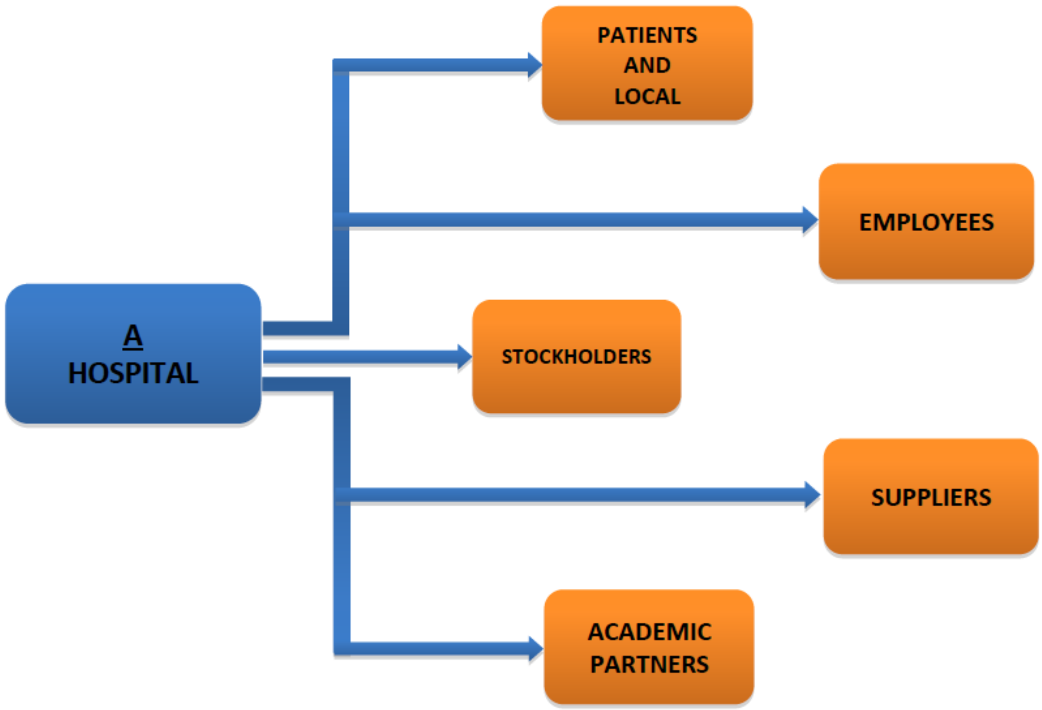

Fig. 2.5 Hospital A and its stakeholder relationships

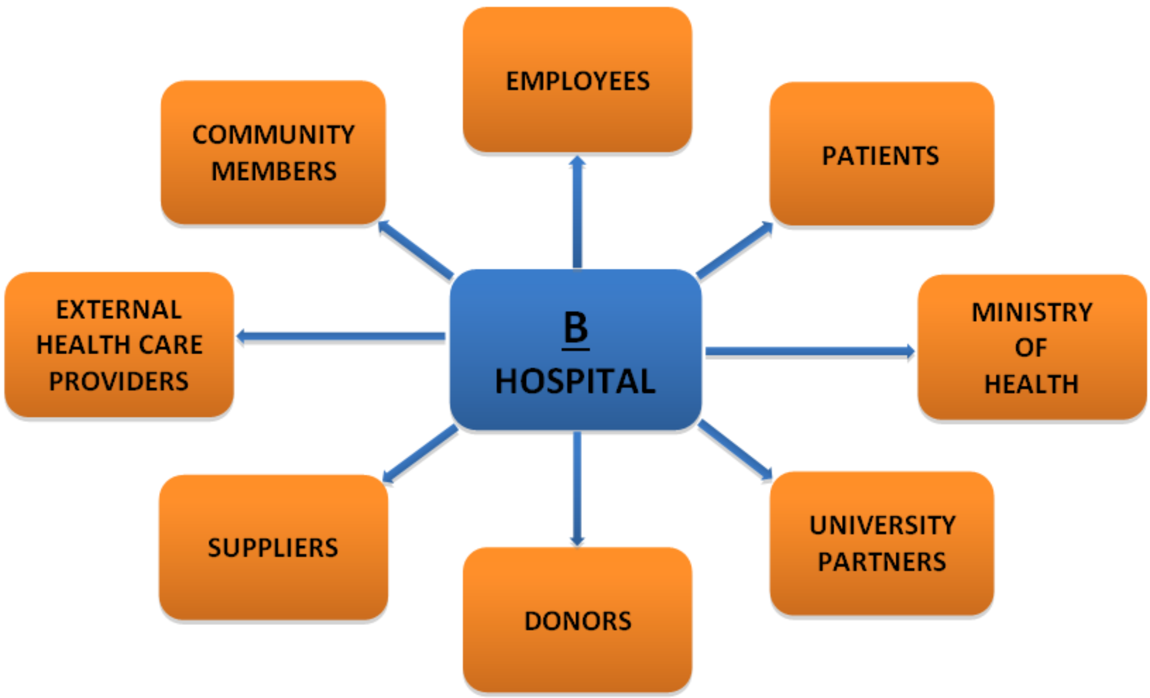

Fig. 2.6 Hospital B and its stakeholder relationships

The comparative importance of stakeholder gratification attributes can also demonstrate strategic decisions of the clinics. For example, if hospital charges and quality are of uniform importance to patients, a policy that stresses competing on the basis of quality will raise the importance of quality expectations to the targeted set of patients and local communities. Generally, it is best to focus attention on 3 to 5 gratification attributes for each stakeholder; a tactic involving hundreds of performance measures will not prove workable (Kano, Seraku, Takahashi, & Tsuji, 1996). In addition, surveys were carried out to determine exactly what satisfies the different stakeholder. In some situations, handing-out questionnaires to randomly selected employees is difficult as most of them complained about lack of time to complete the surveys and thus we resort to face-to-face interviews during their break times. Furthermore, the same strategy was utilized when dealing with stakeholders such as patients and local communities, volunteers and donors and finally the community members. E-communications such as emails, telephonic conversation was employed when dealing with stakeholders, academic partners and suppliers due to schedule constraints. A complete feedback and weighting description of the survey can be found in Appendix 4.

2.3.2. Performance Measures

Measuring performance is presently being used to evaluate the impact of operations on the stakeholders of the hospital. This is despite the fact that this can be marked 'as appraising the effectiveness and efficiency of action' when measuring the impact of the hospital's performance on patient's satisfaction. It is not as conspicuous in the cases of measuring the impact of the hospital's actions and performance on employee satisfaction or local community satisfaction (Bourne & Neely, 2003).

Few gratification attributes may seem complicated to measure on a quantifiable basis, such as career development. Nonetheless, it is usually possible to find suitable metrics such as the number of employees participating in career development training or seminars. A further likelihood is to quantify the results of surveys, e.g., percentage of employees who participated in career development seminars and evaluated their performance based on certain scales. The common concept is that all stakeholder supposition must have one or more quantifiable metrics that can be trailed over time such that the effect of improving performance programs can be measured (Curtice, 2006). A number of methods are available to determine actual performance levels, depending on the type of metric: empirical observation, sampling, questionnaire, etc. For the purpose of this research, questionnaire was utilized to ask participating stakeholders important questions in a survey. Using the survey, expectations were extracted from the participating stakeholders.

AVERAGE VALUES HOSPITAL A		
Employees		
Gratification Attribute	**Imp.**[10]	**Gap**
Suitable Salary	3	53,33333
Secure & Pleasant working conditions	2,333333333	40
Up-to-date technology to make work easier	2	45
Development of Career	2,333333333	40
Patients & Local Communities		
Gratification Attribute	**Imp.**	**Gap**
Good quality of medical services	2,8	60
Affordable care	2,8	46
Spend less time in clinics	1,6	46
Restoration of health	3	58
Stockholders		
Gratification Attribute	**Imp.**	**Gap**
Return on investment	3	40
Solidity	2	40
Awareness	1	60
Liquidity of Investment	2	20
Suppliers		
Gratification Attribute	**Imp.**	**Gap**
Suitable price for health care technologies	3	60
Good partnership with stockholders	2	60
Punctual payment	2	90
Academic Partners		
Gratification Attribute	**Imp.**	**Gap**
Excellent contractual relationship	2	60
Adequate provision of clinical rotations for medical students	2	60
Healthy partnership for research activities	3	70

AVERAGE VALUES HOSPITAL B		
Employees		
Gratification Attribute	**Imp.**	**Gap**
Suitable salary	3	58,33
Secure & pleasant working conditions	2	45
Up-to-date technology to make work easier	1,5	39,17
Development of Career	2,333333333	43,33
Patients		
Gratification Attribute	**Imp.**	**Gap**
Good quality of medical services	3	54
Affordable care	2,4	45
Spend less time in clinics	1,6	47
Restoration of health	3	57
Ministry of Health		
Gratification Attribute	**Imp.**	**Gap**
Adequate budget allocation	3	60
Healthy lifestyle for citizens	2	40
Non-existence of child abuse and violence	2	40
University Partners		
Gratification Attribute	**Imp.**	**Gap**
Excellent contractual relationship	2	60
Adequate provision of clinical rotations for medical students	2	70
Healthy partnership for research activities	3	70
Volunteers & Donors		
Gratification Attribute	**Imp.**	**Gap**
Feel appreciated	2,5	52,5
Personal Development	3	40
Clear line of communication	1,5	57,5

[10] Imp. - Importance

Suppliers		
Gratification Attribute	**Imp.**	**Gap**
Suitable price for healthcare technologies	3	60
Patient compliance data	2	40
Reporting unfavorable events	2	40
Community Members		
Gratification Attribute	**Imp.**	**Gap**
Performance based payments	3	50
Standard measurement for assessing quality	2	40
Adequate provision about risks and benefits of special drugs	2	70

Table 2.4: Average data values for clinics A & B

Table 2.4 represents the average data values obtained by interviewing and questioning the participating stakeholders. As mentioned above, a complete individual weighting and description of the survey can be found in Appendix 4**.** As no historical data existed based on the gratification gaps, current data were obtained by questioning the selected participants and the average value was obtained by compiling the percentage response provided by the participants. A gratification list attributes was compiled by the participants and the grade of importance was selected by each participant based on a scale of high (3), medium (2) and low (1).

The relative importance was obtained by computing the average of the responses for each stakeholder that had more than one participant. Based on the current level of performance and the target set for the various metrics of a gratification attribute, an all-inclusive gap is allocated. The gap is an indication of how much the current level of performance is from the objective level. In this research, the gap is expressed in terms of the target percentage. For instance, if there were one metric for the attribute that had a current performance level of 80 versus a target of 100, then the percent gap would be $100 - 80 = 20$. According to (Curtice, 2006), one of the benefits of a percent gap is that an overall evaluation can then be prepared showing which attributes are farthest from their targets on a comparable basis, which applies to our case. The relative importance of each gratification attribute was multiplied by the gap in actual performance to produce a need for improvement weighting strategy that is utilized in Table 2.5 and 2.6 to discover the processes that need improvements.

Stakeholders	Gratification Attribute	Relative Importance	X	Current Gratification Gap	=	Need for Improvement	Hospital A Process				
							Provide Med. Services	Care for Patients	Manage Employees	Dispense Tech. & Supplies	Manage Financial Resources
Patients & Local Communities	Good quality of medical services	3	X	53	=	159	3	0.5	3	3	1
	Affordable care	2	X	40	=	80	2	3	0	0.5	2
	Spend less time in clinics	2	X	45	=	90	1	1	0	0	0
	Restoration of health	2	X	40	=	80	2	2	1	2	0
Employees	Suitable salary	3	X	60	=	180	0	0	3	0	3
	Secure & pleasant working conditions	3	X	46	=	138	0.5	1	3	2	0.5
	Up-to-date technology to make work easier	2	X	46	=	92	1	2	1	0.5	3
	Development of Career	3	X	58	=	174	0	0	3	1	0.5
Stockholders	Return on investment	3	X	40	=	120	2	0.5	1	0.5	2
	Solidity	2	X	40	=	80	1	0.5	0	0.5	2
	Awareness	1	X	60	=	60	0	0	2	1	0
	Liquidity of Investment	2	X	20	=	40	0	0	0	0	1
Suppliers	Suitable price for health care technologies	3	X	60	=	180	0	0	0	3	1
	Good partnership with stockholders	2	X	60	=	120	1	0	0.5	0	1.5
	Punctual payment	2	X	90	=	180	0.5	0	0	0	0.5
Academic Partners	Excellent contractual relationship	2	X	60	=	120	0	0	1.5	0	0
	Adequate provision of clinical rotations for medical students	2	X	60	=	120	0	1	0.5	0	0.5
	Healthy partnership for research activities	3	X	70	=	210	1	0.5	2	0.5	0
						Improvement Priority	**15**	**11.5**	**21.5**	**14.5**	**18.5**

Table 2.5 - Hospital A: Correlation of process with need for improvement.

