A Decision Support System for Telemedicine Needs Assessments in South Africa

by

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Synopsis

The various applications of Information and Communication Technologies (ICTs) in healthcare are increasingly effective to improve the cost-effectiveness and quality of healthcare service delivery. Telemedicine is such an application, using ICTs to provide health services over a distance. Since 1997, the South African Department of Health has invested large amounts of capital to implement telemedicine systems in South Africa. Unfortunately, telemedicine programs have had little success since, leading to many workstations standing dormant.

Telemedicine implementation decision making that is based on insufficient evidence is identified as one of the underlying problems that cause telemedicine programs to fail. It is proposed that implementation decisions should be based on quantifiable evidence regarding the potential benefits of telemedicine. A decision support system is developed that can be used to quantify potential benefits and plan telemedicine implementation programs accordingly.

The decision support system is modelled and demonstrated using data from the Eastern Cape public health sector. The first phase of the system guides decision makers to identify potential telemedicine benefits as well as data sources that can be used to measure these benefits. The system is scoped to focus on the application of telemedicine to support patient referrals between hospitals. Data sources are considered accordingly, with electronic health record (EHR) data proving to be a feasible primary source for needs assessments, however limiting the benefits that can be quantified.

The analysis of the needs assessment is included in the second phase of the decision support system. Data are extracted, transformed and loaded into a data warehouse from where it can be analysed. The system includes three analysis steps to: map referral patterns, analyse potential benefits of telemedicine programs and determine cost-effective telemedicine solutions by allocating equipment at different hospitals. Analysis techniques used in the system include Pareto analysis, economic analysis, linear programming and the use of a genetic algorithm.

It is proposed that the potential benefit results and equipment allocation algorithm be used to plan telemedicine programs for continuous evaluation. The final phase of the system therefore guides decision makers to use the results for implementation planning as well as evaluability assessments, for future management and evaluation of telemedicine programs.

The decision support system is validated using patient referral data from the Western Cape public health sector. The case study proved that the system is applicable to the real-world and could be a valuable tool for decision makers to base telemedicine implementation planning on quantifiable evidence.

The limitation on size and quality of both the Eastern Cape and Western Cape data sets, caused that the full potential of the system could not be demonstrated and validated. It is recommended that the quality standards of EHR referral reports be improved, to ensure more accurate benefit results. Future work is recommended to include qualitative needs assessments in the scope of the decision support system, hereby increasing the amount of benefits to be assessed. Although it is expected that the developed system is capable to support even better resolution decisions with more detailed data sets, the system developed in this study proved already adequate for improved implementation decision making. This could lead to higher success rates of telemedicine programs and ultimately better quality healthcare for all.

Opsomming

Die verskillende toepassings van Informasie en Kommunikasie Tegnologie (IKT) in gesondheidsorg, speel ŉ rol in toenemende doeltreffendheid om die koste-effektiwiteit en kwaliteit van gesondheidsorg dienslewering te verbeter. Tele-geneeskunde is een van hierdie toepassings, wat IKT gebruik om gesondheidsdienste oor ŉ afstand te kan voorsien. Die Suid-Afrikaanse Departement van Gesondheid belê sedert 1997, groot bedrae kapitaal in die implementering van tele-geneeskunde stelsels, in Suid-Afrika. Ongelukkig het tele-geneeskunde programme min sukses behaal sedertdien, wat veroorsaak dat vele werkstasies dormant is.

Die basering van implementeringsbesluite op onvoldoende getuienis, is geïdentifiseer as een van die onderliggende probleme wat veroorsaak dat tele-geneeskunde programme misluk. Daar word voorgestel dat implementeringsbesluite gebaseer moet word op kwantifiseerbare getuienis ten opsigte van die potensiële voordele van telemedisyne. ŉ Besluitnemingsondersteuning stelsel is ontwikkel wat gebruik kan word om die potensiële voordele te kwantifiseer en dienooreenkomstig implementering van tele-geneeskunde programme te beplan.

Die stelsel is gemodelleer en gedemonstreer aan die hand van data uit die Oos-Kaap publieke gesondheidsektor. Die eerste fase van die stelsel begelei besluitnemers om potensiële voordele van tele-geneeskunde, sowel as data-bronne wat gebruik kan word om hierdie voordele te meet, te identifiseer. Die stelsel is beperk tot ŉ fokus op die ondersteuning wat tele-geneeskunde aan hospitaal pasiënt verwysingstelsels, kan bied. Data bronne is dienooreenkomstig oorweeg: elektroniese mediese rekords (EMR) word erken as ŉ gunstige primêre databron, maar veroorsaak egter beperkings op die aantal voordele wat gekwantifiseer kan word.

Die behoeftebepaling word uitgevoer in die tweede fase van die besluitnemingsondersteuning stelsel. Data is onttrek, getransformeer is en gelaai in 'n data stoor, vanwaar dit ontleed kan word. Die stelsel sluit drie analise-stappe in: verwysingspatroon analise, berekening van potensiële voordele vir tele-geneeskunde programme en die bepaling van koste-effektiewe oplossings deur toekenning van toerusting by verskillende hospitale. Die analise tegnieke wat in die stelsel gebruik word, sluit die volgende in: Pareto analise, ekonomiese analise, lineêre programmering en 'n genetiese algoritme.

Die gebruik van potensiële voordeel resultate en die toerusting toekenning algoritme word voorgestel vir die beplanning vir deurlopende evaluering in tele-geneeskunde programme. Die finale fase van die stelsel is gestruktureer, om besluitnemers te begelei in die gebruik van analise resultate, vir implementering beplanning sowel as evalueerbaarheid studies, wat sodoende deurlopende evaluering en bestuur van tele-geneeskunde programme sal verbeter.Die besluitnemingsondersteuning stelsel is gevalideer deur pasiënt verwysings data van die Wes-Kaap publieke gesondheidsektor, te gebruik. Die gevallestudie het bewys dat die stelsel toepaslik is in die werklike wêreld en kan as ŉ waardevolle hulpmiddel vir besluitnemers dien om tele-geneeskunde implementering beplanning op kwantifiseerbare bewyse te baseer.

Die beperkings op die grootte en gehalte van beide die Oos-Kaap en Wes-Kaap datastelle het veroorsaak dat die stelsel nie tot sy volle reg gedemonstreer en gevalideer kon word nie. Verbeterings in kwaliteit standaarde van EMR verwysing data word aanbeveel om meer akkurate resultate te bekom. Verdere studies wat die byvoeg van kwalitatiewe meetings in die stelsel ondersoek, sal die omvang van potensiële voordele verbeter en dus die algehele waarde van die stelsel verbeter. Alhoewel die ontwikkelde stelsel in staat is om beter resolusie besluite te kan ondersteun met meer gedetailleerde data, is dit bewys dat die huidige stelsel reeds voldoende is om besluitneming te verbeter. Beter besluitneming gevolglik lei tot hoër sukseskoerse van tele-geneeskunde programme en uiteindelik verbeterde gehalte gesondheidsorg vir almal.

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Glossary

Term	*Abbreviation*	*Description*
Information and Communications Technologies	ICT	A collective term for all technologies regarding information and communications management
Telemedicine		Long-distance healthcare service delivery using ICT
Decision Support System	DSS	A conceptual framework that could include modelling problems and quantitative models to support managerial decision making
Clinical Decision Support System	CDSS	The clinical application of a DSS. Clinical decision are supported by the system
Decision Support Telemedicine System	DSTS	A CDSS using telemedicine systems
Health Decision Support System	HDSS	The use of a DSS to support managerial health decisions
Data Warehouse	DW	A repository of data where data are organised and stored in a standardised format
Extraction, Transformation, and Load	ETL	A data warehouse process to collect data, standardise it and putting it into the data warehouse
District Health Information System	DHIS	An open-source health management information systems and data warehouse. The system aggregates routine data relating to health service evaluations
Electronic Health Records	EHR	A records stored in digital format that contain patient data such as medical history, demographic data, billing information *etc*.
International Classification of Disease	ICD	A standard medical classification, managed by the World Health Organisation that provides codes for disease classification.
Linear Programming	LP	A mathematical model for resource allocation problems optimal solution
Genetic Algorithm	GA	A program that is based on evolution principles, to find an optimal solution for a problem

Chapter 1

Introduction

1.1. Background

A primary goal for public health systems is to provide equal, quality health services to the entire population. Most developing countries consider this to be a challenge. At the end of the Apartheid regime, in 1994, the South African Department of Health undertook to make quality healthcare services available to all South African citizens. This approach to healthcare delivery is in accordance with the Alma Atta Declaration, which states that quality healthcare is a basic human right (Kautzky & Tollman, 2008). However, providing quality healthcare for the entire population requires financial and medical resources which are extremely scarce in the South African public health sector.

This acute shortage of financial resources, leads to a dearth of medical expertise. Referral systems' aim is to utilise scarce resources more effectively by ranking hospital services according to different levels of speciality and allocating resources accordingly. Patients are referred to the different levels, which allow for access to higher levels of care when needed. However, these referrals are expensive and contribute to the over utilisation of high-level care hospitals, which inevitably causes poor service delivery.

Telemedicine could be a possible solution to the some problems facing the South African public sector. In broad terms, telemedicine can be defined as the use of information and communication technologies to provide long-distance (tele) healthcare services (*medicine*). Since telemedicine can transfer patient information electronically, its application could perhaps reduce the need to transfer patients between hospitals. In 1997, the South African Department of Health commissioned telemedicine programs to be implemented on a national level. One of the primary reasons for this initiative was the numerous benefits that telemedicine could provide in bringing specialised healthcare to rural communities. It has been 14 years since the decision was made, but unfortunately telemedicine implementation projects have produced low success rates.

Telemedicine workstations have been implemented in various hospitals in South Africa. Most of these systems were implemented with limited training and support, leaving doctors and other hospital staff frustrated with the technology and ultimately resistant to use the equipment. Since the introduction of many of these telemedicine workstations, little effort has been made to assess the utilisation of the equipment. Large amounts of capital are standing dormant as evidenced by a moratorium on telemedicine implementation in 2009. The South African Minister of Health reported in 2010 that, of the 86 telemedicine sites in South Africa, only 32 were functional. The current poor performance of telemedicine systems indicates a desperate need for evidence which shows that telemedicine can be beneficial (Department of Health, 2010).

A telemedicine project should be continuously evaluated throughout its lifecycle. Instead many projects are approached on a pilot basis, without the support of needs assessments and evaluation frameworks (Broens *et al.*, 2007; Khoja *et al.*, 2007). Telemedicine systems are often designed from a technological point of view, with insufficient consideration of the clinical needs. Wyatt (1996) refers to this phenomenon as an approach which has, as its primary objective, the promotion of technology; this is known as a 'technology-push' strategy. A 'clinical-pull' strategy is defined as the opposite of technology-push, and is a practice that uses technology to promote a proven clinical need. It is expected that systems that are developed and based on a proven need, have a better chance of being successful and sustainable (Wyatt, 1996).

'Evidence-based management', is a term commonly used in healthcare policy making. It refers to the practice where decision-making is based on facts rather than opinions. Concrete data are used, together with analysis tools and frameworks, to gain evidence which forms a foundation for decisions. According to Hailey *et al*. (2004), there is a lack of evidence that telemedicine is a cost-effective and beneficial alternative to patient referrals.

To follow a clinical-pull approach in telemedicine projects, evidence can be gathered prior to implementation, by conducting a needs assessment. Telemedicine systems that are implemented on the foundation of a thorough needs assessment have a higher possibility of benefiting the health system, than those implemented without considering the needs. Although there is no guarantee of utilisation, if there is a proven need for a system, the capital spent on implementation can be justified. Other issues preventing utilisation can be solved after implementation.

Implementing electronic health record (EHR) systems in South African healthcare facilities is a priority for the Department of Health. The number of hospitals in South Africa that are using EHRs is rapidly growing. These information systems are capable of storing valuable data relating to telemedicine. However, few studies have been done in which medical informatics is used to contribute to telemedicine needs assessments. Because data are crucial in making evidence-based decisions, the clinical-pull approach should draw upon relevant data to determine whether telemedicine would have the potential to be beneficial at or in a given facility or region.

1.2. Problem Statement

Since the South African National Telemedicine Strategy was announced in 1997, the government made significant investments in the public health sector to enable telemedicine services. Unfortunately, the majority of the telemedicine projects failed and many are not reaching their full potential. The usage of telemedicine workstations are not justifying the capital spent. It is proposed the success rate and cost-effectiveness can be improved if informed decisions, based on historical data, can be made prior to implementation.

1.3. Research Purpose

The purpose of this thesis is to develop a system to support decisions regarding the acquisition of telemedicine equipment in the public health sector of South Africa, based on actual needs as identified through historical data.

1.4. Methodology

This study originated from a monitoring and evaluation project done for the Eastern Cape Department of Health in 2010. The research problem was identified after observing the various challenges telemedicine management faced in implementing systems in the Eastern Cape. This study aims to support decision makers with implementation planning, through quantitative needs and evaluability assessments.

A combination of statistical modelling and computer simulation methods are used, to reach the implementation decision support purpose. According to Mouton (2008:163) a statistical study aims at “developing and validating accurate representation (models) of the real world… the model is used to generate expected values that are compared with actual data.” This thesis is approached accordingly: The decision support system was developed (using data from the Eastern Cape public health sector) and validated (using data from the Western Cape public health sector). The system uses actual data to generate the expected potential benefits for telemedicine implementation, using a computer simulation (genetic algorithm), programmed for this purpose.

The modelling of the decision support system is the main purpose of the thesis and is documented as such, using an illustration of the system (Figure 1) as a roadmap. The needs assessment process from Steadham (1980) was combined with decision support system frameworks by Turban *et al*. (2007) and data warehouse design frameworks by Kimball and Ross (2002). Evaluability assessment guidelines by Bashshur, Shannon and Sapci (2005) provided the structure for the evaluability assessment that was included in the decision support system, illustrated in Figure 1.

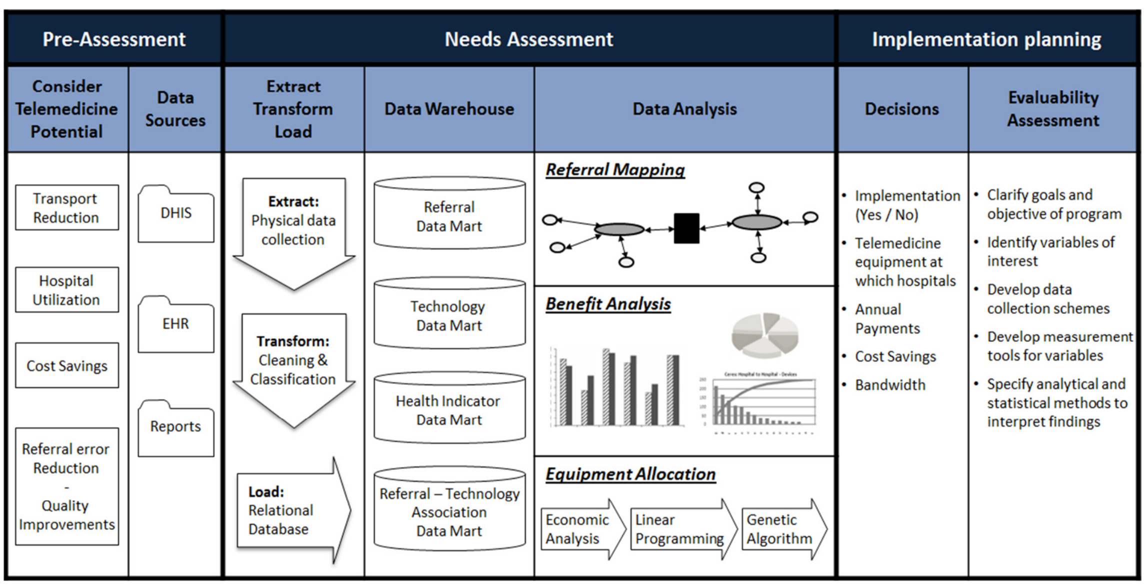

Figure 1: The Decision Support System (DSS) for Telemedicine Implementation

At the beginning of each chapter the roadmap is revisited to illustrate how the work done in that chapter relates to the structure of the decision support system. The document is therefore structured in such a way that it serves both as a report on the research done and a manual, for future use of the decision support system, in South Africa.