Stakeholders	Gratification Attribute	Relative Importance	X	Current Satisfaction Gap	=	Need for Improvement	Hospital B Process				
							Provide Med. Services	Care for Patients	Manage Employees	Dispense Tech. & Supplies	Manage Financial Resources
Employees	Suitable salary	3	X	58	=	174	0	0	3	0	3
	Secure & pleasant working conditions	2	X	45	=	90	0.5	1	3	2	0.5
	Up-to-date technology to make work easier	2	X	39	=	78	1	2	1	0.5	3
	Development of Career	2	X	43	=	86	0	0	3	1	0.5
Patients	Good quality of medical services	3	X	54	=	168	3	0.5	2	3	1
	Affordable care	2	X	45	=	90	2	3	0	0.5	2
	Spend less time in clinics	2	X	47	=	94	1	1	0	0	0
	Restoration of health	3	X	57	=	171	2	2	1	2	0
External Health Providers & Ministry	Adequate budget allocation	3	X	60	=	180	0	1	2	3	3
	Healthy lifestyle for citizens	2	X	40	=	80	2	1.5	0	0	1
	Non-existence of child abuse and violence	2	X	40	=	80	1	0	0	0	0
University Partners	Excellent contractual relationship	2	X	60	=	120	0	0	1.5	0	0
	Adequate provision of clinical rotations for medical students	2	X	70	=	140	0	1	0.5	0	0.5
	Healthy partnership for research activities	3	X	70	=	210	1	0.5	2	0.5	0
Volunteers & Donors	Feel appreciated	3	X	53	=	159	0	1	2	0	0
	Personal Development	3	X	40	=	120	0.5	2	3	0	2
	Clear line of communication	2	X	58	=	116	0	0.5	0.5	0	0.5
Suppliers	Suitable price for healthcare technologies	3	X	60	=	180	0	0	0	3	1
	Patient compliance data	2	X	40	=	80	0.5	1.5	0	2	0
	Reporting unfavorable events	2	X	40	=	80	0	0.5	0	1.5	0
Community Members[11]	Performance based payments	3	X	50	=	150	1	0	0.5	0	1.5
	Standard measurement for assessing quality	2	X	40	=	80	0.5	0	2	1.5	0
	Adequate provision about risks and benefits of special drugs	2	X	70	=	140	2	2	1	1	0
						Improvement Priority	**18**	**21**	**28**	**21.5**	**19.5**

Table 2.6 - Hospital B: Correlation of process with need for improvement.

[11] Public clinics are non-profit organizations, and therefore, have members instead of shareholders.

The correlation matrix on the previous page was established for both clinics A and B. It is instituted between the stakeholder gratification attributes and the hospital's processes to comprehend the degree to which each of the process influences each attribute. By way of illustration, the process "provide medical services" has a high influence on "good quality of medical services" and receive a base score of 3 based on the matrix, while the same process has little influence on “personal development” resulting in a base score of 0. When these base scores are combined with the attribute weighting scheme the result is a chart similar to the one in Table 2.5 and 2.6. This table clearly shows which processes must be improved in order to close the most important gaps in meeting stakeholder expectations. In the priority for improvement, as can be seen in the table, it differs for both hospital A and hospital B, which could be due to different policies adopted by both hospitals as they are private and public entities, respectively. However, the main priorities for improvements are the same for both hospitals but they differ between the second priorities for improvement. In the case that an existing hospital falls within an optimal location for CVD clinics to be determined in Chapter 4 and 5 the following priority for improvement would be taken into account. Taking into consideration the time constraint and sources available, the stakeholder analysis carried out was done for a public and a private hospital and may not be representative when done for a 100 hospital over the region.

Conventional financial measures provide a biased overview of the performance of a hospital, and do not help to pinpoint where performance improvements are needed. A more balanced approach considers the expectations of all stakeholders of the clinics, and measures the level to which these expectations are attained. In utilizing the method as described by (Curtice, 2006) during the course of this research, a balanced approach is used to define the stakeholders, determining their expectations, and then analyzing the gaps that exist in actual versus expected performance levels in meeting these expectations.

2.4. CONCLUSION

In this chapter, identification of residence location was carried out. We identified the locations of existing specialized CVD treatment centers within the province. Statistics was generated based on previous research carried out and utilizing these statistics from various sources mapping out the disease was done appropriately.

In addition, a stakeholder analysis was carried out in a balanced approach by collecting questionnaire response and interviews of all stakeholders. This clearly shows the priorities of improvements differ between the private and public hospitals, when applied to a case of CVD treatment, the priorities of improvement are same for both hospitals but differ between the second priorities for improvement. As we check further, the priorities tend to be the same for both hospitals (see Table 2.5 and 2.6). This point is taken into account when determining the optimal locations for new centers.

CHAPTER 3
LITERATURE REVIEW

In this chapter, a literature review is carried out with respect to the location-allocation problem considered in this research. Section 3.1 presents the search criteria and sources utilized in obtaining relevant literatures. This chapter starts with an introduction into location theory in Section 3.2. In addition we present and analyze previous research on location-allocation problems. This chapter is ended with a conclusion statement in Section 3.3.

3.1. LITERATURE APPROACH

In this section, an outline on the process of how the necessary articles are obtained for our research is described. The search terms utilized and the criteria for the selection of articles are also explained.

Research Database

The database Scopus has been primarily used to search for related literature on the subject of this research. This is because Scopus covers almost all the leading scientific journals in our research area. Therefore, it is primarily sufficient for this research. The success of conveying this research is based on the articles utilized and on the appropriate search terms used to obtain the articles. Different search terms are used with respect to obtaining appropriate articles for Location-Allocation Problem such as “Optimal Location Determination for Facilities”. Through the process we utilized Boolean functions such as “AND and OR” as the AND function restricts the search process to the exact terms expected and the OR function enlarges the search process within and beyond the terms expected but associates it with other necessary terms that are relevant.

Search Terms

- “Optimal Location Determination for Facilities”
- “Location-Allocation of Health Care Facilities”
- “Location-Allocation Models”
- “Maximal Covering Location Problem”
- “Location-Allocation of Production Facilities”
- “Determining the Optimal Locations for Health Care Centers”
- “Facility Location Models”
- “Location-Allocation Problems” AND “Facility Location Models or MCLP”

As the search terms are executed, selected criteria are considered. With the assistance of the selection criteria listed, the number of found articles based on its relevance and availability are narrowed down.

- Limit to "Engineering", "Decision Sciences", "Mathematics" and "Business Management and Accounting"
- Categorize on relevance and consider top 25
- Categorize on cited by and consider top 20
- Inspect titles and abstract on relevance
- Scan for availability

Google Scholar is utilized to search for articles that are not available on Scopus. Depending on the type of search terms, the search criterion might differ in certain cases but the criteria listed above are the general case utilized.

3.2. RELATED WORK

Research on location theory initially started in the early 1900's when Alfred Weber examined how to locate a single warehouse such that the total distances between the warehouse and customers is minimal (Weber, 1929). Following this embryonic study, location theory was driven by some applications which inspired researchers from different field of study. The development and investment in a new facility such as a hospital, is typically expensive and a time-delicate project. Before a facility can be established, excellent sites must be identified, suitable capacity specifications must be determined for the facility, and large amounts of capital must be assigned. While the main aim driving the location of a facility is dependent on the firm or government, the soaring costs associated with this action makes almost any location-allocation project a long-term investment. Thus, facilities which are positioned today are anticipated to be running for a long period of time. Natural changes during the life-span of the facility can drastically affect the interest of a particular location, twirling today's optimal location into an investment disaster. Therefore, establishing the best sites for new facilities is an important strategic challenge (Ye & Chuang, 2011).

In the field of Operations Research, researchers have created a vast number of mathematical models to solve a wide range of location-allocation problems. A number of different objective functions have been devised to make such models applicable to different situations. Regrettably, the produced models can be extremely difficult to solve to optimality (Meng, Ma, Han, & Wu, 2013).

The computational difficulty presented by intricate facility location models has, until lately, limited most study in this realm to fixed and deterministic problems. In fixed and deterministic problems, all inputs such as time, distances and demands are all known quantities and outputs are cited as a zero-one decision values (Berman, Hajizedeh, & Krass, 2013). While such problems can provide users with awareness about generic location selection, modeling the uncertainties that are important in making real-world decisions are quite impossible for these models. Location of hospitals and clinics providing either private or public health services is very critical in assuring that the selected location sites serves the cause of minimizing community cost or maximizing the benefits for the habitants. Likewise, the capacity allocation to these hospitals possesses a direct impact on the system's efficiency as a whole. The formulation of the location-allocation model represents an important role in healthcare planning, as it yields a framework for exploring problems with regards to accessibility, differentiating the caliber of previous location decisions, and providing several solutions change and improve the existing system (Rahman & Smith, 1999).

The most crucial issue highlighted during the course of this research is the selection of a suitable objective function or measure. Formulating the objective function highly depends on the ownership of the hospitals, both whether private or public and the condition of the hospitals, as has been earlier mentioned (Rushton, 1987). As mentioned in Chapter 2, taking into consideration the private hospital and public hospital, private hospitals are often cited to achieve stated organizational objectives, such as maximize profit or minimize cost. Contrary to private hospitals, the goals and objectives of public facilities are more strenuous to realize (ReVelle, Marks, & Liebman, 1970). For example, in this research the problem is to locate specialized CVD clinics and the possible criterion is to minimize the average distance (or time) a patient must travel in order to reach the hospital or maximize the population the clinic has to cover. Furthermore, note that a vast number of recent literature exists for locating healthcare facilities, ranging from modeling health care facilities for moving population group (Ndiaye & Alfares, 2008) to determining the optimal location of health care facilities in a defined setting (Shariff, Moin, & Omar, 2012) taking into account cost structure and capacity. Table 3.7 is the concept matrix that summarizes the review of literature with respect to the location-allocation models. In addition, it reflects the main differences between the existing literature and the present research.

Table 3.7: Concept Matrix

Articles	Type		Model Features		
	Application	Theoretical	Capacitated	Uncapacitated	Multi-Objective
Weber, A (1929)		+			+
Shariff et al. (2012)	+		+		
Rahman and Smith (2000)	+		+		
Ndiaye and Alfares (2008)	+	+	+		+
Dantrakul et al. (2014)	+		+		
Church and ReVelle (1974)		+		+	
Owen and Daskin (1998)		+	+	+	+
Song et al. (2013)	+	+			+
Church and ReVelle (1976)		+		+	+
Doerner et al. (2007)	+		+		
Berman et al. (2013)	+		+		
Hakimi (1964)	+	+			+
Faruque et al. (2012)					
Curtin and Hayslett-McCall (2010)	+			+	
Toso and Alem (2014)	+		+		
Ye and Chuang (2011)	+		+		
Meng et al. (2013)	+	+			
This Research	***+***	***+/-***		***+***	***+***

Since the most recent mode include characteristics of cost, capacity and pre-defined case studies and considering that the relevant data for our case are not exclusively available for this research, we extend our literature search to both Maximal Covering Location Problem (also known as the MCLP) and the p-Median models. With these models, we aim to select the most suitable in tackling the research objective in determining the optimal location for CVD clinics taking into account maximum population coverage.

3.2.1. Maximal Covering Location Problem (MCLP)

Maximal Covering Location Problem (MCLP) utilized in numerous studies in the past tackles the problem of locating facilities. It was first proposed by Church and Re Velle (1974) and is one of the most familiar models utilized in planning of public healthcare that seeks to maximize the population to be covered given a restrained number of clinics. An ample amount of research has been executed using MCLP to model clinic locations and several techniques from heuristics to exact methods have been suggested to solve the model. Several researchers such as Oppong (1996), Batta et al. (2014), and Li et al. (2011) provide detailed description of these models, and interested readers should refer to these papers.

Lately, the MCLP has been utilized to successfully solve larger models with higher complexity and models with greater than one objective (Doerner, Focke, & Gutjahr, 2007). The MCLP aims to obtain the solution to the problem of facility locations such that the coverage of order for services within a given acceptable service distance is maximized. Because the MCLP has been shown to be extremely combinatorially complex, a number of heuristics have been developed (AdensoDiaz & Rodriguez, 1997; Galvao, Espejo, & Boffey, 2000). Furthermore, the MCLP can be visualized as an alternative formulation of other well-known location models such as the Location Set Covering model and the p-Median model (Church & ReVelle, 1976). To formulate this problem mathematically, the following notation is necessary:

$$Maximize \quad z = \sum_{i \in I} a_i y_i \qquad (1)$$

$$subject\ to: \quad \sum_{j \in J} x_j = \boldsymbol{p} \qquad (2)$$

$$\sum_{j \in N_i} x_j \leq y_i, \qquad \forall i \in\ j \qquad (3)$$

$$x_j \ \in \{0,1\} \qquad \forall\, j \in J \qquad (4)$$

$$y_i \ \in \{0,1\} \qquad \forall i \in I \qquad (5)$$

Where,

$I =$ denotes the set of demand nodes;

$J =$ denotes the set of facilitiy sites;

$S =$ the distance beyond which a demand point is considered "uncovered";

$d_{ij} =$ the shortest distance from node i to node j;

$p =$ the number of facilities to be located;

$a_i =$ population to be served at demand node i;

$N_i = \{j \in J | d_{ij} \leq S\}$;

$$x_j = \begin{cases} 1 & \text{if point } j \text{ is a facility,} \\ 0 & \text{otherwise.} \end{cases}$$

$$y_i = \begin{cases} 1 & \text{if point } i \text{ is not served by facility within } S, \\ 0 & \text{otherwise.} \end{cases}$$

The objective (1) is to maximize the number of people served or "covered" within the desired service distance. The number of facilities allocated is restricted to equal p in constraint (2). Constraints of type (3) allow y_i to equal 1 only when one or more facilities are established at sites in the set N_i. Constraint (4) & (5) are binary requirements for the model variables.

3.2.2. The p-Median Model

The basic p-Median model (see below) established by Hakimi (1964) is one of the most favored models for locating public facilities (Dantrakul, Likasiri, & Pongvuthithum, 2014). According to Sleeb & McLaerty (1992), it has successfully been utilized in controlling the outbreak of disease. The model below minimizes the distance between customers and facilities. To formulate this problem mathematically, the following notation is also formulated:

Inputs:

$i =$ index of patient node

$j =$ index of potential facility site

$p =$ the number of facilities to be located

$d_{ij} =$ the distance between node i and potential facility j

$h_i =$ demand at node i

Decision variables:

$$X_j = \begin{cases} 1 & \text{if point } j \text{ is a facility,} \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if point } i \text{ is being served by facility at } j, \\ 0 & \text{otherwise.} \end{cases}$$

$$Minimize \ \sum_i \sum_j d_{ij} Y_{ij} \qquad (6)$$

$$subject\ to\colon \ \sum_j X_j = p \qquad (7)$$

$$\sum_j Y_{ij} = 1 \quad \forall i, \qquad (8)$$

$$Y_{ij} \leq X_j, \quad \forall i, j, \qquad (9)$$

$$X_j \ \in \{0,1\} \quad \forall\, j, \qquad (10)$$

$$Y_{ij} \ \in \{0,1\} \quad \forall i, j, \qquad (11)$$

The objective function (6) minimizes the total distance between patients and hospitals. Constraint (7) ensures that exactly p facilities are opened. Constraint (8) stipulates that every household/patient is assigned to a hospital. Constraint (9) authorizes assigning only to places at which hospitals have been located. Constraint (10) & (11) are binary requirements for the model variables. Another variation of the p-Median model is described as finding the location of p facilities such that the total demand-weighted distance between customers and facilities is minimized (Owen & Daskin, 1998) and as such is formulated as:

$$\text{Minimize} \sum_i \sum_j d_{ij} Y_{ij} h_i \qquad (12)$$

Constraints (13)-(17) are identical to (7)-(11) of the basic p-Median model.

$$\text{subject to: } \sum_j X_j = p \qquad (13)$$

$$\sum_j Y_{ij} = 1 \quad \forall i, \qquad (14)$$

$$Y_{ij} \leq X_j, \quad \forall i, j, \qquad (15)$$

$$X_j \in \{0,1\} \quad \forall j, \qquad (16)$$

$$Y_{ij} \in \{0,1\} \quad \forall i, j, \qquad (17)$$

The p-Median model is quite captivating since it captures the fact that as the combined weighted distance of travel is getting smaller, the more favorable it is for customers to visit the nearest facility. It has often become a norm that the use of facilities decreases expeditiously when the time for customer to reach these facilities exceeds a specific time. According to Rahman (1991), this is the norm with the use of healthcare facilities in rural areas in developing states. Therefore, it is only reasonable to consider constraints dealing with time and maximum distances when formulating location-allocation problems (Rahman & Smith, 2000).

3.3. CONCLUSION

In this section, literature review was carried out. We were able to analyze two types of facility location models: Maximal Covering Location Problem (MCLP) and the p-Median Model. MCLP is considered a variant of the prominent p-Median model, so we aim to propose extensions that are a close relative to the p-Median problem rather than the MCLP, as it already takes into account maximum coverage. The p-Median model is selected because it determines the optimal locations of facilities based on the number of facilities p without or with capacity or cost constraints. In addition, in the following chapter we propose extensions to the p-Median model with respect to maximum coverage to better address our objective.

CHAPTER 4
FORMULATION AND ANALYSIS OF MATHEMATICAL MODEL

In this chapter, we discuss our mathematical model developed based on the p-Median model, which takes into account the maximum distance to travel and population coverage. This is initiated by the model formulation in Section 4.1. In Section 4.2, we present extensions and variants in connection to our model. Section 4.3 presents the conclusion of the chapter.

4.1. MODEL FORMULATION

In the previous chapter, we carried out literature review and selected the p-Median model as a basis for our model formulation. Over the next sections we will present our models and variants of our models that may provide different insights to policy makers.

4.1.1. The CVD Location Model (CVDLM) - Maximizing the population served with p hospitals and distance limit D.

The model below is a proposed extension of the p-Median model. It deals with maximizing the service level in the case of a distance limit. In (Owen & Daskin, 1998), models exist for which the maximum distance between points i and j is minimized. In this section, we incorporate the distance limit for which a specified distance is needed to transfer a patient with emergency conditions from a point i to a hospital at j. Therefore, in such cases, the model below is suitable. The formulation maximizes the population for which distance limits are introduced so that fewer hospitals are needed and the emergency situations are fully taken into consideration. In this research, the study area is divided into grid points (See Fig. 4.7).

Inputs:

$i = \text{index of patient node}$

$j = \text{index of potential clinics}$

$p = \text{the number of clinics to be located}$

$d_{ij} = \text{the distance between patient } i \text{ and potential clinic } j$

$D \ = \text{the acceptable distance limit (maximum distance)}$

$Pop_i = \text{subgroup population at point } i$

Decision variables:

$$X_j = \begin{cases} 1 & \text{if point } j \text{ is a hospital,} \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if point } i \text{ is served by hospital at } j, \\ 0 & \text{otherwise.} \end{cases}$$

Objective function (18) maximizes the population served with p hospitals and D distance limit.

$$\text{Maximize} \sum_{i=1}^{n} \sum_{j} Pop_i Y_{ij} \qquad (18)$$

Constraint (19) ensures that exactly P hospitals are opened.

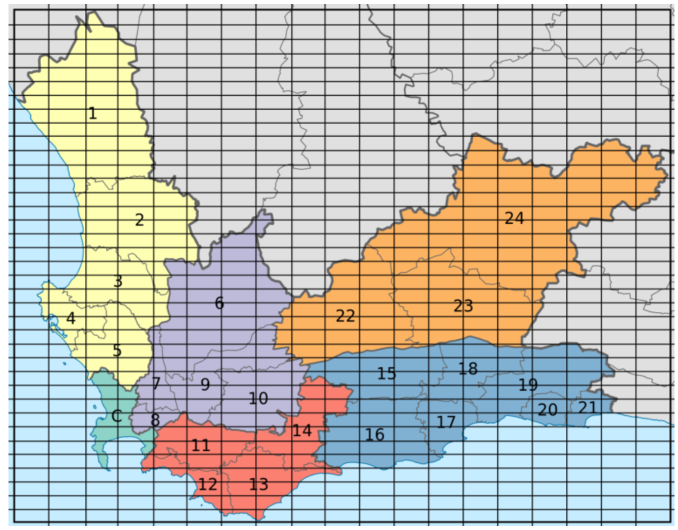

Figure 4.7: Grid representation of the study area (The I/O point of the graph is at the left down corner of the graph.)

$$\text{subject to:} \sum_{j=1}^{n} X_j = p \qquad (19)$$

Constraint (20) stipulates that every household/patient is at least assigned to a hospital within the specified distance limit D.

$$\sum_{j} Y_{ij} \leq 1 \quad \forall i, \qquad (20)$$

Constraint (21) authorizes assigning only to places at which hospitals have been located within the distance limit D.

$$Y_{ij} \leq X_j \quad \forall\, i,j \quad \{\forall i,j \mid d_{ij} \leq D\} \qquad (21)$$

Constraint (22) & (23) are binary requirements for the model variables.

$$X_j \in \{0,1\} \quad \forall\, j, \qquad (22)$$

$$Y_{ij} \in \{0,1\} \quad \forall i,j, \quad \{\forall i,j \mid d_{ij} \leq D\} \qquad (23)$$

In comparison to the already existing p-Median models, here the distance limit is introduced to incorporate emergency services and maximize the population that is covered by a clinic within the supposed distance limit D. The CVD Location Model above always provides a feasible solution since it does not stipulate that all demands have to be met.

4.2. EXTENSION AND VARIANTS OF THE MODEL

Policy makers or government officials may have different objectives than those that can be obtained with the CVD Location Model. These objectives may lead to variants of the CVD Location Model, with different constraints and/or objective function. Therefore, we demonstrate by answering multiple question as well as small variations of the model.

Q1: What is the lowest number of p, for which all the habitants have access to clinics within a distance limit D?

Q2: Given a number p, how do we allocate the p clinics optimally? The word "optimal" may pose different characteristics, and as such we ask what is optimal?

4.2.1. The Least *p*-Clinic Model (LPCM)

Q1: What is the lowest number of p, for which all the habitants have access to clinics within a distance limit D?

$Decision\ variables$:

$$X_j = \begin{cases} 1 & \text{if point } j \text{ is a hospital,} \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if point } i \text{ is served by hospital at } j, \\ 0 & \text{otherwise.} \end{cases}$$

Objective function (24) minimizes p to locate within a distance limit D to serve the population.

$$\text{Minimize } p \qquad (24)$$

Constraint (25) stipulates that every household/patient is assigned to a hospital within the specified distance limit D.

$$\sum_j Y_{ij} = 1 \quad \forall i, \qquad (25)$$

Constraint (26) is identical to constraint (19) of the CVD Location Model

$$\text{subject to: } \sum_{j=1}^{n} X_j = p \qquad (26)$$

Constraints (27) – (29) are identical to constraint (21) – (23) of the CVD Location Model

$Y_{ij} \leq X_j \quad \forall\, i,j \quad \{\forall i,j \mid d_{ij} \leq D\} \qquad (27)$

$X_j \in \{0,1\} \quad \forall\, j, \qquad (28)$

$Y_{ij} \in \{0,1\} \quad \forall i,j, \quad \{\forall i,j \mid d_{ij} \leq D\} \qquad (29)$

$p \geq 0 \quad is\ implied\ by\ (21) and\ (23) \qquad (30)$

With the Least p-Clinic Model (LPCM), we are able to determine the lowest number of clinics p needed for all population groups to have access within a specific distance limit. It can be executed prior to the CVD Location Model to determine the best p value.