The decision support system was developed using data from the Eastern Cape Province public health sector. Through the collection and use of real data to develop the system, it is specially designed to fit the South African healthcare profile. The system was also validated through a case study, based on data from the Western Cape public health sector, to further ensure that the system is applicable for South African public health management decision making. The case study also demonstrates the quantitative analysis of real patient data, as modelled in the decision support system.

During the execution of this study, a chapter for a book was written and subjected to a peer review process. The chapter entitled "Clinical-Pull Approach to Telemedicine Implementation Policies, using health Informatics, in the Developing World", was accepted for publication and will be published in 2012 by IGI Global. The book is entitled "Telemedicine and E-Health Services, Policies and Applications: Advancements and Developments", edited by Joel Rodrigues, Isabel de la Torre Diez and Beatrix Sainz de Abajo. Since the chapter is a publication of the work done in this study, the literature review, framework and other sections of this thesis closely resemble the content of the chapter. The chapter is included in the publication bundle submitted with the thesis.

1.5. Scoping

There are numerous ways of applying telemedicine principles in healthcare. The scope of this study is limited to investigating the support that telemedicine systems could lend to the hospital referral structure in the public health sector of South Africa. Needs assessments, conducted in this study, are also limited to a data-based approach, focussing on patient record data, as an indication of the potential that telemedicine systems could have in a given hospital network.

Implementation policies and decision-making requires assessment from clinical, economic and social perspectives. The suggested decision support system has a primary focus on the quantitative assessment of benefits for telemedicine implementation. The clinical and social perspectives of telemedicine implementation should also be included in thorough needs assessments. However, since this study examines the use of health informatics for the quantitative assessment, clinical and social perspectives are not directly included in this thesis.

1.6. Outline of this Study

The system consists of three sections, as indicated at the top of the roadmap in Figure 1. The first section is the pre-assessment phase. During this phase, the potential benefits of implementing telemedicine are considered, by taking the data sources available into account. In Chapter 2, the theory behind decision support systems and needs assessments is discussed as foundational knowledge from which the system is developed. Chapters 3 and 4 are dedicated to the pre-assessment phase, by means of a literature review, which explores the applications and benefits of telemedicine, as well as data sources.

The second section of the system contains the essence of the needs assessment, including data collection methods, warehousing and analysis. This section is explained in Chapter 5, which will focus on the methodology of the study. The decisions that could be supported will be discussed in Chapter 6 together with evaluability assessment and other considerations for implementation planning. A case study on the Western Cape public health sector is documented in Chapter 7. The thesis is concluded with Chapter 8 which will discuss the relevance and, some of the limitations of the study, as well as recommendations for future research.

Chapter 2

Needs Assessments and Decision Support

Healthcare organisations all over the world, including South Africa, are challenged by constraints on their financial resources. In South Africa, there is an evident need for improvement in service delivery which would enhance the effectiveness and efficiency of treatment processes. These improvements are dependent on informed decision-making. It is commonly expected of healthcare managers to provide quantifiable information about system performance and resource allocation. However, in the absence of electronic systems, this information is often hard to find and even harder to interpret intelligently. Nonetheless, the rapid development of Information and Communication Technologies (ICTs) has provided a platform for automated decision-making. Tan and Steps (1998) recognize the advanced possibilities provided by the automation in decision-making, allowing decision makers to collect, store and analyse data.

Needs assessments have proven to be invaluable for decision-making, especially during implementation planning. The application of needs assessments in telemedicine implementation planning is discussed in this chapter, followed by an overview of decision support systems for the management of telemedicine.

2.1. Health Needs Assessments

Medical practitioners are trained to assess the needs of individual patients before treatment begins. Most practitioners are accustomed to following a systematic approach that they were taught during training and which was later refined through clinical experience (Murray & Graham, 1995). This systematic approach is based on the needs of an individual patient and is unlikely to reflect the needs of an entire population. Furthermore, it is unlikely that different communities would have exactly the same healthcare needs. The importance of assessing the needs of each community separately is often neglected. Too many high-level decisions are based on what some people perceive to be the needs of the population, resulting in many health services being ineffective and a waste of scarce resources (Murray & Graham, 1995; Wright, Williams, & Wilkinson, 1998).

Prior to performing needs assessments, it is important to clarify what is meant by the term 'need', since different disciplines often do not have the same perceptions of what needs are. Wright, Williams and Wilkinson (1998), state that the concepts of needs, demands and supply are commonly confused. Their distinction between need, demand and supply is illustrated in Figure 2 below.

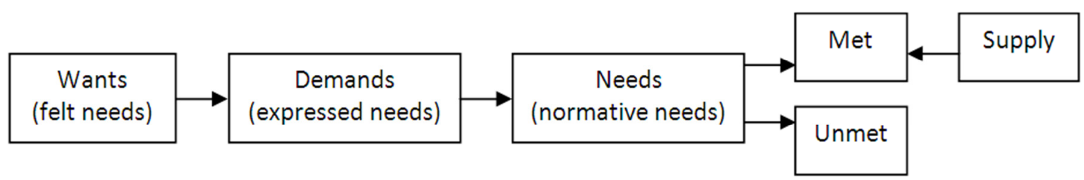

Figure 2: Relation between Needs, Demands and Supply (Adapted from Wright, Williams, & Wilkinson, 1998)

According to Stevens and Gillam (1998) and Wright, Williams and Wilkinson (1998), the definition of 'need' in the healthcare discipline is commonly accepted to be 'the capacity to benefit'. Medical practitioners are likely to experience 'demand' as the needs of the patients, but in reality, these demands can reflect what patients believe they need, rather than what their true needs are. Demand can be influenced by the media, creating an interest among patients for a service. Supply also affects demand, for example, the number of beds that are available in a hospital. 'Supply' is the care that is provided by health professionals. This is largely dependent upon policies and the resources available in terms of money, specialists and technology (Stevens & Gillam, 1998; Wright, Williams, & Wilkinson, 1998).

A needs assessment for telemedicine programs is a form of general health needs assessment. Wright *et al.* (1998) define a health needs assessment as "the systematic approach to ensuring that the health service uses its resources to improve the health of the population in the most efficient way" (p. 1310). Telemedicine, being a health service, therefore conforms to the same principles that are applicable to health needs assessments.

Many telemedicine evaluation frameworks and techniques can be cited, but telemedicine needs assessments are still considered to be almost an art form, requiring creative solutions to determine the need for telemedicine in a given setting (Harrop, 2002). There is no universal and quick-fix recipe, as different areas of assessment require different approaches. Quantitative, qualitative, or a combination of both research methods can be used for assessments (Wright, Williams, & Wilkinson, 1998).

There are a variety of formal and informal approaches to assessing needs. Steadham (1980) argues that selecting the appropriate research method is of critical importance to ensure that the results reflect the true need that is being determined. Figure 3 below illustrates the process of a needs assessment. Steadham (1980) argues that pre-assessment is important in order to consider the situation and select the appropriate methods. Data collection and analysis are often time-consuming tasks, hence the need to be sure that the correct methods are followed.

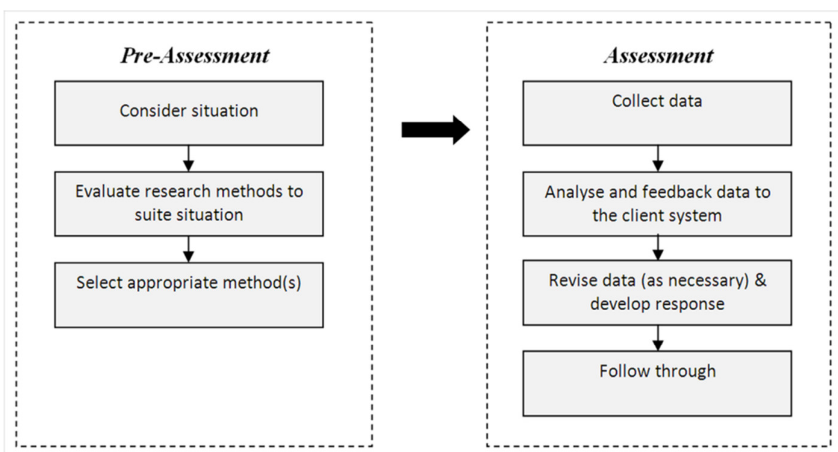

Figure 3: The Needs Assessment Process (Adapted from Steadham, 1980)

2.2. Decision Support Systems (DSS)

In previous years, decision-making was considered an art. Managers had to develop this talent through trial and error. Creativity, intuition and experience, as opposed to scientific evidence, played a critical role in making decisions. In recent years, productivity has become a major determinant in whether an organisation will be competitive. The need for productivity has necessitated that management decisions are accurate, and therefore based on evidence rather than intuition. Furthermore, as the business environment has evolved, decision making has become more complex, thus increasing the difficulty in making competitive decisions (Turban, Aronson, Liang, & Sharda, 2007).

There are a variety of tools and techniques that decision makers can use to assist them in making better decisions. The use of computerised support is common in any competitive organisation's managerial decision-making processes. Decision Support Systems (DSS) is an umbrella term that describes the use of computerised systems that support organisational decision making. Turban *et al.* (2007) p. 755 defines a decision support system as "a conceptual framework for a process of supporting managerial decision making, usually by modelling problems and employing quantitative models for solution analysis".

2.2.1. Health Decision Support Systems

In the healthcare environment, Decision Support Systems (DSS) are commonly understood as being clinical decision support systems. Clinical Decision Support Systems (CDSS) are specifically designed to support clinicians with decision making. These systems would typically use input data, from a specific patient or medical case, to perform an analysis and then give an output stating possible diagnoses and treatment options on which the clinician can base his or her decisions (Berner, 1998).

Nannings and Abu-Hanna (2006) defined Decision Support Telemedicine Systems (DSTS) as a combination of telemedicine and clinical decision support systems. DSTS are a subset of CDSS, in that both these systems are used for clinical purposes. Telemedicine, using ICTs to provide long-distance health services, combined with clinical decision support, results in long-distance clinical decision support. Hence DSTS can be explained as being long-distance CDSS (Nannings & Abu-Hanna, 2006).

CDSS are not the only DSS in the healthcare environment. Tan and Sheps (1998), in the book, "Health Decision Support Systems", describe systems that are used for health management decisions. These Health Decision Support Systems (HDSS) differ from CDSS as not only do they support clinical decisions but also make decisions relating to healthcare management. The purpose of HDSS is to improve the efficiency and effectiveness in which health service administrators or clinicians make decisions. The result is optimisation of personal and organisational performance for these decision makers (Tan & Sheps, 1998).

There are different approaches in developing HDSS. The foci of the systems are dependent on the purpose of the DSS. A system can, for example, have an organisational focus, aiming towards executive thinking when considering health issues. Data-Based HDSS are data intensive and are thus largely dependent on population health data and statistical analyses. Model-Based HDSS make use of existing models to base decisions on. Knowledge-Based HDSS rely on knowledge extraction and decision-making skills while Graphics-Based HDSS use images and other graphics to base decisions on (Tan & Sheps, 1998).

Bediang *et al*. (2010) use the term, 'Medical Decision Support Systems' in a study that presents an overview of CDSS and HDSS in Africa. District Health Information Systems (DHIS), Electronic Medical Records Systems, Telemedicine and mobile health (m-health) are among the systems that were evaluated. The results of this study were that these systems exist, but are new and very limited. The factors that limit their use are: "the relative lack of organization of the systems, inadequate infrastructure, the shortage and disparity of health professionals, a lack of technical skills, language barriers, and the still high proportion of illiterate populations". A recommended solution would be the "training of all stakeholders, clinicians, managers, healthcare system decision makers and, eventually, patients and citizens" (Bediang, Bagayoko, & Geissbuhler, 2010).

Since DSS are relatively new to Africa, it is important to encourage the usage of these systems. Specific challenges in Africa should be met by using existing solutions and adapting them to Africa's needs. By supporting the implementation of these solutions with good evaluation studies, systems can be driven towards sustainable results (Bediang, Bagayoko, & Geissbuhler, 2010).

2.2.2. Data Warehousing

An integral part of data-based decision support systems, is the ability to rapidly analyse large amounts of data, from a variety of sources. *Data warehouse* is the term used for the pool of data, used by the decision support system (Turban, Aronson, Liang, & Sharda, 2007). The data warehouse structures integrate data in order to be readily available for decision makers when needed. Watson (2002) differentiates between the term 'data warehouse', which refers to the repository of data, and 'data warehousing' which includes the entire process. Data warehousing is thus a discipline that includes decision support applications.

Data Marts

The data warehouse usually combines data from different sources and can be a broad collection of databases. Data marts are usually smaller than data warehouses; they focus on particular subsets of the data warehouse. Dependent data marts are formed from the data warehouse and are therefore consistent with the data in the data warehouse. Dependent data mart models are used when a consistent data warehouse is integrated into the entire enterprise. The independent data mart is designed for a unit of the enterprise, which functions independently from the rest of the data warehouse. The independent data mart is therefore a small warehouse isolated from other data marts (Turban, Aronson, Liang, & Sharda, 2007).

After considering the various types of decision support systems, the Data-Based Health Decision Support System, defined by Tan and Sheps (1998), is the best fit of a decision support system that can be used to provide management decision support using health informatics. Therefore the decision support system that is developed in this thesis is technically a data-based health decision support system and not a clinical decision support system or a decision support telemedicine system as might be expected. To keep the terminology simple, the system will not be called a data-based health decision support system, but a decision support system.

The decision makers are identified to be telemedicine managers or policy makers that are involved in the planning of telemedicine programs. Technology developers are not considered as decision makers for implementation although they could also benefit from using the system. The reason for this is because telemedicine developers are likely to be biased in making implementation decisions. Nevertheless, telemedicine developers could use the system to determine the need for developing equipment. This is however a different application of the system, that is not the main focus of this study.

In the next chapter, the applications of telemedicine are explored with a focus on collecting evidence for its feasibility. This is done to construct a knowledge base and scope for the decision support system while investigating the need for such a system.

Chapter 3

Telemedicine as an Aid to Hospital Referrals in South Africa

Primary health care in South Africa has faced many challenges in providing quality care to all South Africans. The Alma Ata declaration that was signed by 134 countries in 1978 served as a global foundation towards providing quality healthcare for all. South Africa unfortunately did not sign the declaration. At the time, South Africa was ruled by the apartheid government which promoted racial fragmentation rather than equality. South Africans were involuntarily divided according to their skin colour. 'Ethnic homelands' were assigned to Africans, where they received healthcare as well as other public services. However these services were poorly managed and delivered inadequate medical services (Kautzky & Tollman, 2008; Benatar, 2004).

The South African government introduced a new national health plan after the African National Congress (ANC) won the election in 1994. This new health plan was based on principles of the Alma Ata declaration, promising equal access to quality healthcare for all South African citizens. The South African public had high expectations for improvement in service delivery. The program could not deliver immediate results as was expected from the public. Challenges related to infrastructure, shortages in clinicians and other resources complicated efforts to transform the healthcare system to reach the vision of quality care for all. (Kautzky & Tollman, 2008; Benatar, 2004).

It has been more than 15 years since the turning point in primary health care for South Africa. Although the health system has grown tremendously, the issue of equity in quality health services in South Africa still remains a considerable challenge. Healthcare facilities in rural areas especially in the areas that were 'ethnic homelands' during the apartheid era, still struggles to provide quality care to the variety of patients (Kautzky & Tollman, 2008). To complicate matters is the fact that the percentage of the South African population that are HIV positive is of the highest in the world. Another burden to the South African health system is the large percentage of unemployment leading to chronic poverty in the country. Many patients cannot afford medical services and are dependent on the health system to provide health services at little to no service income (Benatar, 2004).

Despite many challenges in public healthcare in South Africa, the private sector has grown tremendously since 1970. According to Benatar (2004), services related to 60% of South Africa's health expenditure were received by 18% of the population with private insurance. The patients that can afford private healthcare generally prefer to pay rather than endure long waiting lines and risk poor service in public health facilities. A growing initiative from the public health sector is to consult the private sector for specialist services. An example of this is the outsourcing of radiology cases to private radiologists. Another initiative that has delivered excellent results is public/private partnership hospitals. An effective setting for these hospitals is smaller towns where there is a need for both public and private healthcare but not necessarily for two separate hospitals (Benatar, 2004).

Telemedicine is widely considered to play an integral part in the future of healthcare delivery. The global shortage of healthcare professionals calls for more effective health services. Telemedicine could play a vital role in reducing health process 'waste' relating to hospital referrals and practitioner support. For example, patients could receive a specialist's diagnosis when consulting a general practitioner, without wasting time and money on transport to the specialist.

South Africa's many rural districts and shortage in health practitioners build a strong case for telemedicine implementation. Unfortunately, the South African government has faced many challenges with implementation since the first telemedicine pilot projects were initiated in 1997. The South African Minister of Health reported in 2010 that there is a need for evidence that telemedicine can be beneficial. He attributed the poor performance of telemedicine programs to a severe lack of leadership, inefficient use of funds and a lack of critical skills at provincial offices (Department of Health, 2010).

Using the decision support system that is developed from this study, telemedicine policy makers, in South Africa would be able to assess the needs and potential benefits of telemedicine systems, prior to implementation. Thus creating evidence that telemedicine can be beneficial. The evidence created can then be used to improve the performance of telemedicine projects as well as referral systems in South Africa. Ultimately the decision support system could be used to improve leadership decisions, funds allocation and closed-loop performance management at provincial offices.

In this chapter the first part of the pre-assessment section in the decision support system is discussed as illustrated in Figure 4. Telemedicine is defined, followed by a discussion on application possibilities. The conventional patient referral system is also reviewed with reference to the support that telemedicine could offer to these referrals. The benefits of using telemedicine to support patient referral systems are subsequently explored towards the goal to determine quantifiable evidence for telemedicine potential.

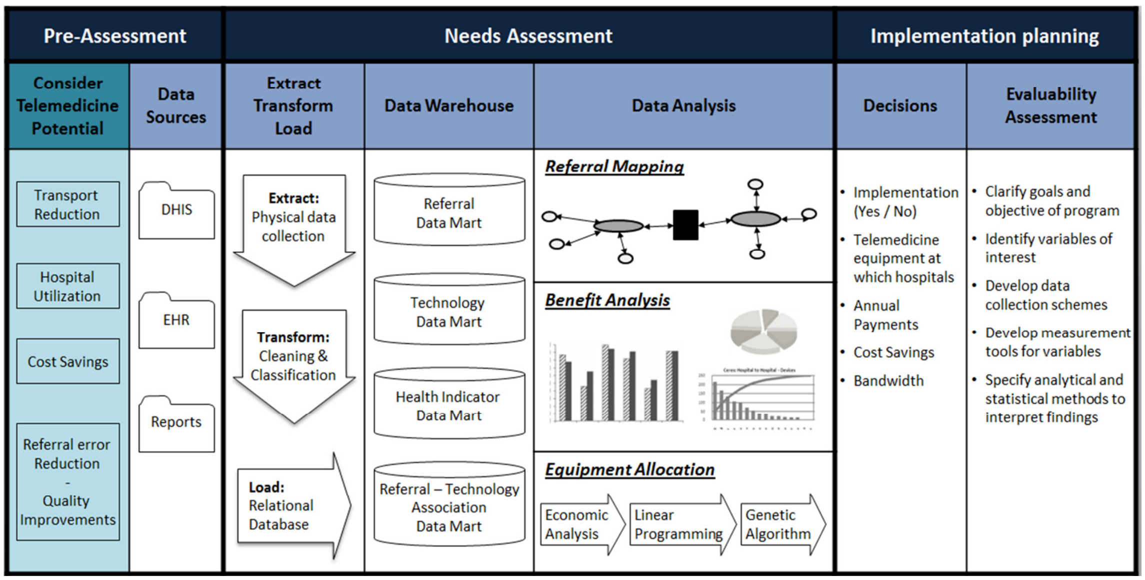

Figure 4: The DSS - Consider Telemedicine Potential

The pre-assessment section of the system is concerned with choosing the appropriate methods and data sources to direct the needs assessment towards the required benefit analysis. The pre-assessment serves as the planning phase of the needs assessment. Decision makers play an integral role in this phase, through directing the needs assessment towards analysing the benefits that would be of most value in the intended telemedicine program.

3.1. Telemedicine Defined

The application of information and communication technologies (ICTs) in healthcare service delivery has evolved drastically over the past 30 years. The use of ICTs in healthcare can be traced back to as early as the mid-19th century, where telegraphy was used during the American Civil War to signal medical information between sites (Field, 1996). ICTs have seen a radical development since then, even to the extent that complicated surgeries can now be performed in remote locations, using robots, manipulated by surgeons. This is just one of many ground-breaking innovations in healthcare technology. However, various challenges still remain in the sustainable and effective use of diagnostic telemedicine systems, which use simple technologies such as telephones, cellular phones and email (Craig & Patterson, 2005; Ferguson, 2006).

There are many different definitions of telemedicine given in the literature. Each definition highlights a combination of the different characteristics of this multi-disciplinary field. Sood, *et al*. (2007) researched 104 peer-reviewed definitions of telemedicine from a literature review and combined it to form one universal definition for modern telemedicine:

> Telemedicine, being a subset of telehealth, uses communications networks for delivery of healthcare services and medical education from one geographical location to another, primarily to address challenges like uneven distribution and shortage of infrastructure and human resources (Sood, et al., 2007, p. 576).

Telemedicine consultations are primarily classified according to the type of interaction that takes place between the patient and the health practitioner. ‘Synchronous telemedicine’ (also called real-time telemedicine) refers to real-time interaction between the sender and the receiver of the data. During such a teleconsultation, there are insignificant time delays between the sending, receiving and collection of data. The most widely used means of synchronous telemedicine is videoconferencing.

Synchronous telemedicine is sometimes preferred by practitioners, since it enables the practitioner to have a conversation with the patient. However, this type of interaction requires high bandwidth, which is often either unavailable or unreliable in the rural areas of South Africa. Moreover, some scheduling difficulties may also occur because the patient and practitioner have to be available at the same time (Craig & Patterson, 2005; Ferguson, 2006).

Table 1: Synchronous Telemedicine

Synchronous Telemedicine	
Attributes	Source
Real-time	**(Craig & Patterson, 2005)**
Live interaction between parties	**(Field, 1996)**
Can be used for more complex medical conditions	**(Ferguson, 2006)**
Effective in emergency situations	**(Ferguson, 2006)**
Equipment is currently expensive	**(Ferguson, 2006)**
Scheduling problematic	**(Harnett, 2006)**
Direct consultation with patient: No added interpretations from third party	**(Ferguson, 2006)**

'Asynchronous telemedicine' (also called store-and-forward or pre-recorded telemedicine) allows data to be sent regardless of the receiver's availability at the time of sending. Unfortunately, this type of interaction causes time delays between the sending, receiving and collection of data. A typical method of asynchronous telemedicine is email consultations between health practitioners. In spite of the fact that this form of telemedicine generally requires lower bandwidth than synchronous telemedicine, the direct interaction between specialist and patient is lost. This is of concern to many practitioners, but could be overcome through good communication from the sender (Craig & Patterson, 2005; Ferguson, 2006).

Table 2: Asynchronous Telemedicine

Asynchronous Telemedicine	
Attributes	Source
Store-and-forward	**(Craig & Patterson, 2005)**
Scheduling flexibility and convenience	**(Field, 1996)**
Not appropriate for emergency consultations	**(Della Mea, 2005)**
Email is cost-effective, robust and familiar	**(Ferguson, 2006)**

3.2. Telemedicine Applications

During the 1960's and continuing until the early 1980's, several telemedicine projects were initiated in the developed world, but according to Bashshur (2002) most of these projects failed due to a lack of funding. ICTs were expensive and technologies were, for the most part, difficult to use. Many telemedicine projects were driven merely as pilot projects, without a business plan or a program that requires results (Bashshur, 2002). Many of the challenges faced by the developed world during the early stages of implementation are still applicable today in the developing world. However with the rapid development of ICTs, the cost has dropped, enabling significant growth in the applications of telemedicine (Field, 1996).

Telemedicine has proved to be effective in a number of different applications. By definition, telemedicine is used to provide healthcare services over a distance. The use of telemedicine is justified in circumstances where barriers hinder the quality or cost-effectiveness of healthcare services. These barriers could include distance, social barriers, physical obstructions, travel risks or even comfort. In this section the rationale behind the implementation telemedicine is discussed with reference to specific applications of telemedicine in healthcare service delivery.

3.2.1. Developing Countries and Rural Health

Telemedicine has many benefits when operational in rural areas. The far distances between healthcare facilities have high transport cost implications. Furthermore patients are discomforted by the need to travel far distances and loose time from work and can sometimes disrupt family obligations. Mostly in developing countries patients do not have access to their own transport and rely on the transport from the healthcare provider. Conventional referrals as the alternative to telemedicine have high cost implications for the sponsoring party that can be reduced by telemedicine referrals (Wootton, Patil, Schott, & Kendall, 2009).

Telemedicine could aid in solving global issues relating to shortages of health practitioners. Figure 5 is a map from the World Health Organisation (2011) that indicates the global density of physicians per 1000 population. According to this map, the African continent has the lowest physician density in the World. South Africa's physician density falls in the second lowest category with 0.5 – 1.4 physicians per 1000 people. These estimations include both the private and public sector of South Africa. In Figure 6, a map of South African indicators for 2008, it is clear that physician density estimations are much lower when excluding the insured population for these figures.

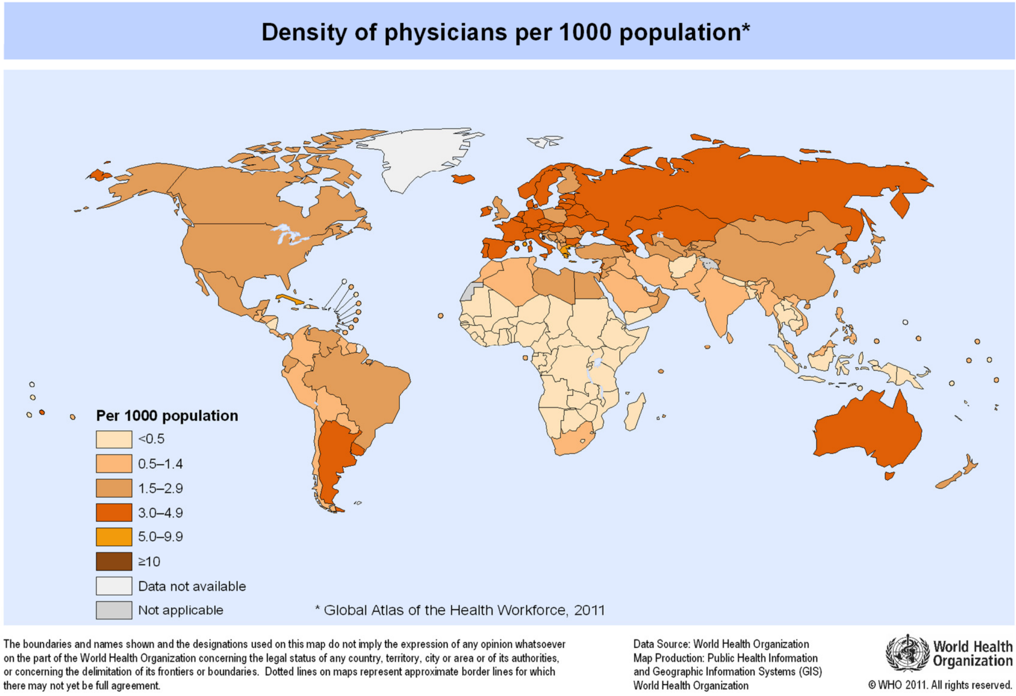

Figure 5: Global Physician Density 2011 (WHO, 2011)

In South Africa there is a vast difference between the level of development in urban and rural districts. Urban districts are generally defined as areas where there are a higher level of development and available infrastructure, whereas rural districts are mostly under-developed. Some farming communities which are isolated by means of distance are also classified as rural districts. In most rural districts, there is a lack of infrastructure, especially in the areas that were defined as 'ethnic homelands' during the Apartheid years. Poverty, illiteracy, lack of sanitation and inadequate housing are some of the factors that causes serious health risks in rural areas. The percentage of the population living in rural areas that need primary healthcare is high (Benatar, 2004).

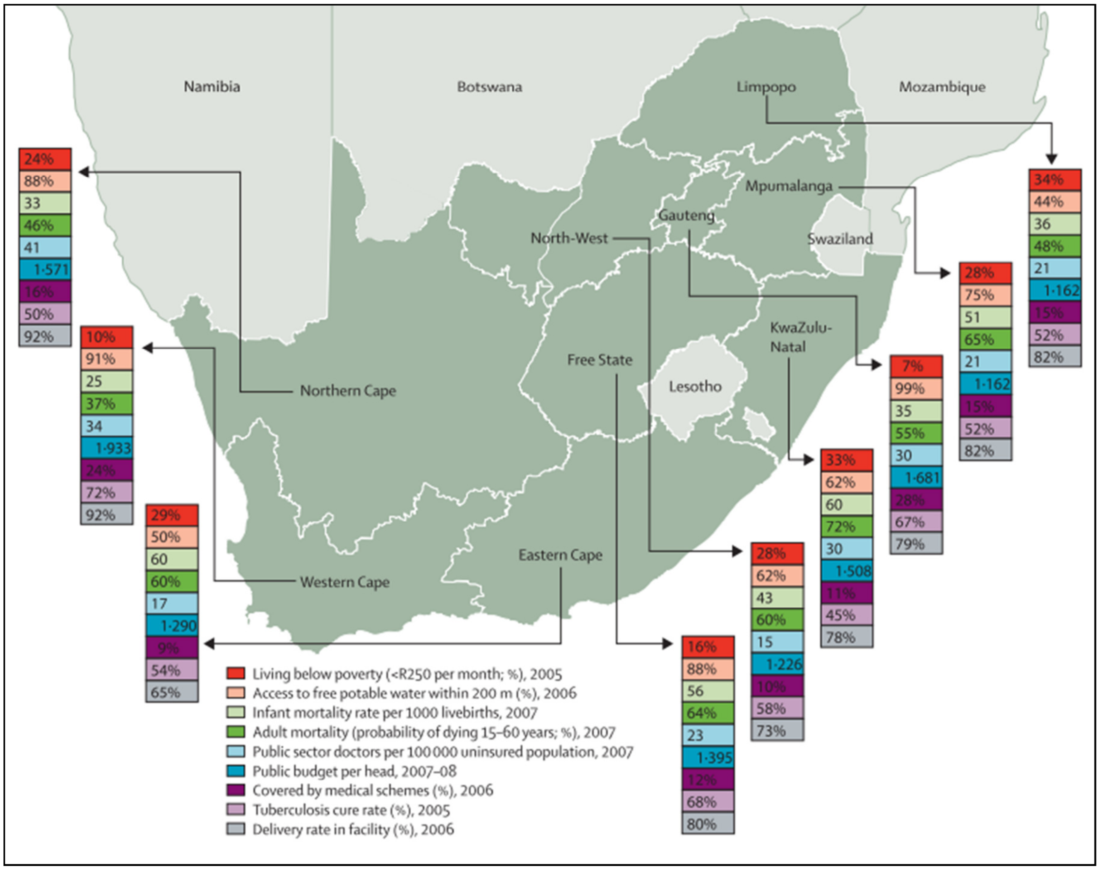

Figure 6: Development and Health Indicators of South Africa 2008
Source: (Coovadia et al., 2009)

Figure 6 shows poverty and health estimates for each province in South Africa. According to this map, the Western Cape has the highest number of physicians per uninsured population with 34 physicians for 100000 people. North-West and Eastern Cape Provinces have the lowest physician density with 15 and 17 physicians per 100000 people respectively.