4.2.2. Optimal Allocation of p CVD Clinics

Q2: Given p, how do we allocate p clinics in an optimal way? In this context, "optimal" may pose different characteristics, and as such we ask what is optimal?

- Idea 1: Maximizing the population served with p hospitals and distance limit D.
- Idea 2: Minimizing the total travel distance.
- Idea 3: Equitable travel distance – The maximum distance traveled by any population group in the optimal solution should be as low as possible.

4.2.2.1. CVD Location Model

Idea 1: Maximizing the population served with p hospitals and distance limit D. (see CVD Location Model).

4.2.2.2. The Minimum Travel Distance Model (MTDM)

Idea 2: Minimizing the total travel distance (Owen & Daskin, 1998)

Decision variables:

$$X_j = \begin{cases} 1 & \text{if point } j \text{ is a hospital,} \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if point } i \text{ is served by hospital at } j, \\ 0 & \text{otherwise.} \end{cases}$$

Objective function (31) the total travel distance of the population groups from point i to j.

$$\text{Minimize} \sum_i \sum_j d_{ij}\, Y_{ij}\, pop_i \qquad (31)$$

Constraints (32)-(36) are identical to (7)-(11) of the basic p-Median model.

subject to: $\sum_j X_j = p$ (32)

$\sum_j Y_{ij} = 1 \quad \forall i,$ (33)

$Y_{ij} \leq X_j, \quad \forall i, j,$ (34)

$X_j \in \{0,1\} \quad \forall j,$ (35)

$Y_{ij} \in \{0,1\} \quad \forall i, j,$ (36)

This is another variation of the p-Median model, which finds the location of p facilities such that the total demand-weighted distance between the patients and clinics is minimized. In addition, this is only possible if constraint (33) holds. If this is not the case, then the total population will not be assigned to a clinic, and as such violating the objective function of the model. For this situation we propose a 2-step approach to avoid these complications.

Step 1: Maximize the population served (see CVD Location Model).

Step 2: Minimize the total distance traveled (see Minimum Travel Distance Model), given $\sum_j Y_{ij} Pop_i = $ Solution of Step 1

4.2.2.3. The Least D Model (LDM)

Idea 3: Equitable travel distance – The maximum distance traveled by any population group in the optimal solution should be as low as possible (Owen & Daskin, 1998).

$Decision\ variables$:

$$X_j = \begin{cases} 1 & \text{if point } j \text{ is a hospital,} \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if point } i \text{ is served by hospital at } j, \\ 0 & \text{otherwise.} \end{cases}$$

The objective function (37) minimizes the maximum distance between any population group and its nearest clinic.

Minimize D (37)

Constraints (38)-(42) are identical to (7)-(11) of the basic p-Median model.

subject to: $\sum_{j} X_j = p$ (38)

$\sum_j Y_{ij} = 1 \quad \forall i$ (39)

$Y_{ij} \leq X_j, \quad \forall i, j$ (40)

$X_j \in \{0,1\} \quad \forall j$ (41)

$Y_{ij} \in \{0,1\} \quad \forall i, j$ (42)

$d_{ij} - D \leq \left(1 - Y_{ij}\right) \times M \qquad \forall i, j$ (43)

Constraint (43) defines the maximum distance between any population group and the nearest clinic, so that the M represents the largest travel distance between any point i and j in the network. For every $Y_{ij} = 0$ or 1, constraint (43) holds due to the impact of the M and as such the maximum distance between any population group is minimized. The Least D Model, a variant of the P-center (Owen & Daskin, 1998) problem is also known as the minimax problem, as we strive to minimize the maximum distance between any population group and its closest clinic.

4.3. CONCLUSION

In this chapter, we presented our formulation and analysis of our models. We propose the CVD Location Model, an extension of the p-Median model by maximizing the population to be covered which is the main idea of the MCLP. We also take into consideration the emergency services by introducing a service distance limit, so that patients within specific distance limits are served by CVD clinics within the distance limit.

We further analyze different situations of our model by generating several questions that are answered by small changes and variants to our model. For example, determining the lowest p required in covering the entire population, locating p in an optimal way and minimizing the maximum travel distance of the population from households to clinics.

CHAPTER 5
COMPUTATIONAL EXPERIMENT AND SENSITIVITY ANALYSIS OF THE MATHEMATICAL MODELS

In this chapter, we investigate our developed CVD Mathematical Model based on the p-Median model to illustrate the sensitivity of the solutions in terms of changeable parameters of the model. This also validates the accuracy of our model because it reacts in a sensible way to changes in the parameters. The chapter is initialized with presenting the summary and execution of the computational analysis for the CVD Location Model and the variants of the models in Section 5.1. Section 5.2 presents the sensitivity analysis of the CVD Location Model. In Section 5.3 we present the conclusion on the computational experiment and sensitivity analysis of the mathematical models.

5.1. COMPUTATIONAL EXPERIMENT

5.1.1. Data Assumptions

In our study we assume that the physical locations of the population groups to be served are known for all the municipalities and are distributed on a flat surface. We consider opening a given number of fixed specialized CVD health care units represented by the grid points in Fig. 4.7. Additional specific assumptions are made to outline the approach that is utilized in this research.

1. The number of hospitals p to locate at a municipality is based on the population density and distances. In cases where comprehensible data is not available then, the views of CVD experts are taken into consideration.
2. Possible sites for the location of the specialized CVD clinics are pre-identified and are all located on the grid point as in Fig. 4.7.
3. The hospital location model is discrete, and as such can be interpreted on a graph. The populated areas are aggregated to form a subsection of the total points of the grid within each municipality.
4. Distance approximation and population proportion as shown in Chapter 2 is used when deciding the closest existing clinic to visit.
5. An equilibrium resolution is made between the number of open hospitals p and the number of preexisting hospitals that fall within the model solution.

5.1.2. Experiment

The mathematical model presented in this paper is a tool for the location of specialized CVD clinics. It is developed as assistance to investors in formulating location-allocation decisions and not as a successor to the decision-making. The results of studying this model may be optimal with respect to the model. However, the models may not be feasible with respect to the complicated political issues experienced in the actual world. As such, the numbers of clinics to locate are decisions left for the government and investors. Therefore, to accurately define the number of CVD clinics to locate, an important aspect to consider is analyzing the population to cover. Assuming that there are no straightforward mathematical formulas or models to obtain appropriate values, it is necessary to base the number of CVD clinics to locate on historical data.

5.1.3. CVD Mathematical Model

The above model was applied to the case of the Western Cape and the different population groups as shown in Fig 4.7. In this model, we introduced a distance limit$D$, set to 60 kilometers. Taking into consideration that the model aims to maximize the population served within the distance limit, the number of specialized clinics needed is set to $p = 20$**.** We estimated the population using a uniform distribution within each municipality and its density. In Appendix 6, the different data used for our application's model including the sizes and the coordinates is presented. The distance between point $i\,(1,\dots,309)$ and $j\,(1,\dots,309)$ are computed and entered into the Advanced Interactive Multidimensional Modeling System (AIMMS) software. The traveling distances were computed as the straight line distances between each population i and potential clinic j. To test the model, we focused on the Western Cape Province. We also focused on the behavior of the optimal solutions under different situations or changes (see Section 5.2, Sensitivity Analysis). Using a PC of 2.00GHz and 4.00GB memory, the run times ranged between 1 to 5 seconds. The program was run for different values of p in order to analyze the optimal solutions and their behavior to changes in the parameters. The model consists of 6085 (6084) variables and 6086 constraints. (See Chapter 6 for geographical placement of the 20 CVD Clinics).

Table 5.8: Optimal Location Coordinates for 20 CVD Mathematical Model

Facility site *j*	*Coordinates*		Facility site *j*	*Coordinates*		Facility site *j*	*Coordinates*		Facility site *j*	*Coordinates*	
	x	*y*		*X*	*Y*		*x*	*y*		*x*	*y*
1	***1***	***33***	6	***3***	***29***	11	***6***	***12***	16	***13***	***6***
2	***2***	***14***	7	***4***	***6***	12	***7***	***6***	17	***13***	***12***
3	***2***	***22***	8	***4***	***12***	13	***9***	***16***	18	***14***	***18***
4	***2***	***26***	9	***4***	***18***	14	***10***	***10***	19	***16***	***9***
5	***2***	***27***	10	***5***	***4***	15	***12***	***12***	20	***16***	***10***

From Table 5.8, it is expected that reducing the number of CVD Clinics to open will change the coordinate points (locations) but will not affect the problem to attain an integer-optimal solution. This result is expected as the model is uncapacitated. However, increasing the distance limit would provide an incentive to reduce the number of clinics (see Section 5.2, Sensitivity Analysis). However, for the case of the Western Cape, for a maximum population coverage given the population density and area, p must be at least 12.

5.1.4. The Least p-Clinic Model (LPCM)

As explained earlier with the Least p-Clinic Model, we aim to minimize the number of clinics required to cover the total population across the grid network. The constraint $\sum_j Y_{ij} = 1\ \forall i$ is utilized rather than the $\sum_j Y_{ij} \leq 1\ \forall i$ utilized in the CVD Location Model. The other parameters and constraints are the same parameters as in the computational experiments of the CVD Location Model. Table 5.9 shows the computational results (Table 5.10, coordinate points) for the case of minimizing p clinics required to cover all populations with a maximum distance set at 60 kilometers.

Table 5.9: Computational results for the LPCM in comparison to CVD LM

	p	RunTime
LPCM	19	42.7 s
CVD LM	19	2.5 s

Table 5.10: Optimal Location Coordinates for Computational experiment of LPCM

Facility site *j*	*Coordinates* *x*	*y*	Facility site *j*	*Coordinates* *x*	*y*	Facility site *j*	*Coordinates* *x*	*y*	Facility site *j*	*Coordinates* *x*	*y*
1	***2***	***14***	6	***4***	***24***	11	***8***	***14***	16	***14***	***25***
2	***2***	***26***	7	***5***	***12***	12	***10***	***15***	17	***15***	***17***
3	***2***	***33***	8	***6***	***4***	13	***11***	***7***	18	***16***	***10***
4	***3***	***18***	9	***6***	***20***	14	***12***	***18***	19	***17***	***24***
5	***4***	***8***	10	***8***	***7***	15	***13***	***10***			

It can be seen from Table 5.9 that the least number of clinics required to cover all population across the grid network is $p = 19$, which is exactly the same case with the CVD Location Model when $\sum_j Y_{ij} = 1\ \forall i$. The only difference is in the run time of the computational experiment as the LPCM takes more time to obtain an optimal solution than the CVD LM. This indicates that the CVD LM also solves problems relating to obtaining the minimum number of facilities required for a giving grid network.

5.1.5. The Minimum Travel Distance Model (MTDM)

Utilizing the minimum travel distance model, we aim to minimize the travel distance between any population group and a clinic. In this model, as explained in Chapter 4, this model is only possible when the constraint $\sum_j Y_{ij} = 1 \; \forall i$ holds. The parameters and constraints of this model are the same with the CVD Location Model except for the objective function. Table 5.11 shows the computational result of the model for minimizing the travel distance between population groups and CVD clinics for $p = 20$. The computational time for the experiment is 29 s.

Table 5.11: Optimal Location Coordinates for Computational experiment of MTDM

Facility site *j*	*Coordinates* *x*	*y*	Facility site *j*	*Coordinates* *x*	*y*	Facility site *j*	*Coordinates* *x*	*y*
1	***2***	***15***	8	***4***	***6***	15	***7***	***13***
2	***2***	***28***	9	***5***	***12***	16	***11***	***8***
3	***3***	***7***	10	***5***	***16***	17	***12***	***15***
4	***3***	***8***	11	***6***	***4***	18	***13***	***8***
5	***3***	***9***	12	***6***	***9***	19	***15***	***10***
6	***3***	***10***	13	***7***	***3***	20	***16***	***9***
7	***3***	***21***	14	***7***	***9***			

5.1.6. The Least D Model (LDM)

In the Least D Model, the objective is to minimize the maximum distance traveled by any population group to the closest CVD clinic. In the solution, the maximum distance traveled by any population group is low as possible. We introduce a new constraint that defines the maximum distance between any population group and the nearest clinic. Nevertheless, the parameters of this model are exactly same as the CVD Location Model. Table 5.12 shows the computational result of the model.