Telemedicine could make a tangible difference in bringing specialised services to isolated areas in South Africa. Provinces with low physician density could benefit the most from telemedicine, because through telemedicine services patients could have remote access to physicians from areas with higher densities. In such a way, telemedicine promotes equity of services, by distributing scarce resources across the borders, using communications technologies.

3.2.2. Specific Telemedicine Applications

Telemedicine can be applied in all medical fields were a diagnosis can be made from data transferable through ICTs. The data could take on many forms such as images, sound or video files. As previously mentioned, some telemedicine applications require synchronous consultation in which the specialist has real-time interaction with the patient. Listed below are different telemedicine applications. Table 3 indicates what type of information and interaction some of these application require.

- Medical Tele-consultations
- Tele-cardiology
- Tele-dermatology
- Tele-dentistry
- Tele-ophthalmology
- Tele-Oncology
- Tele-pathology
- Tele-radiology
- Tele-neurology
- Tele-wound care

Table 3: Telemedicine classification
(Adapted from Craig & Patterson, 2005 and Ferguson, 2006)

		Information transmitted	
		Text &Still Images	**Audio & Video**
Interaction	**Synchronous (real-time)**		**Tele-psychiatry,**
	Asynchronous (pre-recorded)	**Tele-radiology, Tele-dermatology, General medicine**	**Tele-radiology, Tele-cardiology, Tele-neurology**

3.3. Telemedicine Management

South Africa like many other developing countries has identified telemedicine to support many of the challenges faced in the public health sector. It has been proven that telemedicine could assist healthcare systems in bringing specialised medical services to isolated communities (Martinez *et al.,* 2004). Since the goal of the decision support system is to guide decision makers to make informed management decisions, it is important to have a broader perspective on the areas that telemedicine managers should consider. In this section some of the important aspects relating to telemedicine management are explored.

3.3.1. Policy and Legislation

Telemedicine often requires cross-disciplinary interaction as well as interprovincial collaboration. Policies and legislation are a prerequisite in deploying telemedicine across disciplinary and provincial borders. Policies regarding standardisation and security are essential to ensure that quality of care and patient safety are not compromised. Policies and legislation closely corresponds to financing telemedicine projects. If there are gaps in financing policies the risks of project failure increases due to the possibility of insufficient funds (Broens, *et al*., 2007).

3.3.2. Evidence for Telemedicine Benefits

The growing global awareness of telemedicine led to a substantial growth in published articles concerning telemedicine. Many studies have been done to evaluate the effectiveness and benefits of telemedicine systems. However systematic reviews done by Roine, Ohinmaa and Hailey (2001), Clarke and Thiyagarajan (2008), Hailey, Ohinmaa and Roine (2004) and Curioso and Mechael (2010) agree that there are not sufficient studies done that scientifically and rigorously assess the benefits of telemedicine systems. Scientific evidence of the clinical effectiveness and cost-effectiveness of telemedicine remains lacking (Clarke & Thiyagarajan, 2008; Curioso & Mechael, 2010; Roine, Ohinmaa, & Hailey, 2001). Hence the evident need for “hard evidence produced by rigorous scientific studies that evaluate its benefits and costs” (Bashshur, Shannon, & Sapci, 2005, p. 296).

3.3.2.1. Policy Making

Healthcare evaluation often unites scientific studies and political drivers that could have conflicting outcomes. Scientific studies place an emphasis on methodologies and research design to provide factual evidence through reliable measurements using data collection and analysis (Stevens *et al*., 2001). Political motivators are driven by priorities related to public policies, funding parties and allocation of funds (Bashshur, Shannon, & Sapci, 2005). Sensible policies are however based on factual information such as the costs and benefits of the program (Roine, Ohinmaa, & Hailey, 2001). Therefore scientific studies and political motivations share a common goal to gather evidence rather than speculations.

The evaluation of programs is typically driven by political concerns regarding the performance of the health program. Telemedicine, especially in the developing world, was introduced to address political and public concerns regarding quality and equity in healthcare. Telemedicine program evaluation therefore assesses the extent to which telemedicine programs addresses issues such as equity of quality care and reducing costs in healthcare (Bashshur, Shannon, & Sapci, 2005).

Program evaluation is directed towards providing decision support for policy makers to determine the current status of the program, identify better alternatives, assess the effects and provide decision support on actions to be taken (Bashshur, Shannon, & Sapci, 2005). Evaluation that is built on scientific evidence promotes acceptance among clinicians and provides policy makers with confidence towards achieving defined goals and objectives.

The scope of telemedicine is continuing to evolve as new telemedicine technologies emerge and more applications become feasible (Roine, Ohinmaa, & Hailey, 2001). The wide range of telemedicine applications, technologies and perspectives complicates the evaluation of telemedicine as a fixed entity (Stevens, Fitzpatrick, Abrams, Brazier, & Lilford, 2001). Telemedicine programs can differ between people, settings and times. However when assessing telemedicine programs for policy purposes a more general assessment of telemedicine with respect to the health system is required. Policy making within the health system would not require details regarding the different applications of telemedicine but rather the overall benefits the programs (Bashshur, Shannon, & Sapci, 2005).

3.3.2.2. Telemedicine Services versus Systems

Taylor (1998) surveyed publications in telemedicine and distinguished between telemedicine systems and services. According to Taylor (1998) studies on telemedicine systems were technically focused and included equipment specifications, safety and effectiveness. The majority of these studies were concerned about the technical performance of systems relating to the diagnostic accuracy of decision making supported by telemedicine equipment. Telemedicine services however are not only concerned with whether the technology works, but rather in the effectiveness of care and benefits that can be obtained using the technology (Taylor, 1998).

Wyatt (1996) defines the development of telemedicine systems without a concern for a need of the technology as 'technology-push' and argues that a 'clinical-pull' approach, where a needs assessment is done prior to development, serves as a better foundation for successful implementation. Hebert (2001) describes program evaluation as examining technology use to "provide a service or deliver a program" (p. 1145). Program evaluation, with the emphasis on usage of technology and service provision, could be considered to be the evaluation complimenting a clinical-pull approach.

3.3.2.3. Dimensions for Telemedicine Assessment and Evaluation

Bashshur *et al.* (2005) adapted a model for evaluation approaches as shown in Figure 7. The model identifies three different dimensions for telemedicine evaluation. The first dimension separates the applications by grouping them in three speciality areas; public health, education and clinical. The second dimension takes into account that evaluation can be done from different perspectives. The perspectives of the society, provider and client are of importance in telemedicine evaluation. The third dimension divides telemedicine programs by technology usage. A telemedicine program using asynchronous technology differs from a program using synchronous technology. Bandwidth and peripheral devices also have a noteworthy impact on the program characteristics (Bashshur, Shannon, & Sapci, 2005).

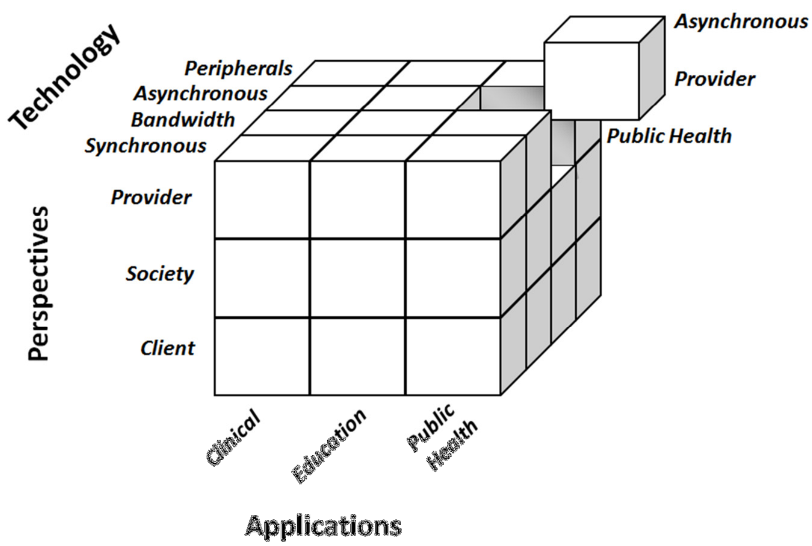

Figure 7: Three Dimensions for Telemedicine Evaluation (Adapted from Bashshur, Shannon, & Sapci, 2005)

The focus of the decisions supported by the system is on asynchronous technology from a provider's perspective in the public health application of telemedicine. It is generally accepted that it is not yet feasible to use synchronous technologies in the public health sector of South Africa. Many hospitals, especially in the rural areas, do not have reliable internet connections. Low bandwidth also limits the connectivity for real-time consultations. Another significant constraint is that the nature of practitioners' schedules currently do not allow for reliable continuous real-time telemedicine consultation. It is expected that in the future, when ICT implementations and bandwidth capacity increase, it will become feasible to expand to synchronous telemedicine.

The decision support system considers the potential benefits of asynchronous telemedicine systems in public healthcare from a policy perspective. Once the need for a telemedicine program has been proven and systems are implemented, the potential of telemedicine from the needs assessment can be used to serve as a benchmark for evaluation.

3.3.2.4. Evaluation Typology

Taylor (1998) identified that evaluation regarding services should consider the stages of the implementation life cycle as each phase has unique measurements and outcomes. The implementation life cycle in short consists of a feasibility study, pilot project, program and outcome. The typology of program evaluation as suggested by Bashshur *et al.* (2005) closely corresponds to the implementation life cycle mentioned by Taylor (1998). The typology of program evaluation according to Bashshur *et al.* (2005) is as follows: (1) evaluability assessment, (2) documentation evaluation, (3) process evaluation and (4) summative or outcome evaluation.

Evaluability assessment takes place during the planning phase of telemedicine programs. During this stage the aim is to assess what should be evaluated in the program and to develop tools for evaluation. The goals and objectives of the program are defined and used as a benchmark for further evaluation. Evaluability of the program is assessed prior to implementation, since tools for evaluation are likely to be included into the program design (Bashshur *et al*., 2005).

Documentation evaluation includes the sequential description of the implementation of the program. The aim is to contribute towards improving the implementation of telemedicine projects, by documenting pitfalls, tips and guidelines for future projects. *Process evaluation* is performed after the program is implemented and is continued throughout the life-cycle of the program. This evaluation phase is directed towards measuring the process variables that influence the performance of the program (Bashshur *et al*., 2005).

Summative or outcome evaluation determines the extent to which the system satisfies the intended effects of the system. Scientific methodologies such as cost-benefit and cost-effectiveness analyses are used to evaluate the performance of the system. Evaluation tools that were developed in the evaluability assessment phase are used to evaluate the performance of the program in relation to the previously defined goals and objectives (Bashshur *et al*., 2005).

Evaluability assessments, builds the foundation for further evaluation and could play an integral role in implementation policies, because it defines the goals and objectives for the program and develop tools to evaluate performance. Documentation, process and outcome evaluation are all introduced after implementation, and are therefore of less importance to implementation policy making. Nevertheless implementation policies should be evaluated throughout the entire life cycle of the program. Evaluability assessment is included in the implementation planning phase of the decision support system. In Chapter 6, an evaluability assessment is discussed using the results from the needs assessment to develop tools and goals for the telemedicine program to be implemented.

3.3.3. Infrastructure

In areas where there is a lack of infrastructure, telemedicine implementation is severely challenged. Telemedicine, using ICTs is primarily dependent on infrastructure such as electricity and telecommunications. Most developing countries face challenges due to a lack of infrastructure. In rural areas the need of power cables and telephone lines can be overcome with solar energy and wireless communications technologies. However, these new technologies are expensive and might not be sustainable and reliable. Since reliability and sustainability is a prerequisite for telemedicine, it is essential that these technologies adhere to quality standards before implementation (Wootton *et al*., 2009).

3.3.4. Ethical Concerns and Risk Issues

Telemedicine, like many other fields in healthcare has many ethical concerns. In an asynchronous telemedicine consultation, patient data are transferred from one clinician to another. Data being send electronically causes many risks for patient privacy and confidentiality. This leads to the need of patient consent prior to a telemedicine consultation. The patient has the right to deny consent which will prevent a telemedicine consultation from taking place. This complicates matters especially in educational instances (Stanberry, 2001).

3.3.5. Clinicians' Acceptance of Telemedicine Equipment

A common trend in telemedicine implementation projects is the resistance of clinicians to accept and practice telemedicine. Human factors play an undeniable role in the acceptance of most new technologies. Telemedicine and information technologies are often accused of being 'user unfriendly'. Decisions regarding purchasing of equipment are frequently based on grants and other financing specifications rather than appropriateness and requirements. Clinicians are not considered to be technology experts and are therefore not trained to solve technological difficulties. It is therefore critical that equipment should be reliable and easy to operate. However this is mostly not the case. In the case where practitioners are sceptical concerning the quality and integrity of equipment, a natural and necessary resistance of usage will occur. Furthermore clinicians cannot spend long hours in learning the correct use of complicated and 'user unfriendly' hardware or software (Field, 1996).

Telemedicine can be seen as an alternative to conventional referrals between hospitals. Many practitioners have established referral networks with specialists whom they know personally. Telemedicine might change this culture when specific specialists are assigned to telemedicine consultations. Telemedicine might also make use of specialists that are geographically very far from the patient. Therefore the patient would not have been send to this specialist through conventional referrals. If a patient still needs to be referred after the telemedicine consultation, the patient will need to see a different specialist than the telemedicine specialist. This might cause inconsistency in treatment (Field, 1996).

3.3.6. Training and Support

An essential part of any technology implementation is training and support. The need for training is amplified in the healthcare sector where clinicians were mostly not sufficiently trained in the use of computer technology. Training should be conducted in such a way to ensure that clinicians will be able to use technology without the supervision of teaching personnel. Training without support is mostly inefficient and might result in the technology being discarded. Since clinicians mostly do not have much spare time, they would typically not spend much time trying to get acquainted with new technology. Therefore if support is not available when needed, the technology will be neglected (Broens *et al.*, 2007).

3.4. Hospital Referrals and Telemedicine

A universal goal of Primary Health Care (PHC) is to provide quality healthcare for the entire population. However, limited resources, among other constraints in developing countries, prevent public health sectors from reaching this goal. Treating patients as close as possible to their homes, at the lowest possible cost but still providing quality care with the necessary expertise, is a challenge, especially in developing countries. To this end, referral systems contribute to the deliberate distribution of expertise by distinguishing between different levels of care. In this way, scarce resources are allocated to higher-level health facilities, resulting in a cost-effective practice where patients arriving at low-level care facilities, are referred to higher-level facilities if they need more specialised treatment. In such a way, resources are allocated to those who need it (Hensher, Price, & Adomakoh, 2006).

3.4.1. The Referral System: Definitions and Characteristics

All healthcare facilities, on all levels of care, send and receive patients to and from other facilities. It is to be expected that higher-level hospitals would likely receive more referrals than they send, whereas hospitals on a lower-level would probably send more referrals than they receive. Hensher *et al.* (2006) defined a referral as:

> Any process in which healthcare providers at lower levels of the health system, who lack the skills, the facilities, or both, to manage a given clinical condition, seek the assistance of providers who are better equipped or specially trained to guide them in managing or, to take over responsibility for a particular episode of a clinical condition in a patient (Hensher, Price, & Adomakoh, 2006, p. 1230).

The definition for a referral does not exclude the use of ICTs and therefore, includes telemedicine practices. According to the definition of telemedicine, the delivery of any long-distance healthcare service, using an ICT, can be regarded as telemedicine. ICTs are moreover, commonly used to assist in referrals, for example, a simple telephone call between practitioners during patient referrals could be argued as being a form of telemedicine.

Since the overlapping of definitions could be the cause of some confusion, for the purposes of this study, the following definitions are used:

A *telemedicine referral* is a referral during which a patient is diagnosed, treated, or both using an ICT, to prevent having to transport the patient to another facility.

A *transfer referral* is a referral during which a patient is physically transferred to another health practitioner or facility.

The referral system distinguishes between the three levels of care according to the availability of specialised personnel and the sophistication of diagnostic and therapeutic technologies. Table 4 lists and describes the functions of the three levels of care in hospitals. A fourth type of healthcare facility, the specialised hospitals, also plays a role in the referral system and is also mentioned in Table 4. Specialised hospitals perform different functions from other hospitals, in the sense that patients are referred to these facilities for specialised treatment, rather than for diagnostic purposes. Asynchronous telemedicine would therefore, not be a feasible alternative for the majority of referrals to specialised hospitals.

Table 4: Standard Definitions of Hospital Levels
(Adapted from Hensher, Price, & Adomakoh, 2006 and World Health Organization, 2003)

Disease Control Priorities Project: Terminology and definitions	Alternative terms
<u>*Primary-level hospital:*</u> Few specialties – mainly internal medicine, obstetrics, gynaecology, paediatrics, general surgery, general practice, limited laboratory services for general analysis	***District hospital*** ***Rural hospital*** ***Community hospital*** ***General hospital***
<u>*Secondary-level hospital:*</u> Highly differentiated by functions with 5-10 specialties Sizes range from 200 – 800 beds	***Regional hospital*** ***Provincial hospital*** ***General hospital***
<u>*Tertiary-level hospital*</u> Highly specialized staff and technical equipment- for example cardiology, intensive care unit, and specialized imaging units, clinical services highly differentiated by function. Could have teaching activities Sizes range from 300 – 1500 beds	***National hospital*** ***Central hospital*** ***Academic, Teaching or University hospital***
<u>*Specialised hospital*</u> Specialise in specific diseases or conditions such as tuberculosis, psychiatry, substance abuse, infectious diseases and rehabilitation	

The hierarchy of referrals between the hospitals in South Africa, as described in Table 4, are illustrated in Figure 8 below. As can be seen, in South Africa, there are few selected tertiary hospitals nationwide that provide specialised services (National referral services) as an add-on to the usual services of a tertiary hospital. One of these national referral tertiary hospitals also provides a highly specialised service and is called the Central Referral Unit. Although regional and tertiary hospitals treat a high percentage of referral patients, these hospitals are not restricted to referred patients. However, the amount of 'non-referred' patients in tertiary hospitals is restricted by limiting the emergency ambulance services at these hospitals (National Department of Health, 2003).

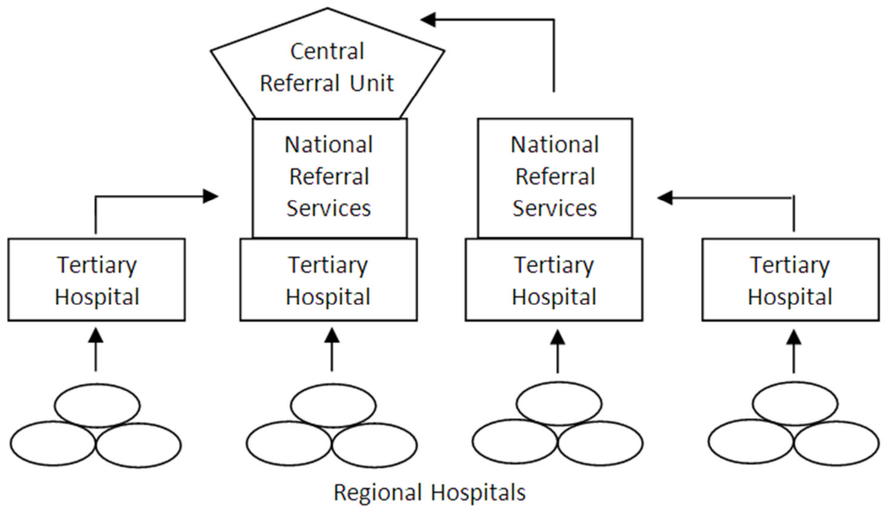

Figure 8: Referral Hierarchy in South Africa
(Adapted from National Department of Health, 2003)

3.4.2. Benefits of Using Telemedicine as an Aid to Referrals

Transfer referrals between the different health facilities serve as a crucial link so that all patients have access to higher-levels of care. Unfortunately, there are risks involved in patient referrals and they are not always feasible. Transportation of patients between facilities also has high cost implications (Hensher, Price, & Adomakoh, 2006). Telemedicine could aid referral systems by reducing the negative aspects (Bashshur, Reardon, & Shannon, 2000). Currently, asynchronous telemedicine referrals are not considered to be an absolute replacement for transfer referrals since not all diagnoses and treatments can be performed using asynchronous telemedicine (Della Mea, 2005). Yet, transfer referrals could serve as a control case for telemedicine referral evaluation studies, in those consultations where telemedicine is effective in eliminating the need to travel.

The South African Minister of Health expressed concern regarding the poor performance of telemedicine programs. He reported that in the beginning of 2010 only 32 telemedicine sites were functional of the 86 telemedicine sites in the public health sector. He blamed the poor performance on "a lack of coordination and leadership; ·lack of critical skills at the department's provincial offices; ·inadequate budgets; ·inefficient use of available funds; weak IT infrastructure and inadequate, unreliable connections" and expressed the need for quantifiable benefits of telemedicine (Department of Health, 2010).

Telemedicine could be highly beneficial in the rural areas in South Africa. Unfortunately there are also many challenges in implementing systems in rural areas. Infrastructure such as electricity, information and communication technologies and transport services are mostly not functional or not available in rural areas. The lack of efficient transport services amplifies the need for telemedicine, but also causes challenges in support and maintenance. In an environment where users of telemedicine equipment are not trained technology, the reliable support of IT is crucial.

Consistency and quality of healthcare

In statistical analysis, a type I error is defined as the false detection of a fault. During type I errors, unnecessary action is taken, while type II errors occur from failing to detect an error and thus, neglecting to take the necessary action (Gitlow *et al.,* 2005). In terms of medical referrals, type I errors occur when patients are unnecessarily referred. In contrast, type II errors occur when patients who should have been referred, were not. Table 5 illustrates the referral errors and their consequences.

There are few medical risks in type I errors, because if the initial diagnosis is correct, it would be confirmed by the second consultation. The cost of referring a patient during a type I error could be considered a waste, because it does not add any value to the service. Type I errors also result in patients being admitted to hospitals further away from home and occupying beds in high-care hospitals, with a limited number of available beds.

On the other hand, type II errors result in high medical risks for the patient because of failure to refer them. Costs are perhaps reduced by not referring a patient, but the quality of care would certainly be compromised. Furthermore, in the healthcare environment, equity of care and the safety of the patient are considered more important than marginal savings. Cautious practitioners would therefore be more likely to 'play it safe' by referring more cases than necessary. This would, in turn lead to a pattern of type I errors occurring more frequently than type II errors.

Table 5: Referral Errors

	Patient Referred	**Patient Not Referred**
Referral Not Necessary	Type I Error (Unnecessary Cost)	No Error
Referral Necessary	No Error	Type II (Medical Risk)

According to Craig and Patterson (2005), the consistency of quality care could be improved through telemedicine. Telemedicine provides practitioners with an easier and more effective means to obtain a second opinion than would otherwise have been possible. Second opinions can serve as a quality control measurement, limiting the chances of misdiagnosis. When a practitioner is in doubt about a patient's diagnosis, a telemedicine referral can greatly reduce the amount of possibly unnecessary, referrals thereby reducing costs. More importantly, through regular use of telemedicine systems, a practitioner can afford to refer more patients at lower costs and therefore double-check even if he/she is relatively sure of the diagnosis. Hence, by reducing the amount of type II errors, the medical risks also decrease.

Telemedicine referrals allow a local doctor to remain involved in the diagnosis of the patient by simultaneously collaborating with a specialist who has a higher level of knowledge (Hjelm, 2005). This holds many benefits, especially in smaller districts where respective practitioners sometimes have a long-standing relationship with the patient and are more familiar with a patient's medical history than the specialist. Therefore, this collaboration between the local doctor and the specialist, affords the patient the best possible treatment.

Improved Communication

Good communication between hospitals is essential in ensuring that information, regarding the current condition and medical history of a patient, does not get lost. The fact that different hospitals' information systems are not synchronised in South Africa, complicates the transfer of patient information. In this country, patients are required to take a booklet, containing their medical history, with them when they are referred to another hospital. However, patients sometimes lose these booklets, forcing specialists to prescribe treatment without any knowledge of a patient's medical history or a letter of referral. Until hospital information systems are linked and synchronised, patient information will continue to get lost, contributing to medical risks (Nakahara, *et al*., 2010).

A further explanation for documentation, concerning a patient's medical history, getting lost is caused by stress suffered by patients being transferred from one hospital to another. Telemedicine referrals can reduce this type of human error during a referral. In the case of a telemedicine referral, all the appropriate information is sent together in a bundle, thereby reducing the risk of information being lost. In circumstances where the receiver requires additional information about the patient, this can be requested from the sender, thus improving communication between the sender and the receiver in the referral.

Equity and Improved Access to Specialists

Hensher *et al.* (2006) found that specialists prefer to practice at tertiary hospitals rather than hospitals offering lower levels of care. One of the main reasons for this is that tertiary hospitals are almost always located in metropolitan areas. Another reason is that tertiary hospitals have access to better resources that allows for valuable professional experience and opportunities for private practice. Typically, patients in remote and rural areas only have direct access to primary health care. Telemedicine could improve equity of care between patients living in rural and urban areas. Since secondary and tertiary care is more accessible in urban areas. Thus, rural patients can have faster access to specialists by saving time on referral administration and travelling (Hensher, *et al*., 2006).

The phenomenon mentioned above, where practitioners migrate away from rural areas, leaves these areas with a critical shortage of highly trained health practitioners (Ferguson, 2006). Telemedicine referrals could, therefore, serve as an outsourcing mechanism to utilise specialists' time more effectively. The use of telemedicine could also reduce the effect of staff shortages, by training general healthcare practitioners, for example, nurses, to indirectly deliver medical services and treatment that were previously restricted to specialists. Support, provided by appropriate doctors and specialists, via information and communications technology, could empower nurses to be an integral part of service delivery in the South African healthcare system. In addition, this would reduce the amount of valuable time spent by doctors by consigning time-consuming tasks to nurses, therefore ensuring better utilisation of resources (Ferguson, 2006).

Practitioner Support

The trend of skilled professionals moving away from rural areas often leave those left behind feeling isolated. Professionals with little experience in rural areas are therefore in need of guidance and support from specialists and professionals in tertiary hospitals with more experience. The referrals system ideally meets this need through the collaboration of professionals between the different levels of care (Hensher, *et al*., 2006; Wootton, 1998).

Education

Telemedicine can be used as an educational tool for undergraduate and postgraduate studies but also continuing training of health professionals. Information and communication technologies are suitable to provide support networks through which students can remain connected to their professors while being away from campus during practical training. This allows professors to be involved in the training of the student even though they are not present at the facility. The students can collaborate with professors and fellow students and therefore are not isolated in a remote or rural area (Ferguson, 2006; Hjelm, 2005). Some telemedicine systems have been developed specifically for training purposes. An example of this is the virtual patient that is used by students and practitioners to create a safe environment for the development of consultative skills (Hjelm, 2005).

Hospital Utilisation

In most developing countries the number of available beds in many high-level care facilities is severely constrained. Furthermore many of these hospitals do not have the resources to sustain good quality care during high occupation seasons. Therefore high utilisation of these hospitals inevitably leads to low quality of care in these hospitals. The number of patients admitted to tertiary hospitals can be reduced, by referring more patients through telemedicine, hence treating more patients in district hospitals, clinics or even at home. Telemedicine would therefore reduce the utilisation of tertiary hospitals allocating resources more effectively (Hjelm, 2005).

Reduction in Transport

One of the most obvious advantages of telemedicine is that, in remote or rural areas, patients no longer need to travel from one health facility to another (Hjelm, 2005). Predominantly, patients in rural areas are in the extreme, low income group and cannot afford to travel far distances to receive specialised treatment. Furthermore, some special populations such as the elderly, pregnant women, disabled and acute sick patients can avoid taking health risks normally accompanied by travelling (Alverson, *et al*., 2008; Craig & Patterson, 2005; Jahn & De Brouwere, 2001).

Reduces Cost

Telemedicine has the potential to fundamentally restructure the way in which healthcare is delivered. If restructuring is done in such a way that service processes are more efficient, specialist time spent per patient, transport and hospital stay can be reduced. In the long term, these reductions will ultimately contribute towards overall cost savings (Hjelm, 2005). Telemedicine services are expected to have financial benefits, but various sources have stated that there is not efficient evidence to confirm this (Craig & Patterson, 2005; Hjelm, 2005; Hailey, Ohinmaa, & Roine, 2004; Roine, Ohinmaa, & Hailey, 2001).Measuring these benefits could be challenging as proven by the lack of evidence for telemedicine benefits (Clarke & Thiyagarajan, 2008; Curioso & Mechael, 2010). In Chapter 4, some data sources are discussed used by the decision support system for quantitative measurements of benefits.

Chapter 4

Identifying Data Sources

The opportunities for using healthcare data in decision making are continuously increasing with the evolvement of Information and Communication Technologies (ICTs). Decision makers, such as healthcare providers and insurance companies, rely on data intensive statistical indicators to make informed decisions. Some of the data that were originally collected to assess provincial and national health indicators are available for research studies. However, these data sets that were intended for health indicators are mostly of a general nature and are not always suitable for detailed research.

Unfortunately, there are limited data available which relates to telemedicine. This can possibly be attributed to the fact that both the telemedicine initiative and computerised health information systems in South Africa are relatively new. Furthermore, since telemedicine needs assessments were mostly done qualitatively, programs and systems, to collect and store quantitative data for telemedicine needs assessments, have not yet been introduced. Therefore, finding the appropriate data for the decision support system could be a challenge.

Since there are little quantifiable data available on telemedicine referrals, other sources were considered which could provide the decision support system with data. Hospital referral data are similar to telemedicine data, since telemedicine could potentially refer patient information electronically. The potential (or need) for using telemedicine can be assessed by focussing on cases where telemedicine could have been used, as an alternative to physical patient transfers. As discussed in Chapter 3, telemedicine is considered as a support medium for hospital referrals.

Figure 9 lists three data sources that are identified as possible sources for telemedicine decision support: District Health Information Systems (DHIS), Electronic Health Records, and Reports. These are all sources that contain data on patient referrals. In this chapter health informatics, as a research field, and medical coding, for standardisation, is discussed, followed by an exploratory view on the data sources used by the system. The chapter concludes with a discussion on how the data available in the mentioned sources can be used to assess the benefits of telemedicine and thereby determine the need for telemedicine implementation.