Table 5.12: Computational results for the LDM in comparison to CVD LM

	$p = 12$		$p = 16$	
	Min D	**RunTime**	**Min D**	**RunTime**
LDM	**55**	6.08 s	**50**	5.24 s
CVD LM	**55**	1.58 s	**50**	1.26 s

In Table 5.12, we make a comparison for both the Least D Model and the CVD Location Model. It can be seen that for both models, the minimum distance to travel for maximum population cover are equal. Given p number of clinics to locate, the only difference is in the computational experiment time as shown in the table. In addition, this also indicates that for policy makers who decide to hub on the minimization of the distance between a population group and a clinic, the CVD Location Model can be utilized in such cases. Furthermore, it can be seen for the different contexts of which policy makers or planners could select a condition as an objective, the CVD Location Model could be utilized in such situations with little variants in certain constraints and parameters. In the following section we would present the sensitivity analysis of our CVD Location Model as this model represents a variant of the other explained models.

5.2. SENSITIVITY ANALYSIS

Earlier in this chapter, we initialized by determining the locations for 20 CVD clinics. The number of clinics can differ between different situations since it is largely dependent on the availability of resources and capital. For instance, transportation to clinics, government or investor budget to locate lower number of CVD clinics. We decrementally reduce the number of clinics for the first case from 20 to 1. Other parameters of the model are assumed to be fixed. The result of the experiment is shown in Table 5.13.

Table 5.13: Computational results of the sensitivity analysis for changes in number of clinics.

No of Clinics (p)	**20**	**17**	**14**	**12**	**11**	**9**	**7**	**5**	**2**	**1**
Solving Time	1.45 s	1.41 s	1.36 s	1.34 s	1.65 s	0.64 s	0.58 s	0.50 s	0.47 s	0.6 s
% Covered (D=60km)	100	100	100	100	96.2	87.1	74.2	49.2	24.2	12.9

Furthermore, given the integer constraint as explained in Chapter 4, it is expected that within a distance limit of 60 km, all population groups are covered if $p \geq 12$. However, this is only possible since the problem is uncapacitated. As the number of clinics drops, the percentage of covered population reduces accordingly. It is expected that if the problem becomes capacitated, then based on the capacity of the clinics, the number clinics to open may increase or decrease. However, this is dependent on the capacity and the distance limit that has been set since as the capacity of the clinic increases, it would accommodate more population with a larger distance limit and vice versa.

In addition, as can be seen in Table 5.13, there is a slight difference between locating 12 clinics and 11 clinics. This leads to a differential of 3.8% of the population without coverage. Next, we focused on keeping the number of clinics constant. Along with this, we gradually reduce the distance limit D, from 80 km to 35 km. Other parameters of the models are assumed to be constant. We utilized 3 different values of p: $p = 12$ (this is used because, at least for maximum coverage, as earlier analyzed p must be ≥ 12), $p = 14$ (this is used because we take into account the least hospital to locate and the number of already existing clinics to find a midpoint of both situations for $p = 12$ and 16) and $p = 16$ (this is used because it is equivalent to the same number of currently existing clinics in the Western Cape).

Table 5.14: Computational results of the sensitivity analysis for *p* = 12, 14, 16 and reduction in D from 80km to 35km.

Distance Limit	80	75	70	65	60	55	50	45	40	35
No of Clinics (*p*)	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**
Solving Time (p=12)	3.98 s	3.81 s	3.59 s	2.71 s	2.36 s	1.58 s	1.48 s	1.39 s	0.6 s	0.58 s
% Covered (p=12)	**100**	**100**	**100**	**100**	**100**	**100**	**90.2**	**90.2**	**71.2**	**49.2**
No of Clinics (*p*)	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
Solving Time (p=14)	4.12 s	3.90 s	3.51 s	2.81 s	2.26 s	2.25 s	1.03 s	0.75 s	0.55 s	0.59 s
% Covered (p=14)	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**78**	**56.8**
No of Clinics (*p*)	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**	**16**
Solving Time (p=16)	3.13 s	3.1 s	3.09 s	2.09 s	1.56 s	1.28 s	1.26 s	1.26 s	0.31 s	1.01s
% Covered (p=16)	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**85.6**	**62.9**

In the first instance with $p = 12$, the maximum coverage is achieved up until a distance limit of 55 kilometers (Table 5.14). This indicates that with 12 specialized CVD clinics we are able to achieve a maximum coverage of the total population but, reducing the distance limit D to 50 kilometers indicates coverage of 90.2% and reduces up to the value of 49.2% with a distance limit of 35 kilometers (Fig 5.8). It is expected that as the distance limit reduces for $p = 12$ the percentage coverage for the habitants reduces accordingly, leading to coverage in areas of higher population groups as indicated by the variable Y_{ij}.

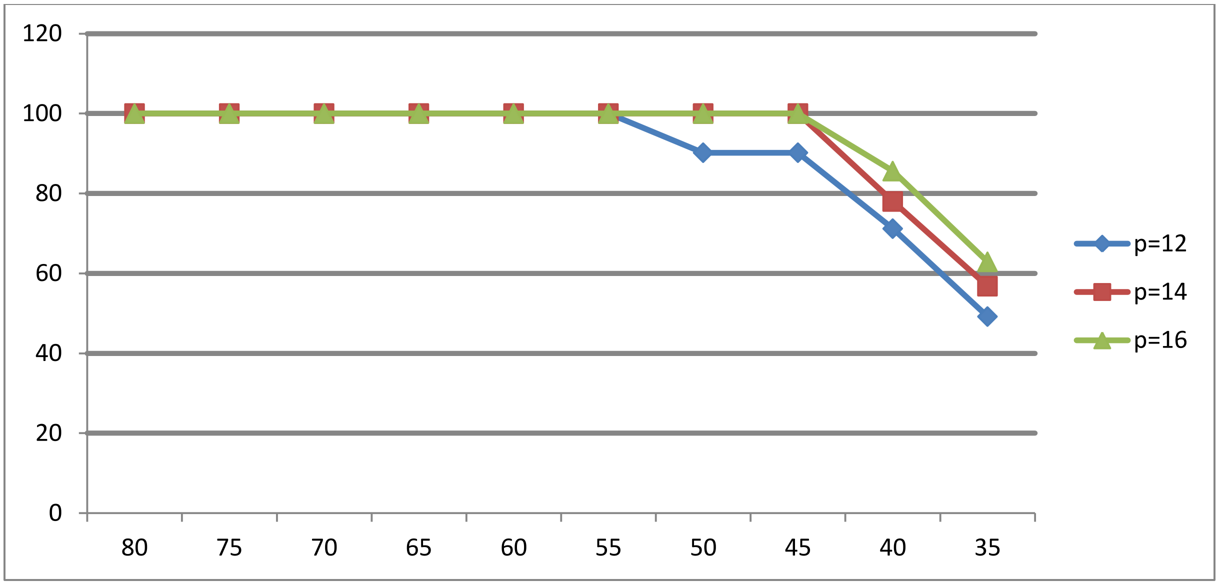

Figure 5.8: Percentage coverage as distance limit D reduces for *p= 12, 14, and 16*

It is also the case in the second and third instances for $p = 14$ and $p = 16$. In both cases, there is a 100% maximum coverage for all populations with a distance limit of 80 km to a distance limit of 45 km. It suddenly deviates significantly when the distance limit is set to 40 km with $p = 14$ covering only 74% of the population, whilst $p = 16$ covers 85.6% of the populations.

5.3. CONCLUSION

Computational tests have been performed on the CVD Location Model and the other variants of the model. We initialized by performing computational experiment for $p = 20$ taking into account the distance limit of 60 km. We also present different variations of the CVD Location Model that answer questions regarding different objectives. Such as, minimizing the p clinics to locate for maximum population coverage and minimizing the maximum distance of travel. Furthermore, the sensitivity analysis is executed for our model with the findings depicting that the CVD Location Model can be utilized for situations pertaining to the location of facilities and networks. In executing the sensitivity analysis of our model, all the computational experiments provided a feasible solution. The only major difference that arises can be seen in the computational time for the different cases and the percentage coverage for the different number of CVD clinics within specific distance limits. This may be an important factor in certain situations and could also be otherwise.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

In this chapter, we discuss the advantages of the mathematical programming model solutions have on patients with CVD and the current system in Section 6.1. In addition, we discuss the overall objective of our research, methods and solutions. In Section 6.2, the recommendations on how the outcomes can be successfully implemented are also presented. Section 6.3 discusses the possibilities of future research.

6.1. CONCLUSIONS

In this research, we proposed the CVD Location Model to solve the location problem for specialized CVD clinics. The model is developed based on the p-Median model. In addition, we present different variations of the model to gratify the different perspective that may be held by the policy makers. The models were then adapted and modified to solve a real data set representing the South African Province of the Western Cape. An analysis carried out on the current situation showed that the current location of the hospitals do not effectively cover over 36% of the population. Taking into account the mathematical models in this research, we maximized the total population being covered within specific distance limit, minimized the distance traveled and obtained the minimum number of clinics required to cover the whole population. The analysis shows that the current total population covered effectively would reduce drastically if no action is taken on the location of specialized CVD clinics. This is guaranteed to affect the working class of the total population and in the long term could be detrimental to the economic growth of the country in general.

In Fig. 6.9 and Fig. 6.10 of the following page, the current 16 existing CVD clinics in the Western Cape and the optimal locations for 20 Potential CVD Specialized Clinics in the Western Cape are shown. As stated and shown in Chapter 5, the percentage coverage depending on the number of clinics are shown in the sensitivity analysis of the model. When compared to the current solution, we arrived at different configurations that can result in the maximum coverage of the population (See Table 6.15).

Table 6.15: Configuration for maximum population coverage

Number of Clinics *(p)*	12	14	16
Distance Limit (D)	55	45	45

Taking into account the growth rate per year of the province, the implementation of the mathematical programming solution proves to be beneficial for the population and of the economy in the long term.

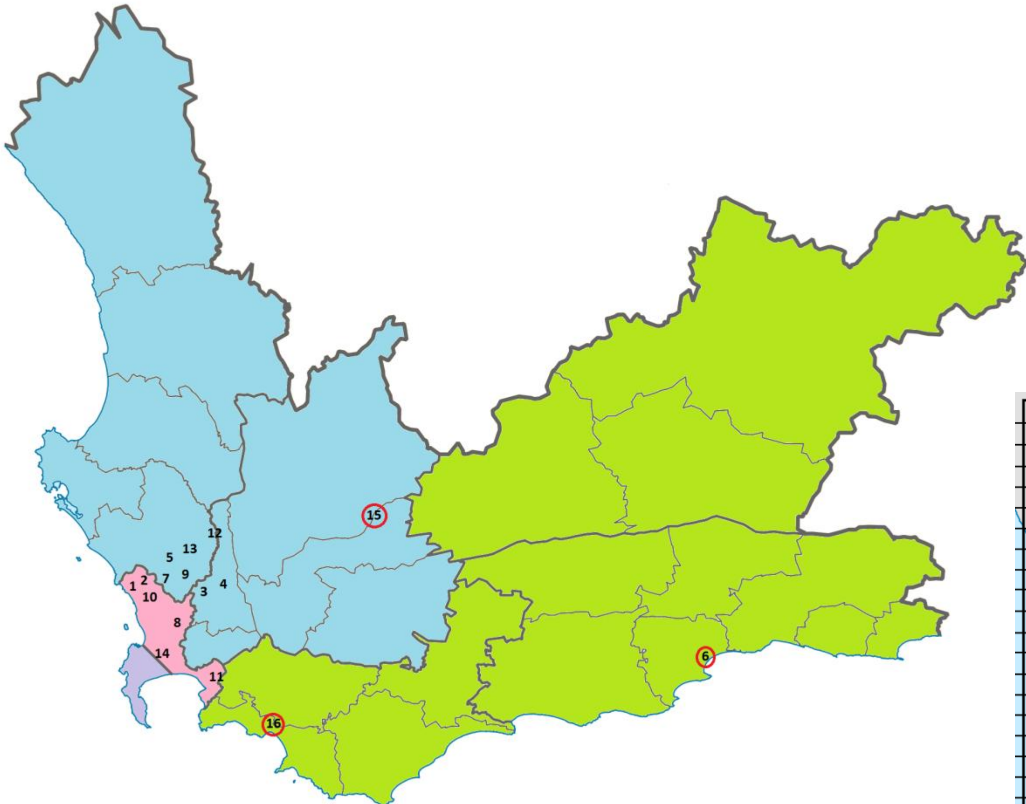

Figure 6.13: The Current 16 Existing CVD Clinics in the Western Cape

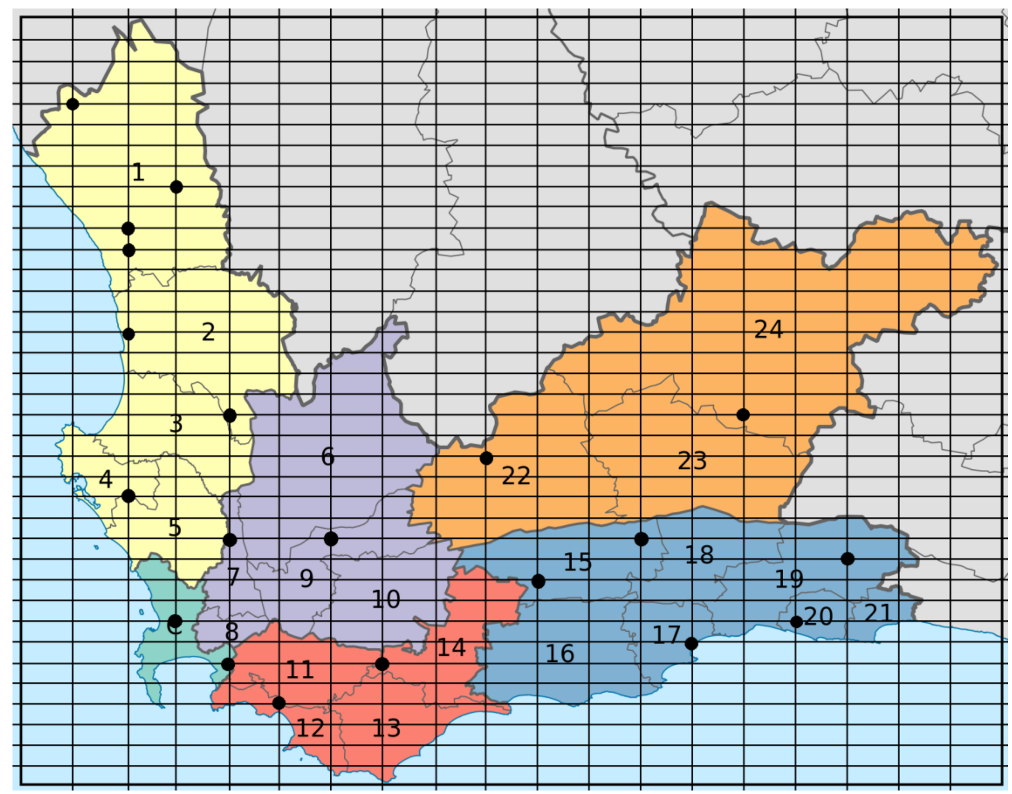

Figure 6.14: The Optimal Locations for 20 Potential CVD Specialized Clinics in the Western Cape represented by the Black Dots.

Based on the result of the CVD Location Model, the potential new locations were identified and analyzed. The result showed that the location of the potential new facilities could effectively cover the total population and in the long term assists in the growth of the economy. In addition, the mathematical programming models presented here will help make planning much easier for the planner or policy makers. The methods used in this research can also be applied to other types of facilities or resource networks, such as government buildings, schools, businesses and other service related networks.

6.2. RECOMMENDATIONS

In this section, we provide recommendations on how the mathematical programming solution should be implemented. Implementing the solution of the models can be considered as a project or development, though this solely depends on the body that authorizes the implementation since our models can be applied in different situations with respect to facility location. We can distinguish two kinds of implementation: a single-time implementation, such as the case study we implemented in this research to locate CVD specialized clinics; and multiple or repeated use of the model, such as production planning difficulty. In the latter instance, regular systems should be prominent to furnish input data to the LP model, and to convert the output into operating specifications. Undertaking a project or development of this nature requires substantial amount of resources, such as money, manpower, time etc. Therefore, this development or project would require various independent activities to be executed simultaneously, although, these activities may not be possible. For example, the start of this project would depend on a government approval. It is expected that executing this development may affect the existence of already existing CVD treatment centers with respect to its location; in such cases the performance measures for improvement carried out in Chapter 2 should be implemented.

The first stage of implementing the solution of this model is to understand the specification and the feasibility of the project. This includes deciding on the size and quality of the facility that is required, and this may differ within locations as the population sizes are taken into account. Different options could be analyzed and preliminary cost estimates maybe carried out. In addition, the economic, financial and social evaluation is carried out in this stage to determine the needs for the development.

The second stage of implementation is initialized by developing the plans for the project. The plans at this phase will establish the boundaries of a strategic design and will be inclusive of all the development's major component. This is done to provide a foundation for the detailed design and exact cost approximation of the development. In addition, it also provides the necessary information for the organization and suitable land procurement.

The third stage of the implementation is financing the development. This is one of the most important stages as this contains the finance for the development, construction and contingency. The constitution and timing of financial availability may impose certain limitation and constraints on the development itself. To avoid this situation, this should be contained in the first stage.

The fourth stage includes the construction and handover to the necessary body for management. This section embodies the detailed design, procurement of suitable contractors and construction contracts and is important towards the successful completion of implementation.

The fifth and final stage of the implementation is the management. Once the implementation of the development is completed, managing the activities within this development is of utmost important. This is to avoid situations that lead to mishandling of resources, etc.

6.3. FUTURE RESEARCH POSSIBILITIES

The mathematical programming introduced in this research could be expanded to allow capital or budget planning constraints. More so, it could be expanded to allow for available land constraints such as having a land availability limitation to determine the number of operated facilities that do not affect the land usage of other public services or resources.

An additional annex is to consider the movement of populations and adapting the models to fit the changes in other words, modeling the uncertainties that could arise if the facilities have been located at its optimal locations. Although in this research we have shown models that introduced the distance limit, such that, the total population covered is maximized taking into account emergency situation. Issues that could be addressed in future research could focus on the positioning of ambulance taking into consideration minimizing the distance, the probability of disease occurrence and all other relevant uncertainties.

The CVD Location Model presented in this research embodies an initial step towards locating the design of a complete specialized CVD clinic covering the total population. Commonly CVD treatment services are combined in regular hospitals. Taking into account how the disease plagues the world as the number one killer, designing a standalone center to deal with this disease should be considered although a complete design of such systems and network is a challenge that will require the solution of several-stage clinic location problems. The model presented in this research is designed to be a commencement of these situations.

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APPENDIX 1: LIST OF LOCAL MUNICIPALITIES IN THE WESTERN CAPE

Name	Code	District	Area (km²)	Population (2011)[1]	Pop. density (per km²)
City of Cape Town Metropolitan Municipality	CPT			3,740,026	1,520.3
Matzikama Local Municipality	WC011	West Coast	12,981	67,147	5.2
Cederberg Local Municipality	WC012	West Coast	8,007	49,768	6.2
Bergrivier Local Municipality	WC013	West Coast	4,407	61,897	14.0
Saldanha Bay Local Municipality	WC014	West Coast	2,015	99,193	49.2
Swartland Local Municipality	WC015	West Coast	3,707	113,762	30.7
Witzenberg Local Municipality	WC022	Cape Winelands	10,753	115,946	10.8
Drakenstein Local Municipality	WC023	Cape Winelands	1,538	251,262	163.4
Stellenbosch Local Municipality	WC024	Cape Winelands	831	155,733	187.4
Breede Valley Local Municipality	WC025	Cape Winelands	3,833	166,825	43.5
Langeberg Local Municipality	WC026	Cape Winelands	4,518	97,724	21.6
Theewaterskloof Local Municipality	WC031	Overberg	3,232	108,790	33.7
Overstrand Local Municipality	WC032	Overberg	1,708	80,432	47.1
Cape Agulhas Local Municipality	WC033	Overberg	3,467	33,038	9.5
Swellendam Local Municipality	WC034	Overberg	3,835	35,916	9.4

Kannaland Local Municipality	WC041	Eden	4,758	24,767	5.2
Hessequa Local Municipality	WC042	Eden	5,733	52,642	9.2
Mossel Bay Local Municipality	WC043	Eden	2,011	89,430	44.5
Oudtshoorn Local Municipality	WC045	Eden	3,537	95,933	27.1
George Local Municipality	WC044	Eden	5,191	193,672	37.3
Knysna Local Municipality	WC048	Eden	1,109	68,659	61.9
Bitou Local Municipality	WC047	Eden	992	49,162	49.6
Laingsburg Local Municipality	WC051	Central Karoo	8,784	8,289	0.9
Prince Albert Local Municipality	WC052	Central Karoo	8,153	13,136	1.6
Beaufort West Local Municipality	WC053	Central Karoo	21,917	49,586	2.3

Table A-29: Demographics of the districts of the Western Cape

APPENDIX 2: PROCEDURE USED IN SELECTING APPROPRIATE STAKEHOLDERS

The procedure[1] used in the ZOPP[2] approach for project definition and by NORAD[3] is as follows:

1 - Write down all the names of interest groups, institutions, individuals, organizations, authorities, who are:

- Concerned in any way with the project
- Located in the region
- Hold an influential position
- May be affected by the problems addressed in the program

2 - Group the parties involved into type of organization; i.e., individual, organizations, government, etc. to facilitate discussion and analysis.

3 - Take a closer look at some of the groups.

Select the most important; i.e., those expected to have particularly strong influence over the project and cannot be ignored.

Analyze these groups according to:

a) Characteristics: social (members, social background, religion, cultural aspects), status of the group (formal, informal, other) and structure (organization, leaders, etc.).

b) The main problems affecting or facing the group (economic, ecological, cultural, etc.).

c) The main needs and wishes, interests (openly expressed, hidden, vested), motives (hopes, expectations, fears), and attitudes (friendly/neutral/hostile towards implementation agencies and others) as seen from the group's point of view.

d) The potential in terms of both strengths (resources) and weaknesses of the group, and what could the group contribute or withhold from the project

e) The linkages indicating main conflicts of interests, patterns of cooperation or dependency with other groups.

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[1] Procedure for identifying stakeholders - Massachusetts Institute of Technology
[2] Objectives-Oriented Project Planning
[3] North American Aerospace Defense Command

- It may be advantageous to define three categories: active, beneficiaries, and those affected.

Finally:

4 - Set priorities: decide whose interests and views are to be given priority in addressing problems?

- Which are the groups most in need of external assistance?
- Which interest groups should be supported in order to ensure positive development? In which way should they be considered?
- What conflicts would occur by supporting given interest groups and what measures can be taken to avoid such conflicts?
- Essentially, how should the project react towards the group?

APPENDIX 3: STAKEHOLDERS WEIGHTING AND DESCRIPTION

The table below represents the average data values obtained by interviewing and questioning of participating stakeholders (Hospitals A and B). As stated above a complete individual weighting and description of the survey can be found in Appendix 4. As no historical data existed based on the gratification gaps, current data were obtained by questioning the selected participants and the average value was obtained by compiling the percentage response provided by the participants. A gratification list attributes was compiled by the participants and the grade of importance was selected by each participant based on a scale of high (3), medium (2) and low (1). The gap is an indication of how much the current level of performance is from the objective level. In this research, the gap is expressed in terms of target percentage to be achieved. For example, if there were one metric for the attribute that had a current performance level of 80 out of a target of 100, and then the percent gap would be 20.