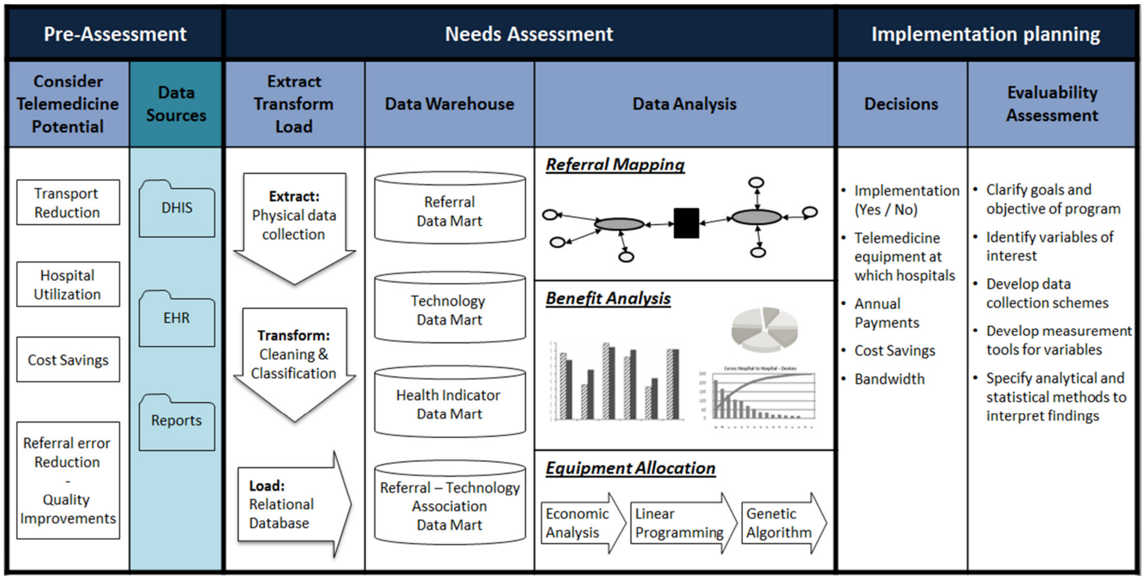

Figure 9: The DSS - Identify Data Sources

4.1. Health Informatics and Telemedicine

The health informatics discipline has grown remarkably with the evolution of ICTs. Health informatics has played a crucial role in delivering healthcare for many decades, contributing to the development of tools for the collection, analysis and sharing of medical data (Imhoff, Webb, & Goldschmidt, 2001). Providing quality healthcare involves the interaction of many different processes and disciplines. Health informatics has spread across various processes such as communication, decision making and education. Diverse perspectives, on how health informatics has influenced healthcare, depend on the different points of view (Hasman, Haux, & Albert, 1996).

The many different definitions for this discipline apparent in the literature, are evidence of the variety of perspectives that exist on health informatics. There are also various opinions as to what the differences between `health informatics` and `medical informatics` are (Imhoff, Webb, & Goldschmidt, 2001; Hasman, Haux, & Albert, 1996). However, for the purposes of this study, the general definition of health informatics given by Imhoff *et al*. (2001) is adopted:

> "Health informatics is not only the application of computer technology to problems in healthcare but covers all aspects of the generation, handling, communication, storage, retrieval, management, analysis, discovery and synthesis of data, information and knowledge in the entire scope of healthcare"(p. 180).

Health informatics can play a number of different roles in healthcare, but ultimately all these roles have the universal goal of improving healthcare quality. Combining the studies of Imhoff *et al*. (2001), Hasman *et al*. (1996) and Williamson *et al.* (2001), the roles of health informatics can be divided into the following categories of application:

- Clinical decision support
- Hospital administration
- Higher-level decision making
- Educational, training and research

4.1.1. Clinical Decision Support

Traditionally, the largest overlap between the fields of telemedicine and health informatics is in the area of *clinical decision support* (Hasman, Haux, & Albert, 1996). Through telemedicine, long-distance clinical decision support is provided through the transfer of information between practitioners (Nannings & Abu-Hanna, 2006). Due to the complexity of integrating information systems, telemedicine systems are often designed in such a way as to be independent from hospital information systems. Hence, these telemedicine systems do not have direct access to the general hospital information system (HIS).

4.1.2. Hospital Administration

Hospital administration, billing and other accounting processes are critical for the business management of a hospital. Health informatics plays an essential role in patient billing calculations, hospital accounting, resource allocation, information management, the evaluation of cost-effectiveness and other information-intensive management processes (Hasman, Haux, & Albert, 1996). Management information systems often use simulation and other tools to optimise operations, effectively allocate resources and ultimately reduce costs for healthcare delivery, without the loss of quality care (Imhoff, Webb, & Goldschmidt, 2001).

4.1.3. Higher-Level Decision Making

Higher-level decision making is concerned with performance indicators and policy making for a district, which could include a number of hospitals. Health informatics, for higher-level management therefore addresses such issues as: district resource allocation, equity between healthcare facilities, district performance and disease burden. Health informatics, on higher management levels, does not involve information on individual patients, but rather information on the population as a whole. Trends and statistics, gathered from the population, equips policy makers and other decision makers to more accurately allocate resources and intervene where necessary (Williamson, Stoops, & Heywood, 2001).

4.1.4. Educational Purposes

The use of real patient information in *education, training and research* is relevant to the needs of patients. An effective method of teaching is through the use of case studies, simulating the conditions, history, treatment and care processes of patients. However, there are many ethical issues in using real data for education and research. It is crucial that the privacy of patients is protected and that research studies are designed in such a way as to accurately reflect reality (Hasman, Haux, & Albert, 1996).

4.2. Disease Classification and Coding

Health information systems are associated with large amounts of data. Standardisation and coding of diseases and other data types are essential for data storage and management. To understand the codes used in EHRs and the decision support system, disease classification and coding is briefly explored.

According to Mony and Nagaraj (2007) p.307, 'clinical coding' is defined as "the translation of diagnoses of diseases, health-related problems and procedural concepts from text to alphabetic/numeric codes for easy storage, retrieval, and uniformity of comparison and analysis". Thus clinical coding plays an integral role in the data management of the decision support system.

One of the first notable attempts to classify diseases for a statistical study was done by John Graunt, on the London Bills of Mortality, in the seventeenth century. He pioneered this field by attempting to estimate the number of children who died under the age of six, at a time when there were no records of mortality age (World Health Organization, 2011). Since Graunt's study, other pioneers such as William Cullen, William Farr, Florence Nightingale and Jacques Bertillon have all made noteworthy attempts to classify diseases (Mony & Nagaraj, 2007; World Health Organization, 2011)

In 1891, the International Statistical Institute, chaired by Jacques Bertillon, commissioned a committee to prepare a uniform classification of causes of death. *The Bertillon Classification of Causes of Death*, as it was originally called, included three classifications with 44, 99 and 161 titles. It was adopted by several countries, with the recommendation of being revised every decade (Mony & Nagaraj, 2007).

The Bertillon Classification of Causes of Death has been revised and expanded ten times since 1891 so as to include morbidity and mortality data. The list, now called the International Classification of Diseases (ICD), is freely available from the WHO and has proven to be a useful tool for health planners and researchers (World Health Organization, 2011; Mony & Nagaraj, 2007).

Over the years, some countries like Australia, Canada and the USA, have modified the standard ICD codes (Bah, 2009). Table 6 lists the different ICD versions and their modifications. Currently the ICD-10 version is used for clinical coding in South Africa. The use of ICD-10 codes is discussed in more detail later. ICD-9-CM, the USA clinical modification of ICD-9 is also discussed later in this chapter, since a data source from the USA is considered for the DSS.

Table 6: Versions of the ICD (Adapted from Bah, 2009)

Abbreviation	Description	Year
ICD	International Classification of Diseases. A disease classification system developed and maintained by WHO	Since 1893
ICD-9 **ICD-10**	Ninth revision of the ICD Tenth revision of ICD	1977 1993
ICD-10-AM **ACHI**	Australian clinical modification of ICD-10 Australian classification of Health Interventions (for procedure coding)	1998
ICD-10-CA **CCI**	Canadian clinical modification of ICD-10 Canadian classification of Health Interventions (for procedure coding)	2001
ICD-9 CM **CD-10-CM** **ICD-10-PCS**	USA Clinical modification of ICD-9 (for both diagnosis and procedure coding) USA Clinical modification of ICD-10 (for diagnosis coding) USA Procedures Code System for ICD-10 (for procedure coding)	1979 2013* 2013*

*** Implementation date in the USA**

An Overview of ICD-10

The ICD-10 is hierarchically structured in three volumes. The first volume has a tabular listing of the diseases, the second volume contains the instruction manual and volume three has an alphabetical index of the diseases. The ICD-10 contains 2046 disease categories, structured in 22 chapters as listed in Table 7 (Mony & Nagaraj, 2007).

Table 7: Chapters of the ICD-10 (Adapted from Mony and Nagaray, 2007)

Chapter	Description
I	Certain infectious and parasitic diseases
II	Neoplasms
III	Diseases of the blood and blood-forming organs, and the immune mechanism
IV	Endocrine, nutritional and metabolic diseases
V	Mental and behavioural disorders
VI	Diseases of the nervous system
VII	Diseases of the eye
VIII	Diseases of the ear
IX	Diseases of the circulatory system
X	Diseases of the respiratory system
XI	Diseases of the digestive system
XII	Disease of the skin and subcutaneous system
XIII	Diseases of the musculoskeletal system
XIV	Disease of the genitourinary system
XV	Pregnancy, childbirth and the puerperium
XVI	Certain conditions originating I the perinatal period
XVII	Congenital malformations and chromosomal abnormalities
XVIII	Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified
XIX	Injury, poisoning and certain other consequences of external causes
XX	External causes of morbidity and mortality
XXI	Factors influencing health status and contact with health services
XXII	Codes for special purposes (e.g. diseases of uncertain aetiology)

The ICD code is structured to have either 3 or 4 digits. The first digit is an alphabetic character, e.g. A to Z. The second and third digits are both numeric characters, followed by a decimal point and a possible fourth digit, also numeric. The first three characters indicate the category of disease, and are mostly divided into subcategories. For example, A15 is respiratory tuberculosis, confirmed bacteriological and histological, whereas A15.O is tuberculosis of the lung, confirmed by sputum microscopy, with or without a culture (Mony & Nagaraj, 2007).

In the following section, data sources from South Africa are explored so as to identify data for the decision support system. Sources such as electronic health records (EHRs) are introduced, where ICD codes are used. Further in this chapter, an alternative data source from the USA is investigated, using ICD-9-CM codes. In Chapter 5 the use of the codes in the DSS are explained in more detail.

4.3. South African Health Data Sources

A growing awareness of ICTs' potential to improve healthcare delivery in developing countries, has led to the evolution and implementation of various health information systems in South Africa. Due to the complex nature of developing health information systems for primary healthcare, together with ICT implementation challenges, initial results from these systems failed to reach their desired potential (Walsham & Sahay, 2006). Some of the contributing factors are; culture, lack of infrastructure and a shortage of skills (Byrne & Sahay, 2003; Williamson, Stoops, & Heywood, 2001). Nevertheless, health information systems in South Africa are continuously improving, leading to much potential for management and decision-making purposes.

4.3.1. Information Systems for Management

The District Health Information System (DHIS) and the Electronic Tuberculosis (TB) Register are examples of well-established health information systems in South Africa. The DHIS was designed to collect data from health facilities and to share aggregated data with the higher levels of the public health system (Williamson, Stoops, & Heywood, 2001). The District Health Barometer (DHB) uses a selected set of data from the DHIS to monitor performance in terms of socio-economic and other healthcare indicators. Annual reports are compiled using data from the DHIS, Electronic TB Register, Statistics South Africa and the National Treasury. Data are analysed and interpreted in such a way as to highlight disparities regarding the equity of services, health resource allocation and efficiency of healthcare processes between districts (Mars & Seebregts, 2008).

The issue of inadequate training and support for ICTs in healthcare applications has been widely covered (Byrne & Sahay, 2003; Mars & Seebregts, 2008; Walsham & Sahay, 2006; Williamson, Stoops, & Heywood, 2001). The need for training and support spans from the data entry-level to high-level management, using the information for decision making. Williamson *et al*. (2001) highlights the issue that managers pay inadequate attention to data entry processes, which leads to poor quality data. An underlying reason for this is possibly the fact that many managers do not appreciate that software is merely a tool which aids in the collecting, storing and analysis of data. Thus an over reliance on the system often leads to many human errors in the data collection process.

The use of the DHIS is separated into three levels for decision support. The first level includes data collection, validation and combining data into sets for transmission to higher levels within a reasonable time frame. Trends, profiles and indicators are compiled and combined in reports at the second level. These monthly reports are available to managers and decision makers, who discuss trends and performances at regular meetings. The third level is for decision making and higher-level management. Information, such as performance indicators and higher-level policy making like the DHB, is used to monitor health success (Mars & Seebregts, 2008; Williamson, Stoops, & Heywood, 2001).

The market for health information systems is rapidly growing in South Africa and as a result, many international and local companies are becoming involved. This has necessitated the consideration of interoperability between information systems. To address the issues and promote interoperability, several standards have been accepted, including standards from the International Organization for Standardization (ISO). The ICD-10 coding standard has been adopted as South Africa's national diagnosis coding standard for both the public and private sectors. However, there are still no agreed standards for procedures, pharmaceuticals, surgeries, pathology, radiology or clinical terms.

Procedural standards such as the National Health Reference Price List (NHPRL) and the related Uniform Patient Fee Schedule (UPFS) are used in the public sector. The National Pharmaceutical Product Interface (NAPPI) is used for coding new medical devices and medicines (Bah, 2009). The adoption of Logical Observation Identifiers Names and Codes (LOINC) is being considered for Electronic Health Records (EHR) as there are currently no national standards for this purpose (Mars & Seebregts, 2008).

4.3.2. Electronic Health Records

The South African Electronic Health Record (EHR) initiative was started in 2003, in the form of a planning workshop, to standardise the implementation of EHRs on a national level. This workshop provided a foundation from where the National Strategic Framework for EHRs in South Africa was compiled. The National Strategic Framework defines an EHR as "a longitudinal collection of personal health information of a single individual, entered or accepted by healthcare providers, and stored electronically" (National Department of Health, 2007, p. 8).

The implementation of EHRs in South Africa is growing rapidly. In 2008, more than a third of the provincial hospitals, nationwide, had implemented computerized systems (Mars & Seebregts, 2008). It is expected that the percentage of hospitals using EHR has increased significantly since 2008, because it has become evident that the use of computerized systems offers many benefits to the health system and management of these hospitals.

The purpose of the South African National EHR Strategy, to integrate health record systems throughout the country, has not yet been realized. Currently, a number of different commercial EHR systems are implemented throughout South Africa. The EHR Strategy is aimed at making all South African citizens' records accessible, whenever or wherever the patients seek medical attention. Furthermore, the ideal of the National Department of Health (2007) is to merge telemedicine records with EHRs, but substantial growth is necessary before theory can become practice. The standardisation of data between telemedicine and EHR systems will simplify future system merging.

The integration of telemedicine records with EHRs will be made easier by the merging of all EHRs throughout the country. If EHRs are stored on a central data warehouse, with practitioner access, the need to send data between hospitals will be reduced. However, storing images and video files for diagnostic purposes would require much more storage space than storing mere text files, which is currently the standard for EHRs. Telemedicine cost calculations and performance evaluation could also benefit from integration with; patients' financial data, referral patterns, diagnostic data and procedure data, which are included in EHRs.

EHR data play an integral part in financial calculations of medical procedures. Likewise, this data can also be used to calculate some of the benefits of telemedicine. Ultimately, if telemedicine systems can be integrated with EHRs, these calculations can be done automatically by a decision support system.

The South African National Department of Health (2007) has listed the different data attributes that a South African public healthcare EHR should contain and these are illustrated in Table 8. Some of these attributes could be useful in a telemedicine needs assessment and the methodology in using specific attributes, is discussed in Chapter 5.

Table 8: Listed contents of the South African EHR
(Adapted from National Department of Health- South Africa, 2007)

Personal Details	Demographic data	Past Medical History	Major Medical Events
• Name (First name and surname)	• Names	• Diagnosis	• Parity / Gravidity
• Physical + Postal Address	• DOB/Age	• Treatments and procedures	• Genetic markers
• Postal Code	• Gender	• Medications	• Pre-dispositions to illness
• Telephone numbers	• Nationality	• Free text field	• Current treatment
• ID number	• Address	• Institutions (Hospital / clinic etc.)	• Blood group
• Next of kin details	• Telephone contact(s)	• Practitioner	• Allergies
• Guardian details	• Family linkage	• Dates (treatment/entry/exit/death)	• Donor status
• Date of birth		• Encounter outcomes	• Episode history
• Insurer / med aid – number		• Categorisations	– Facility or institution ID
• Insurer / med aid – name		• Previous blood results – history	– Care provider ID
• Employment		• Test results	– ICD-10 diagnoses
• Level of education		• Vaccinations	– Procedures (CPT-4 or other standard)
• Gender		• Confidentiality indicator	– Discharge summary (Free text)
• Religion			– Medication (prescribed vs. dispensed)
• Marital Status			– Lab Results
• Number of children			– Imaging results (Image storage - out of scope)
• Unique patient identifier (ID)			
• Nationality			
• Blood groups			
• Allergies			
• Current chronic conditions			
• Current medication			
• Current medical conditions			
• Current practitioner /GP			
• Immunisation Status			
• Disability status			
• Pregnancy status			
• Smoking indicator			

4.4. Telemedicine Benefits Assessment using EHRs

In Chapter 3 the different benefits, that could be expected if telemedicine is used as a support medium for hospital referrals, were explored. Ideally, all the benefits of telemedicine should be assessed prior to the implementation of a telemedicine program. However, assessing these benefits requires the use of different research methods and data sources.

As discussed previously, this study has a focus on asynchronous technology, from a provider's perspective, in the public health application of telemedicine. After exploring data sources available for assessment in South Africa, the benefits that can be measured using discharge data from EHRs, were separated from those that were not quantifiable using EHR data. Measurements that could quantitatively assess the need for telemedicine and thus aid in decision making for implementation, are included in the system and are listed below.

- Hospital utilisation
- Reduction in transport
- Reduces cost
- Quality improvements by reducing referral errors

An estimate of the potential number of referrals, which could have been avoided through the use of telemedicine, is measured by the system. By determining this number, the maximum potential utilisation of the telemedicine system is estimated. The utilisation of the telemedicine system has an influence on the benefits of telemedicine, as listed above. The potential utilisation of the system is combined with other needs assessment methods, to determine the extent of the quantitative benefits.

The quantitative measurement of quality and reliability of telemedicine systems is a complex and diverse task. There are little data available from health information systems that can be used to thoroughly audit the quality of care a patient receives, with or without telemedicine. Other benefits that are not easily measured using data are listed below.

- Reduced information loss
- Equity and improved access to specialists
- Practitioner support
- Education

Data to quantify these benefits are not readily available in EHRs, and are therefore not included in the system. Nevertheless, these benefits are relevant to telemedicine needs assessments. Monitoring and evaluation studies, after implementation, and effective utilisation could assess the extent to which the telemedicine system can obtain these benefits. These studies are not included in this thesis, but should be considered in future work.

4.5. Alternative Data Sources

South African hospital discharge data sets are still in their infancy, when compared to some of the data sources available from developed countries, like the USA. Data acquired from discharge reports of South African EHRs have various limitations. Alternative data sources were therefore also considered so as to serve as a supporting study in using discharge data in the decision support system.

The United States of America, Centre for Disease Control and Prevention, annually publishes a data set called the National Hospital Discharge Survey (NHDS). These data sets contain national probability data dedicated to providing information on characteristics of non-Federal short-stay hospital in-patient discharges. Identifiable information on patients was removed from the data sets, reducing a number of ethical concerns. This enabled the USA Centre for Disease Control and Prevention to publish the data and make it freely available for research purposes (Centers for Disease Control and Prevention, 2011).

The NHDS started in 1965 and has been conducted annually ever since. Between 1988 and 2007, 500 hospitals were included in the sample, resulting in approximately 270,000 in-patient records per year. In 2008, the sample was reduced, to include only 239 hospitals. Hospitals with an average length of stay of longer than 30 days are excluded. Other hospitals with fewer than six beds are also excluded (Centers for Disease Control and Prevention, 2011).

According to the Centre for Disease Control and Prevention (2011) website, the sample selection was broadened at the beginning of 1988, by using two data collection procedures. The first procedure is done using a manual system, performed by hospital staff in the U.S. Bureau of the Census. Data are collected by sample selection and medical transcription from hospital records. The other selection procedure is an automated system that collects data from purchased electronic data files. Commercial organizations, hospitals, state data systems and hospital associations are all included in the samples collected by the automated systems.

The combination of the manual and automated systems therefore, provides for a variety of data included in the data sets. The published data files contain information on the patient, including age, sex, race, ethnicity, marital status, and expected sources of payment. Hospital administration details such as admission and, discharge dates and status, are also included, allowing for a calculation on the length of stay. The ninth revision of the International Classification of Diseases, Clinical Modification (ICD-9-CM) is used to code medical information about patients, including diagnoses and procedures. There is a minimum of one and a maximum of seven diagnoses listed for each entry. It is possible that a case could have no procedures or up to four per entry (Dennison & Pokras, 2000; Centers for Disease Control and Prevention, 2011).

Since the NHDS data contains data from thousands of hospital discharges, these data sets are a useful source for performing statistical analyses to determine the relationship between diagnoses and procedures. However, using a developed country's data for a developing country's assessment is not without limitations and compromise.

Nevertheless, since this study is exploratory into how health informatics could be used for telemedicine needs assessments perfect accuracy is not the goal, which allows for some degree of experimentation. The use of NHDS data should therefore be considered as a pilot study, to evaluate whether it is possible to use health informatics for telemedicine needs assessments. Further details on the use of NHDS data are discussed in Chapter 5.2.4 and Appendix B.

In the next chapter, the methodology of the analysis behind the needs assessment is discussed, followed by case studies and a discussion on how the decision support system can be used in South Africa.

Chapter 5

Data Warehousing and Analysis for Telemedicine Needs Assessments

The data warehouse and analysis forms the core of the decision support system. In the previous chapters, theory behind decision support systems and needs assessments was discussed, followed by an exploratory overview of telemedicine applications, management and benefit assessment. Some quantitative data sources were reviewed, with the intention of gathering quantitative data to assess the potential benefits of telemedicine in South Africa. The previous chapters all formed part of the knowledge base, called the pre-assessment phase, of the decision support system. In this chapter, a methodology for the needs assessment, including; data collection, warehousing and analysis, is discussed as illustrated in Figure 10.

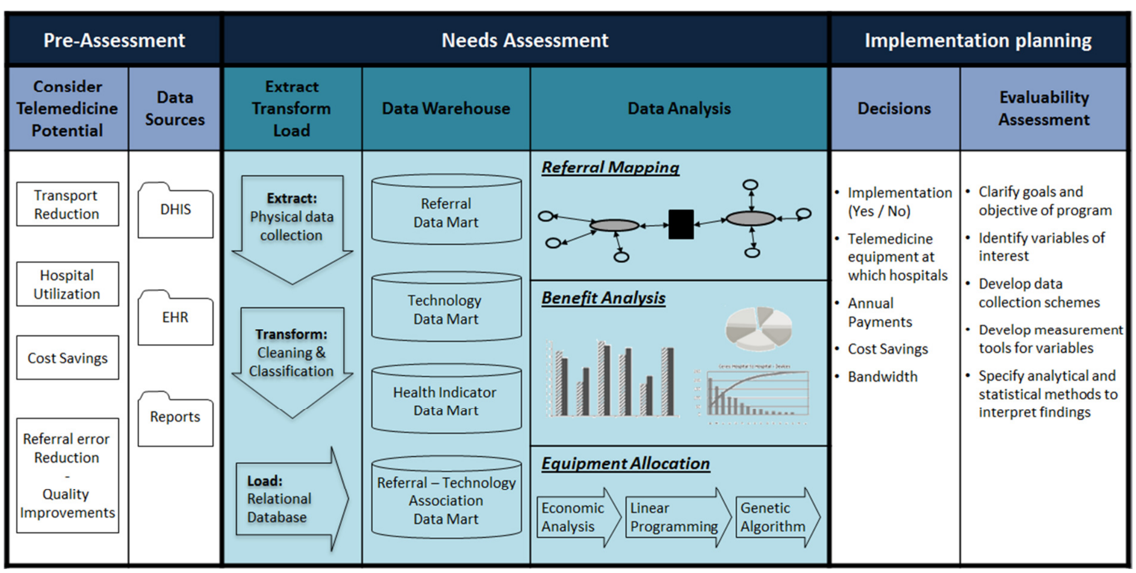

Figure 10: The DSS - Performing the Needs Assessment

The system uses potential benefits, calculated in the needs assessment, to support implementation decisions. If the analysis of patient data in the needs assessment is inaccurate, decisions are based on incorrect results, leading to poor decisions and ultimately possible implementation failure. Health indicator and referral data, from the public health sector in the Eastern Cape Province of South Africa, were used to demonstrate the system.

The Eastern Cape Department of Health is committed to improving hospital referral systems, by introducing telemedicine in the province. As was discussed in Chapter 1, the research study originated from a monitoring and evaluation study done on telemedicine implementation in the Eastern Cape. The need for telemedicine implementation decision support, as well as the potential to use discharge data from EHRs, were discovered during the monitoring and evaluation project. The decision support system was therefore originally developed, for telemedicine decision makers, at the Eastern Cape Department of Health. In Chapter 7, the decision support system is also validated by using EHR data from the Western Cape Department of Health.

Table 9 below outlines the data that were used to demonstrate the decision support system. Data collection methods and analysis are further explained in the remainder of this chapter.

Table 9: Outline of data used to build the Decision Support System

	Health Indicator Data	**Referral Data**
Description	General statistics of the hospitals. Indications of the size and workload of the hospital	Referral data of patients that have been referred from one hospital to another
Population	Eastern Cape Department of Health Hospitals: DHIS, Delta 9	Eastern Cape Department of Health Hospitals: DHIS, Delta
Collecting methods	Request extraction from Delta 9 database	Request extraction from Delta 9 database
Sample	Indicator data from all hospitals in the Eastern Cape using Delta 9, for 2010	Referral data from all hospitals in the Eastern Cape using Delta 9, for 2010
Data Attributes	• Number of beds • Patient Day Equivalent • Cost per patient day • Bed utilization rate • Transfer distances • Patient transfer cost	• Diagnosis • Referral reason • “Referred to” hospital name • Date admitted • Date of discharged • Patient Date of birth • Patient Financial bracket • Patient Gender • Patient Suburb • Length of stay
Analysis	Economic Analysis	• Statistical Analysis • Referral Mapping

5.1. Data Collection (Extract-Transform-Load)

One of the primary goals of telemedicine programs is to improve the quality of care, by referring patient information to specialists, thereby reducing the need to transfer patients to another facility. By examining the referral processes in hospitals (prior to telemedicine implementation), the potential of telemedicine to change existing referral processes is assessed. Collecting applicable data from the available data sources could possibly enable decision makers, using the DSS, to determine the extent to which a telemedicine program could change the existing referral processes and ultimately healthcare service delivery.

To analyse the data for the needs assessment, the data have to be in a form that would allow the use of mathematical models and other analysis tools. Data are extracted, transformed and loaded into a data warehouse (Figure 11), before being analysed. The three data sources, identified in the previous chapter, contain different types of data. The extract, transform and load procedures to collect data from the sources are therefore source specific. The data collection procedures are discussed separately in order to clearly illustrate the necessary considerations.

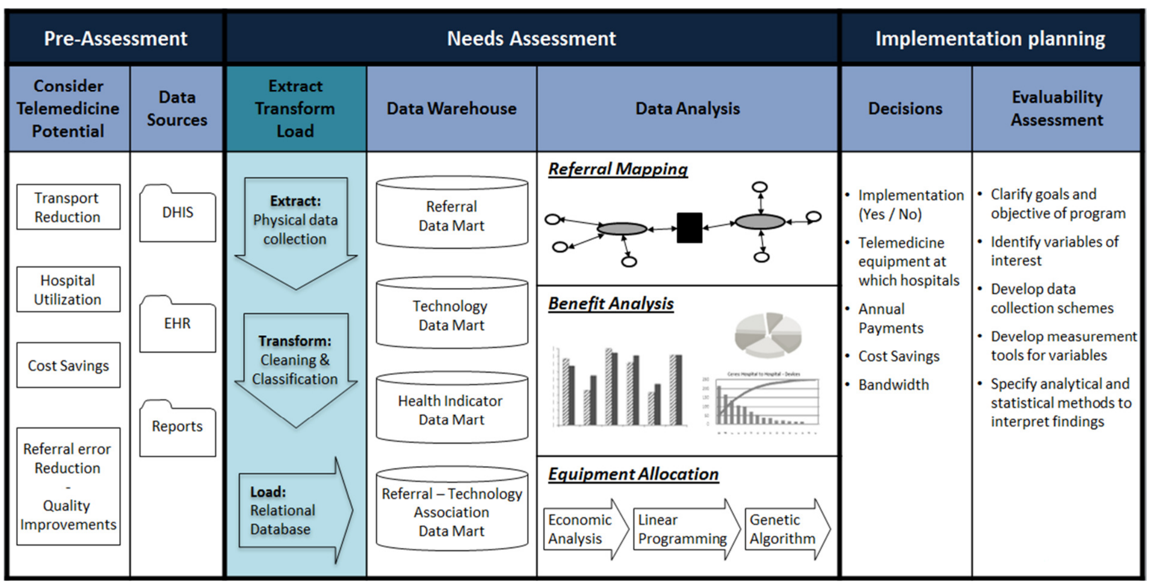

Figure 11: The DSS - Extract, Transform, Load

5.1.1. Electronic Health Records

The electronic health record initiative, driven by the National Department of Health, has led to a growing number of commercial applications implemented in South African Hospitals. According to Mars and Seebregts (2008), EHR implementations are driven by provincial departments, with the result that a variety of systems can be found in the different provinces. The Eastern Cape Department of Health has implemented UniCare™ systems in several hospitals. This system was jointly developed by Ethniks Systems and Delta 9™ who have since joined forces (Ethniks, 2011). Although UniCare™ is the correct name of the system, it is often referred to as the Delta 9 system.

According to Ethniks (2011), the key objective of the UniCare™ system is to aid in effective hospital management. The system is especially designed to help in the following hospital processes:

- Admissions
- Pre-admissions
- Billing
- Credit control
- Reporting
- Dispensing
- Stock control
- Retail interface
- Electronic claim submissions (EDI)
- Management information

As part of admission management, patient data are entered into the system. Patient data includes personal details of the patients, demographic information and medical histories. Dates of admissions and discharges are also entered into the system, as well as the reason for discharge. The UniCare™ system has therefore been identified as a source from which referral information can be extracted for the decision support system.

Extract

Collecting data from EHRs requires extensive consideration of ethical guidelines and standards for patient privacy protection. Standards may vary in different countries. In South Africa it is required that research studies have ethical clearance from a health ethics committee, registered with the South African Department of Health's National Health Research Ethics Council (NHREC). Furthermore, approval from the Department of Health is a prerequisite, prior to collecting data from hospital information systems.

Ethical considerations and approval

The health system engineering group, within the Department of Industrial Engineering, compiled a code of conduct for their own research, see Appendix A. This study adheres to these requirements, and is conducted according to accepted and applicable National and International ethical guidelines and principles, including those of the International Declaration of Helsinki, October 2008.

Ethical approval was granted by the Health Research Ethics committee of Stellenbosch University (SU) who is registered with the NHREC. The Eastern Cape Department of Health approved this study on condition that the ethical conduct, as stipulated in the research proposal submitted to them and the ethical approval document from the SU health research committee, is complied with.