Public Hospital A

Employees 1		
Gratification Attribute	**Importance**	**Gap**
Suitable Salary	3	50
Secure & Pleasant working conditions	3	30
Up-to-date technology to make work easier	2	40
Development of Career	2	50

Employees 2		
Gratification Attribute	**Importance**	**Gap**
Suitable Salary	3	60
Secure & Pleasant working conditions	2	30
Up-to-date technology to make work easier	2	50
Development of Career	3	40

Employees 3		
Gratification Attribute	**Importance**	**Gap**
Suitable Salary	3	50
Secure & Pleasant working conditions	2	60
Up-to-date technology to make work easier	2	45
Development of Career	2	30

Patients & Local Communities 1		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	60
Affordable care	3	50
Spend less time in hospitals	2	40
Restoration of health	3	60

Patients & Local Communities 2		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	70
Affordable care	3	50
Spend less time in hospitals	1	40
Restoration of health	3	60

Patients & Local Communities 3		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	60
Affordable care	3	50
Spend less time in hospitals	2	50
Restoration of health	3	70

Stockholders 1		
Gratification Attribute	**Importance**	**Gap**
Return on investment	3	40
Solidity	2	40
Awareness	1	60
Liquidity of Investment	2	20

Suppliers 1		
Gratification Attribute	**Importance**	**Gap**
Suitable price for health care technologies	3	60
Good partnership with stockholders	2	60
Punctual payment	2	90

Patients & Local Communities 4		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	2	50
Affordable care	3	40
Spend less time in hospitals	2	50
Restoration of health	3	60

Patients & Local Communities 5		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	60
Affordable care	2	40
Spend less time in hospitals	1	50
Restoration of health	3	40

Academic Partners 1		
Gratification Attribute	**Importance**	**Gap**
Excellent contractual relationship	2	60
Adequate provision of clinical rotations for medical students	2	60
Healthy partnership for research activities	3	70

Table A-31: Gratification Attribute data for Hospital A

Public Hospital B

Employees 1		
Gratification Attribute	**Importance**	**Gap**
Suitable salary	3	60
Secure & pleasant working conditions	2	50
Up-to-date technology to make work easier	2	55
Development of Career	1	40

Patients 1		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	60
Affordable care	1	50
Spend less time in hospitals	1	40
Restoration of health	3	60

Employees 2		
Gratification Attribute	**Importance**	**Gap**
Suitable salary	3	60
Secure & pleasant working conditions	2	40
Up-to-date technology to make work easier	1	50
Development of Career	3	40

Employees 3		
Gratification Attribute	**Importance**	**Gap**
Suitable salary	3	60
Secure & pleasant working conditions	2	40
Up-to-date technology to make work easier	1	40
Development of Career	2	40

Employees 4		
Gratification Attribute	**Importance**	**Gap**
Suitable salary	3	50
Secure & pleasant working conditions	2	60
Up-to-date technology to make work easier	2	40
Development of Career	2	50

Employees 5		
Gratification Attribute	**Importance**	**Gap**
Suitable salary	3	60
Secure & pleasant working conditions	2	50
Up-to-date technology to make work easier	1	30
Development of Career	3	50

Patients 2		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	50
Affordable care	3	40
Spend less time in hospitals	3	60
Restoration of health	3	55

Patients 3		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	50
Affordable care	2	40
Spend less time in hospitals	1	55
Restoration of health	3	60

Patients 4		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	60
Affordable care	3	50
Spend less time in hospitals	1	40
Restoration of health	3	50

Patients 5		
Gratification Attribute	**Importance**	**Gap**
Good quality of medical services	3	50
Affordable care	3	45
Spend less time in hospitals	2	40

Employees 6		
Gratification Attribute	**Importance**	**Gap**
Suitable salary	3	60
Secure & pleasant working conditions	2	30
Up-to-date technology to make work easier	2	20
Development of Career	3	40
Restoration of health	3	60

Ministry of Health 1		
Gratification Attribute	**Importance**	**Gap**
Adequate budget allocation	3	60
Healthy lifestyle for citizens	2	40
Non-existence of child abuse and violence	2	40

University Partners 1		
Gratification Attribute	**Importance**	**Gap**
Excellent contractual relationship	2	60
Adequate provision of clinical rotations for medical students	2	70
Healthy partnership for research activities	3	70

Volunteers & Donors 1		
Gratification Attribute	**Importance**	**Gap**
Feel appreciated	3	50
Personal Development	3	40
Clear line of communication	2	60

Volunteers & Donors 2		
Gratification Attribute	**Importance**	**Gap**
Feel appreciated	2	55
Personal Development	3	40
Clear line of communication	1	55

Suppliers 1		
Gratification Attribute	**Importance**	**Gap**
Suitable price for healthcare technologies	3	60
Patient compliance data	2	40
Reporting unfavorable events	2	40

Table A-33: Gratification Attribute data for Hospital B

APPENDIX 4: LIST OF CVD STATE-OF-THE-ART EQUIPMENT AND PRICES

Equipment		Price (South African Rands)
1®	ECG	25,000
	X-Ray	Varies
	Blood Pressure Monitor	1,000 (Varies)
	Auxiliary Equipments	-
2®	ECG (High Class)	600,000 (Varies)
	X-Ray	Varies
	Blood Pressure Monitor	1,000 (Varies)
	Auxiliary Equipments	-
3®	ECHO	1.5 Million
	Coronary Care Unit (Beds)	-
	Auxiliary Equipments	-
	Computed Tomography Scan	16 Million
	ECG	600,000 (Varies)
	IT Networks	5 Million

Table A-34: Approximated price list for CVD treating equipments

The separation seen above between 1®, 2® and 3® represent the different stages of treatment for patients whereby:

1®- primary care in the lowest level

2® - represent a higher level of 1®

3®- is the advanced level that handles every level of the heart disease and as such all equipments utilized in the 2 levels below are also required in the level 3®. The prices seen above are estimated and approximated and may differ between countries and or manufacturers. Furthermore, auxiliary equipments are as much as important as the equipments above but in this research we focus on the main equipments needed to conquer this epidemic.

Examples of Auxiliary Equipment

- Stethoscopes
- Tables
- Beds
- Syringes
- Medications
- Etc

APPENDIX 5: POPULATION DATA AND COORDINATES

		Pop Points		
West Coast District DC1	**391766**	**45**		
		12		
		7		
		12		
		14		
City of Cape Town	**3740026**	**5**		**748005,2**
Overberg DC3	**258176**	**11**		
		8	188468	
		3	69708	
Cape Winelands DC2	787490	26		
		10		
		4		
		5		
		3		
		4		
Central Karoo DC5	**71011**	**22**		**3227,773**
Eden DC4	**574265**	**26**		
		18	396243	
		6	132081	
		2	45941	

	Coordinates					
No (Xj)	**Horizontal**	**Vertical**		**Pop(i)**	**Case 7 New Pop (i)**	**Case 6 New Pop (i)**
1	1	15	**West Coast District DC1**	8814,74	8814,74	8814,74
2	1	16	**West Coast District DC1**	8814,74		8814,74
3	1	17	**West Coast District DC1**	8814,74	8814,74	8814,74
4	1	28	**West Coast District DC1**	8674,8	8674,8	8674,8
5	1	29	**West Coast District DC1**	8674,8	8674,8	8674,8
6	1	30	**West Coast District DC1**	8674,8	8674,8	8674,8
7	1	31	**West Coast District DC1**	8674,8	8674,8	8674,8
8	1	32	**West Coast District DC1**			
9	1	33	**West Coast District DC1**			
10	2	12	**West Coast District DC1**	8814,74	8814,74	8814,74
11	2	13	**West Coast District DC1**	8814,74	8814,74	8814,74

12	2	14	**West Coast District DC1**	8814,74	8814,74	10514,32
13	2	15	**West Coast District DC1**	8814,74	8814,74	8814,74
14	2	16	**West Coast District DC1**			
15	2	17	**West Coast District DC1**			
16	2	18	**West Coast District DC1**			
17	2	19	**West Coast District DC1**			
18	2	20	**West Coast District DC1**			
19	2	21	**West Coast District DC1**	8814,74	8814,74	8814,74
20	2	22	**West Coast District DC1**	8814,74	12042,54	8814,74
21	2	23	**West Coast District DC1**	8814,74	8814,74	8814,74
22	2	24	**West Coast District DC1**	8814,74	8814,74	8814,74
23	2	25	**West Coast District DC1**			
24	2	26	**West Coast District DC1**	8674,8	30687,8	8674,8
25	2	27	**West Coast District DC1**	8674,8	8674,8	9674,2
26	2	28	**West Coast District DC1**	8674,8	8674,8	8674,8
27	2	29	**West Coast District DC1**	8674,8	8674,8	8674,8
28	2	30	**West Coast District DC1**	8674,8	8674,8	8674,8
29	2	31	**West Coast District DC1**	8674,8	8674,8	8674,8
30	2	32	**West Coast District DC1**			
31	2	33	**West Coast District DC1**			
32	2	34	**West Coast District DC1**			
33	2	35	**West Coast District DC1**			
34	2	36	**West Coast District DC1**			
35	3	7	**City of Cape Town**	748005,2	748005,2	748005,2
36	3	8	**City of Cape Town**	748005,2	748005,2	748005,2
37	3	9	**City of Cape Town**	748005,2	748005,2	845004,75
38	3	10	**City of Cape Town**	748005,2	748005,2	748005,2
39	3	11	**West Coast District DC1**	8814,74	8814,74	8814,74
40	3	12	**West Coast District DC1**	8814,74	8814,74	8814,74
41	3	13	**West Coast District DC1**	8814,74	8814,74	8814,74
42	3	14	**West Coast District DC1**	8814,74	8814,74	8814,74
43	3	15	**West Coast District DC1**	8814,74	8814,74	8814,74
44	3	16	**West Coast District DC1**	8954,7	8954,7	8954,7
45	3	17	**West Coast District DC1**	8954,7	8954,7	8954,7
46	3	18	**West Coast District DC1**	8954,7		9057
47	3	19	**West Coast District DC1**	8954,7	8954,7	8954,7
48	3	20	**West Coast District DC1**	8814,74	8814,74	8814,74
49	3	21	**West Coast District DC1**	8814,74	32372,74	8814,74
50	3	22	**West Coast District DC1**	8814,74	8814,74	8814,74
51	3	23	**West Coast District DC1**	8814,74	8814,74	8814,74
52	3	24	**West Coast District DC1**	8814,74	8814,74	8814,74

53	3	25	**West Coast District DC1**			
54	3	26	**West Coast District DC1**	8674,8	8674,8	8674,8
55	3	27	**West Coast District DC1**	8674,8	8674,8	8674,8
56	3	28	**West Coast District DC1**	8674,8	17489,54	8674,8
57	3	29	**West Coast District DC1**	8674,8	32232,8	8674,8
58	3	30	**West Coast District DC1**			3232,65
59	3	31	**West Coast District DC1**			
60	3	32	**West Coast District DC1**			
61	3	33	**West Coast District DC1**			
62	3	34	**West Coast District DC1**			
63	3	35	**West Coast District DC1**			
64	4	4	**Overberg DC3**	34853	34853	34853
65	4	5	**Overberg DC3**	34853	34853	34853
66	4	6	**City of Cape Town**	748005,2	748005,2	748005,2
67	4	7	**Cape Winelands DC2**	29530,9	53088,9	36000,4
68	4	8	**Cape Winelands DC2**	29530,9	29530,9	29530,9
69	4	9	**Cape Winelands DC2**	29530,9	29530,9	29530,9
70	4	10	**Cape Winelands DC2**	29530,9	29530,9	29530,9
71	4	11	**Cape Winelands DC2**			
72	4	12	**Cape Winelands DC2**			
73	4	13	**Cape Winelands DC2**			
74	4	14	**Cape Winelands DC2**		8814,74	
75	4	15	**West Coast District DC1**	8954,7	8954,7	8954,7
76	4	16	**West Coast District DC1**	8954,7	8954,7	8954,7
77	4	17	**West Coast District DC1**	8954,7	8954,7	8954,7
78	4	18	**West Coast District DC1**	8814,74	8814,74	8814,74
79	4	19	**West Coast District DC1**	8814,74	8814,74	9521
80	4	20	**West Coast District DC1**	8814,74	8814,74	8814,74
81	4	21	**West Coast District DC1**			
82	4	22	**West Coast District DC1**			
83	4	23	**West Coast District DC1**			
84	4	24	**West Coast District DC1**			
85	4	25	**West Coast District DC1**			
86	4	26	**West Coast District DC1**			
87	4	27	**West Coast District DC1**			
88	5	4	**Overberg DC3**	34853	34853	37842
89	5	5	**Overberg DC3**		29530,9	
90	5	6	**Overberg DC3**			
91	5	7	**Overberg DC3**			
92	5	8	**Cape Winelands DC2**	29924,62	29924,62	29924,62
93	5	9	**Cape Winelands DC2**	29924,62	29924,62	29924,62

94	5	10	**Cape Winelands DC2**			601
95	5	11	**Cape Winelands DC2**	29924,62	29924,62	29924,62
96	5	12	**Cape Winelands DC2**	29924,62	29924,62	29924,62
97	5	13	**Cape Winelands DC2**	29924,62	29924,62	29924,62
98	5	14	**Cape Winelands DC2**			
99	5	15	**Cape Winelands DC2**	29530,9	29530,9	29530,9
100	5	16	**Cape Winelands DC2**	29530,9	29530,9	29530,9
101	5	17	**Cape Winelands DC2**	29530,9		29530,9
102	5	18	**Cape Winelands DC2**	29530,9	29530,9	29530,9
103	5	19	**West Coast District DC1**			
104	5	20	**West Coast District DC1**			3521
105	5	21	**West Coast District DC1**			
106	5	22	**West Coast District DC1**			
107	5	23	**West Coast District DC1**			
108	6	1	**Overberg DC3**			
109	6	2	**Overberg DC3**			
110	6	3	**Overberg DC3**	23558	23558	23558
111	6	4	**Overberg DC3**	23558	23558	23558
112	6	5	**Overberg DC3**	23558		23558
113	6	6	**Overberg DC3**	23558	23558	23558
114	6	7	**Overberg DC3**			
115	6	8	**Cape Winelands DC2**	29924,62	29924,62	29924,62
116	6	9	**Cape Winelands DC2**	29924,62	29924,62	29924,62
117	6	10	**Cape Winelands DC2**	29924,62	29924,62	29924,62
118	6	11	**Cape Winelands DC2**			
119	6	12	**Cape Winelands DC2**			
120	6	13	**Cape Winelands DC2**			
121	6	14	**Cape Winelands DC2**			
122	6	15	**Cape Winelands DC2**			
123	6	16	**Cape Winelands DC2**			
124	6	17	**Cape Winelands DC2**			2741
125	6	18	**Cape Winelands DC2**			
126	6	19	**Cape Winelands DC2**			
127	6	20	**Cape Winelands DC2**			
128	7	1	**Overberg DC3**			
129	7	2	**Overberg DC3**	23558	23558	23558
130	7	3	**Overberg DC3**	23558	23558	23558
131	7	4	**Overberg DC3**	23558	23558	23558
132	7	5	**Overberg DC3**	23558	23558	23558
133	7	6	**Overberg DC3**			
134	7	7	**Cape Winelands DC2**			

135	7	8	**Cape Winelands DC2**	29924,62	29924,62	29924,62
136	7	9	**Cape Winelands DC2**	29924,62	29924,62	36925
137	7	10	**Cape Winelands DC2**	29924,62	29924,62	29924,62
138	7	11	**Cape Winelands DC2**			
139	7	12	**Cape Winelands DC2**	31499,6	31499,6	31499,6
140	7	13	**Cape Winelands DC2**	31499,6	31499,6	31499,6
141	7	14	**Cape Winelands DC2**	31499,6	31499,6	31499,6
142	7	15	**Cape Winelands DC2**			
143	7	16	**Cape Winelands DC2**			
144	7	17	**Cape Winelands DC2**			
145	7	18	**Cape Winelands DC2**			
146	7	19	**Cape Winelands DC2**			
147	7	20	**Cape Winelands DC2**			221,36
148	7	21	**Cape Winelands DC2**			
149	7	22	**Cape Winelands DC2**			
150	8	3	**Overberg DC3**			
151	8	4	**Overberg DC3**			
152	8	5	**Overberg DC3**			
153	8	6	**Overberg DC3**			
154	8	7	**Overberg DC3**			
155	8	8	**Cape Winelands DC2**	29924,62	29924,62	29924,62
156	8	9	**Cape Winelands DC2**	29924,62	29924,62	29924,62
157	8	10	**Cape Winelands DC2**			
158	8	11	**Cape Winelands DC2**			
159	8	12	**Cape Winelands DC2**			
160	8	13	**Central Karoo DC5**			
161	8	14	**Central Karoo DC5**			
162	8	15	**Central Karoo DC5**			
163	8	16	**Central Karoo DC5**			
164	9	4	**Overberg DC3**			
165	9	5	**Eden DC4**			
166	9	6	**Eden DC4**			
167	9	7	**Overberg DC3**			
168	9	8	**Overberg DC3**			
169	9	9	**Overberg DC3**			
170	9	10	**Overberg DC3**			
171	9	11	**Eden DC4**			
172	9	12	**Central Karoo DC5**	3227,773	3227,772727	3227,772727
173	9	13	**Central Karoo DC5**	3227,773	3227,772727	3227,772727
174	9	14	**Central Karoo DC5**			
175	9	15	**Central Karoo DC5**			

176	9	16	Central Karoo DC5			
177	10	5	**Eden DC4**			
178	10	6	**Eden DC4**	22970,5	22970,5	22970,5
179	10	7	**Eden DC4**	22970,5	22970,5	22970,5
180	10	8	**Eden DC4**			
181	10	9	**Eden DC4**			
182	10	10	**Eden DC4**			
183	10	11	**Eden DC4**			
184	10	12	**Eden DC4**			
185	10	13	Central Karoo DC5	3227,773	3227,772727	3227,772727
186	10	14	Central Karoo DC5	3227,773	3227,772727	3227,772727
187	10	15	Central Karoo DC5	3227,773	3227,772727	3624,12
188	10	16	Central Karoo DC5			
189	10	17	Central Karoo DC5			
190	10	18	Central Karoo DC5			
191	10	19	Central Karoo DC5			
192	11	5	**Eden DC4**			
193	11	6	**Eden DC4**			
194	11	7	**Eden DC4**	22013	22013	22013
195	11	8	**Eden DC4**	22013	22013	22013
196	11	9	**Eden DC4**	22013		22013
197	11	10	**Eden DC4**			
198	11	11	**Eden DC4**			
199	11	12	**Eden DC4**			
200	11	13	Central Karoo DC5	3227,773	3227,773	3227,773
201	11	14	Central Karoo DC5	3227,773	3227,773	5841,2
202	11	15	Central Karoo DC5	3227,773	3227,773	3227,773
203	11	16	Central Karoo DC5			
204	11	17	Central Karoo DC5			
205	11	18	Central Karoo DC5			
206	11	19	Central Karoo DC5			
207	11	20	Central Karoo DC5			
208	11	21	Central Karoo DC5			
209	12	5	**Eden DC4**			
210	12	6	**Eden DC4**			
211	12	7	**Eden DC4**	22013	22013	22013
212	12	8	**Eden DC4**	22013	22013	22013
213	12	9	**Eden DC4**	22013	22013	22013
214	12	10	**Eden DC4**			
215	12	11	**Eden DC4**			
216	12	12	**Eden DC4**			

217	12	13	Central Karoo DC5	3227,773	3227,773	3227,773
218	12	14	Central Karoo DC5	3227,773	3227,773	3227,773
219	12	15	Central Karoo DC5	3227,773	3227,773	3227,773
220	12	16	Central Karoo DC5	3227,773		3227,773
221	12	17	Central Karoo DC5			
222	12	18	Central Karoo DC5			
223	12	19	Central Karoo DC5			
224	12	20	Central Karoo DC5			
225	12	21	Central Karoo DC5			
226	12	22	Central Karoo DC5			
227	13	6	**Eden DC4**	22013,5	22013,5	22013,5
228	13	7	**Eden DC4**	22013,5	22013,5	22013,5
229	13	8	**Eden DC4**	22013,5	22013,5	22013,5
230	13	9	**Eden DC4**	22013,5	22013,5	22013,5
231	13	10	**Eden DC4**	22013,5	22013,5	22013,5
232	13	11	**Eden DC4**			
233	13	12	**Eden DC4**			
234	13	13	**Eden DC4**			
235	13	14	Central Karoo DC5	3227,773	3227,773	3227,773
236	13	15	Central Karoo DC5	3227,773	3227,773	3227,773
237	13	16	Central Karoo DC5	3227,773	3227,773	3227,773
238	13	17	Central Karoo DC5			
239	13	18	Central Karoo DC5			
240	13	19	Central Karoo DC5			
241	13	20	Central Karoo DC5			
242	13	21	Central Karoo DC5			
243	13	22	Central Karoo DC5			
244	13	23	Central Karoo DC5			
245	13	24	Central Karoo DC5			
246	13	25	Central Karoo DC5			
247	13	26	Central Karoo DC5			
248	14	8	**Eden DC4**	22013,5	22013,5	22013,5
249	14	9	**Eden DC4**	22013,5	22013,5	22013,5
250	14	10	**Eden DC4**	22013,5	22013,5	22013,5
251	14	11	**Eden DC4**			
252	14	12	**Eden DC4**			37
253	14	13	Central Karoo DC5	3227,773	3227,773	3227,773
254	14	14	Central Karoo DC5	3227,773	3227,773	3227,773
255	14	15	Central Karoo DC5	3227,773	3227,773	3227,773
256	14	16	Central Karoo DC5	3227,773	3227,773	3227,773
257	14	17	Central Karoo DC5			

258	14	18	Central Karoo DC5			
259	14	19	Central Karoo DC5			
260	14	20	Central Karoo DC5			
261	14	21	Central Karoo DC5			
262	14	22	Central Karoo DC5			
263	14	23	Central Karoo DC5			
264	14	24	Central Karoo DC5			
265	14	25	Central Karoo DC5			
266	14	26	Central Karoo DC5			
267	14	27	Central Karoo DC5			
268	15	8	**Eden DC4**	22013,5	22013,5	22013,5
269	15	9	**Eden DC4**	22013,5	22013,5	22013,5
270	15	10	**Eden DC4**	22013,5	22013,5	22013,5
271	15	11	**Eden DC4**	22013,5	22013,5	22013,5
272	15	12	**Eden DC4**			
273	15	15	Central Karoo DC5	3227,773	3227,773	23005,2
274	15	16	Central Karoo DC5	3227,773	3227,773	3227,773
275	15	17	Central Karoo DC5			
276	15	18	Central Karoo DC5			
277	15	19	Central Karoo DC5			
278	15	20	Central Karoo DC5			
279	15	21	Central Karoo DC5			
280	15	22	Central Karoo DC5			
281	15	23	Central Karoo DC5			
282	15	24	Central Karoo DC5			
283	15	25	Central Karoo DC5			
284	15	26	Central Karoo DC5			
285	16	8	**Eden DC4**	22013,5	22013,5	36012,5
286	16	9	**Eden DC4**	22013,5	22013,5	22013,5
287	16	10	**Eden DC4**	22013,5	22013,5	22013,5
288	16	11	**Eden DC4**	22013,5	22013,5	22013,5
289	16	12	**Eden DC4**			
290	16	19	Central Karoo DC5			
291	16	20	Central Karoo DC5			
292	16	21	Central Karoo DC5			
293	16	22	Central Karoo DC5			
294	16	23	Central Karoo DC5			
295	16	24	Central Karoo DC5			
296	16	25	Central Karoo DC5			
297	17	8	**Eden DC4**	22013,5	22013,5	22013,5
298	17	9	**Eden DC4**	22013,5	22013,5	22013,5

299	17	11	**Eden DC4**		
300	17	12	**Eden DC4**		
301	17	23	**Central Karoo DC5**		6000
302	17	24	**Central Karoo DC5**		
303	17	25	**Central Karoo DC5**		
304	17	26	**Central Karoo DC5**		
305	17	27	**Central Karoo DC5**		
306	18	23	**Central Karoo DC5**	8814,74	
307	18	24	**Central Karoo DC5**		
308	18	25	**Central Karoo DC5**		
309	18	26	**Central Karoo DC5**	8954,7	