The manner in which data was collected was so as to protect patient or participant confidentiality. Electronic records were extracted without mention of the names, addresses or file numbers of the patients. Identification numbers were used to extract patient data from more than one hospital. These identification numbers were transformed in the DSS database to a study code. Identification numbers that were linked to the study code were stored in a separate, protected database, which only senior members of the research team had access to. Both databases are password protected, and stored in a secure storage space on the University network. All data will be deleted, upon completion of the study.

Data Specifications

The South African National Strategy for EHRs made provision for the discharge status of each patient, released from a hospital, to be recorded in the EHRs. The UniCare™ system differentiates between four different types of patient discharges. One of these discharge types is referrals. For each patient discharge, the following information is captured:

- Reason for referral (free-text)
- ICD-10 codes (optional)
- Speciality of diagnosis (free-text)
- Date and time of hospital admission
- Date and time of discharge (referral)
- Name of hospital referred to (free-text)

Referral discharge reports offer information which is valuable to telemedicine assessment, because it records information of referrals that might not have been necessary, if telemedicine were an option. All the referral discharge reports for 2010 from all the Eastern Cape public hospitals, using the

UniCare™ system, were extracted to give an estimate of possible telemedicine referrals for a time period. The names of the hospitals, from which data were extracted, are listed in Table 10 below.

Table 10: Hospital Data in the Eastern Cape Data Set

Hospital Name	*Type*	*District*	*Location*	*Referral Entries*
Cecilia Makiwane Hospital	District	Amathole	Mdantsane	24
Dora Nginza	District	P.E. Metro	Algoa Park	356
Frere Hospital	District	Amathole	East London	2
Settlers Hospital	District	Makana	Grahamstown	4
St Elizabeth's Mission Hospital	Regional	Oliver Tambo	Lusikisiki	379
St Patrick's Hospital	District	Oliver Tambo	Bizana	79
Nelson Mandela Academic Hospital	Central	Oliver Tambo	Mthatha	1846
Total				**2690**

Records of patients that were discharged and referred to another hospital were obtained from the information systems. The inclusion criteria are all patients that were referred from one hospital to another within the sampled year, and who are therefore, potential telemedicine patients. The exclusion criteria were all patients who were not referred, or who visited the sampled hospital and were therefore not potential telemedicine patients.

Data files

Data were extracted by Ethics from the UniCare™ system into an electronic format that could be imported into the data warehouse. Data files are in CSV format that is compatible with Microsoft Excel, so that the data can be transformed using Microsoft Excel.

Transform

Data extracted from UniCare™ are in the form that the hospital administrators entered it into the system. The data have thus, not been cleaned in any way. Basic cleaning of the data, to eliminate ambiguity and incomplete or incorrect entries, is necessary before more advanced transformation can be done. Furthermore, to protect the anonymity of patients, data that could reveal the identity of patients are removed. It is of the utmost importance to transform the data in such a way that the study complies with ethical guidelines, as was adhered to in the extraction process.

Since referral data in the EHRs were not originally captured for telemedicine assessments, the data are not suitable for analysis in the original extracted form. Currently the standards for EHRs in South Africa allow discharge reports to contain a large amount of free-text. The intuitive, unstructured and uncategorised nature of free-text entries restricts data analysis.

Subsequently, data extracted from UniCare™ contains large amounts of free-text. The following fields in the discharge reports are free-text fields:

- Reason for referral
- ICD-10 codes (optional)
- Name of hospital referred to

The decision support system compiles reports, using quantitative analysis of data. The transformation from free-text to standard fields and codes is essential to enable quantitative data analysis. Therefore, free-text fields have to be transformed and linked to standard lists that would promote consistency in the analysis.

Transforming 'reason of referral' and ICD-10 free-text fields

The 'reason for referral' field contains a free-text description of the assumed diagnosis of the patient. Ideally, ICD-10 codes should be used to record the reason for referral. Since entering an ICD-10 code requires extra effort from the administrator, for the majority of referrals, free-text is used. ICD-10 codes are only required for medical aid patients. In the public health sector, patients with medical aid are in the minority. The 'reason for referral' field is therefore, the only available referral diagnosis for the majority of the recorded referrals.

It is not, however, ideal to convert a 'reason for referral' into an ICD-10 code without access to the patient file. Nevertheless, a person with knowledge of the healthcare environment could convert free-text descriptions into ICD-10 codes with relative accuracy. ICD-10 codes are obtainable from standard lists, made available by the World Health Organisation. During transformation the 'reason for referral' and ICD-10 codes, listed in the discharge reports, were converted to generic ICD-10 codes using an web-based application made freely available for this purpose by the World Health Organisation (2011).

Data transformation was done in Microsoft Excel, using the 'replace', 'remove duplicates', 'sort', and 'lookup' functions. After transformation was completed, the data set no longer contained descriptions of diagnoses, but only ICD-10 codes indicating the diagnosis for which the patient was referred.

Transforming hospital names

The names of hospitals, to which patients were referred, as recorded in the discharge report, were transformed into a standard list of hospital names. Spelling mistakes and incorrect discharge entries were corrected, using the 'replace', 'remove duplicates' and 'sort' functions of Microsoft Excel. Of the 2690 discharge entries included in the data set, 218 entries could not be transformed into hospital names, due to data capturing errors. Thus 8% of entries were not suitable for analysis after transformation and were deleted from the data set.

Load

Data were stored after the extraction and transformation of the data. Microsoft Excel was used as data warehouse software. Data were loaded into a worksheet that was created with the sole purpose of storing the transformed data. In section 5.2 the data warehouse of the decision support system is explained with reference to where and how the data were stored once the extraction, transformation and loading procedures were completed.

5.1.2. District Health Information Systems (DHIS) and reports

Telemedicine could possibly improve indicators of district health, such as hospital utilisation, patient referral transport and health expenditure. The DHIS captures data to assess these indicators. The estimated number of telemedicine referrals was used to determine the effect that telemedicine has on district health indicators. To assess this, district health data were used to assess the effect of telemedicine on a district.

Extract

DHIS are more established in South Africa than EHRs. The data from the district health information system were specifically collected and analysed to assess health indicators of hospitals. The indicators, necessary for the decision support system, are similar to those analysed for district barometers. The data collection process for indicators from DHIS is therefore, less complex than the processes to obtain data from EHRs.

Ethical considerations and approval

Health indicator data does not contain patient specific data. Ethical considerations are therefore, not a concern in the extraction of health indicator data. Although it is not a requirement, health indicator data were requested with EHR data, and were therefore under the same ethical clearance.

Data specifications

Health indicator data were extracted for the same hospitals and time period as the EHR data (2010). Published reports, containing already analysed indicators for the above mentioned hospitals, were also collected for consistency. The following items were extracted:

- Hospital utilisation
- Hospital expenditure
- Hospital patient day equivalent (PDE)
- Patient transfer costs
- Hospital number of bed
- Hospital average length of stay

Data files

Health indicators data were not only extracted from the DHIS; EHRs and internet sources were also used to populate the Health Indicators Data Mart. All data were extracted as Microsoft Excel files, to ensure compatibility during the transformation process.

Transformation and Loading

Little transformation was necessary to prepare the data for analysis, since data to analyse indicators, were already cleaned and analysed to some extent. It was therefore, feasible to load the data into the warehouse, using Microsoft Excel, after minimal transformation.

5.2. Data Warehouse

The data warehouse comprises of four data marts, namely the *Referrals Data Mart, Technology Data Mart, Health Indicator Data Mart and Referral-Technology Association Data Mart* (Figure 12). Information stored in these data marts is relevant for telemedicine needs assessments and is stored in such a way that the data can be analysed effectively for decision making.

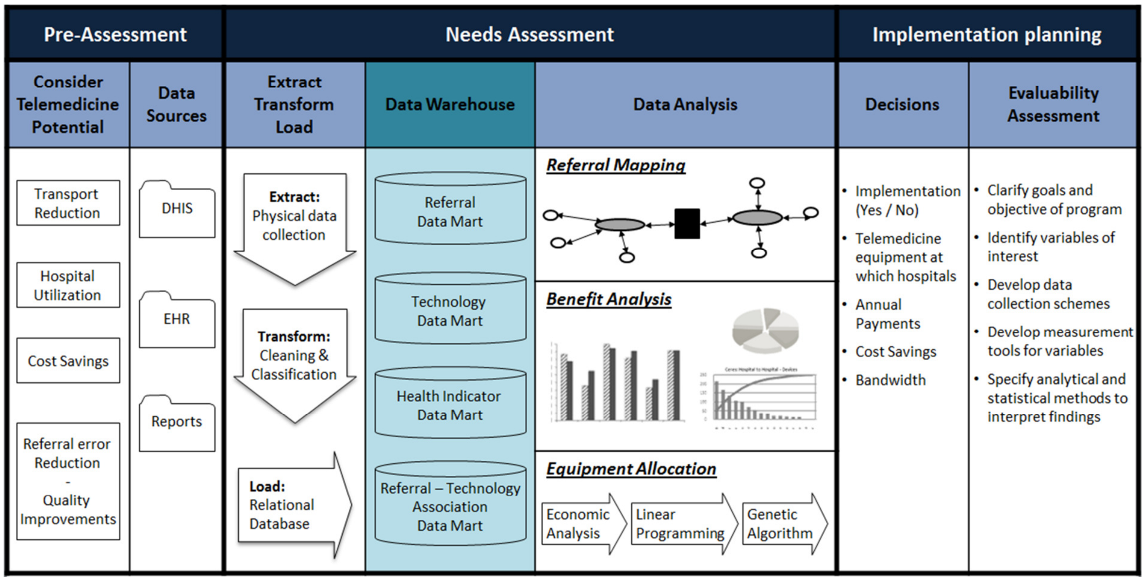

Figure 12: The DSS - Data Warehouse

5.2.1. Referrals Data Mart

The referrals data mart is populated using data from the EHR discharge reports. The 'reason for referral', discharge dates and hospital names are the data entities that are extracted, transformed into standard codes and loaded into the referrals data mart of the database, as is shown in Figure 13.

Hosp	Cat	Area(Suburb)	Gender	DOB	Age	Language	Referred To (Cleaned)	ADMITTED	Discharged	Recorded ICD	Dpt	Diagnosis	ICD from Diagnosis
StElizabeth							NELSON MANDELA ACADEMIC I	02-03-2010	03-03-2010		SURGICAL	CELL CARCINOMA	C34.9
StElizabeth							NELSON MANDELA ACADEMIC I	07-01-2010	28-01-2010		SURGICAL	POST TRAUMATIC HEADACHE	G44.3
StElizabeth							NELSON MANDELA ACADEMIC I	26-01-2010	27-01-2010	C41.1	SURGICAL	FRACTURE MANDIBLE	S02.6
StElizabeth							BEDFORD ORTHOPAEDIC HOSP	05-01-2010	06-01-2010		MEDICAL	FRACTURE FOOT	S92.9
StElizabeth							NELSON MANDELA ACADEMIC I	13-01-2010	14-01-2010		MEDICAL	HAEMATOMA	O71.7
StElizabeth							NELSON MANDELA ACADEMIC I	03-03-2010	03-03-2010		MEDICAL	POLYCYSTIC OVARY SYNDROME	E28.2
StElizabeth							NELSON MANDELA ACADEMIC I	08-01-2010	08-01-2010		MEDICAL	HEAD INJURY	S09.9
StElizabeth							NELSON MANDELA ACADEMIC I	12-04-2010	13-04-2010		SURGICAL	WRONG ENTRY	
StElizabeth							UMTHATHA GENERAL HOSPITA	12-01-2010	13-01-2010		SURGICAL	FRACTURE MANDIBLE	S02.6
StElizabeth							BEDFORD ORTHOPAEDIC HOSP	08-11-2010	09-11-2010		MEDICAL	ARTHRITIS SEPTIC	M00.9
StElizabeth							NELSON MANDELA ACADEMIC I	13-01-2010	13-01-2010	K45	PAEDIATRIC	FOREIGN BODY IN ABDOMINAL	Y61
StElizabeth							UMTHATHA GENERAL HOSPITA	15-01-2010	19-01-2010		SURGICAL		
StElizabeth							UMTHATHA GENERAL HOSPITA	18-01-2010	19-01-2010		MEDICAL	ACUTE ABDOMEN	R10.0

Figure 13: Eastern Cape Referral Data

5.2.2. Technology Data Mart

The technology data mart is a repository of medical equipment and subcomponents that can potentially structure a telemedicine workstation. Technology data requirements and equipment prices are included in this data mart. The data in Table 11 are estimations for DSS demonstration purposes and should not be considered as accurate. Decision makers need to populate and maintain this data mart with more specific telemedicine device prices and costs before accurate results can be obtained.

Table 11: Technology Referral Mart

Equipment	Data format	Bandwidth	Price (new)*
Basic workstation	Text	Low	R 50,000.00
Bronchoscope	Image	High	R 30,000.00
Camera	Image	Medium	R 10,000.00
CT Scan	Video	High	R 1,200,000.00
ECG	Text	Low	R 60,000.00
EEG Unit	Text	Low	R 40,000.00
Endoscope	Image	Medium	R 25,000.00
MRI	Video	High	R 3,000,000.00
Ophtalmoscope	Image	Medium	R 25,000.00
Otoscope	Image	Medium	R 5,000.00
Retinal Camera	Image	Medium	R 25,000.00
Spirometer	Text	Low	R 10,000.00
Stethoscope	Text	Low	R 3,000.00
Ultrasound	Video	High	R 50,000.00
X-ray (Digital)	Image	Medium	R 100,000.00

*** Prices are estimations from internet market research**

5.2.3. Health Indicator Data Mart

Data, revealing current trends of hospital indicators, are also stored in a separate data mart. The indicator data are used during analysis to calculate the extent to which telemedicine programs influence current trends in healthcare. Other indicators that are necessary for benefit analysis, such as hospital travel distances, are also updated in the indicator data mart after referral mapping. Table 12 shows indicators such as bed utilisation, equivalent number of days that patients were admitted for and daily hospital costs, per patient, for a number of Eastern Cape hospitals.

Table 12: Eastern Cape Health Indicator Data

Hospitals	Beds	Bed Utilisation	In Patient Days	Hospital Daily Cost/Patient
Cecilia Makiwane	829	50%	151326	R 855.00
Dora Nginza	680	78%	190897	R 700.00
Frere	755	87%	239957	R 754.00
Frontier	266	68%	65848	R 652.00
Livingstone	477	98%	170851	R 839.00
PE Provincial	282	59%	60341	R 945.00
Settlers	196	50%	35606	R 586.00
St Elizabeth's	300	65%	70774	R 535.00
St Patrick's	167	61%	36335	R 488.00
Uitenhage	258	70%	66174	R 620.00
Nelson Mandela Academic	698	53%	134196	R 1,034.00

5.2.4. Referral – Technology Association Data Mart

Referral data alone, as stored in the referrals data mart, are not sufficient to determine telemedicine referral potential. The decision support system needs to identify whether these referrals could have been done with telemedicine, if the necessary equipment and programs were in place. Thus, it is necessary to link potential telemedicine equipment to referrals that were made. The referral-technology association data mart is allocated to contain correlations between ICD-10 codes and telemedicine devices.

The novelty of using EHR discharge data to determine the potential for implementing telemedicine programs, calls for a method to link telemedicine referrals to diagnostic codes in discharge reports. The lack of standardisation that links ICD diagnoses to procedures, or hospital services, further strengthens the need for such a study.

Critics could argue that telemedicine is a broad term used for various applications, and it is thus, not possible to make an association between telemedicine and diagnoses. Or that ICD lists, as well as telemedicine technologies, are constantly changing. A counterargument could take the form of a quote from Major Greenwood, who argued that: “The scientific purist, who will wait for medical statistics until they are nosologically exact, is no wiser than Horace’s rustic waiting for the river to flow away” (Greenwood, 1948).

The purpose of this study is to develop a system that can provide support for telemedicine implementation decision makers. For management decision making, it is not necessary to have perfect accuracy in determining which referrals could have been supported with telemedicine. An in-depth association analysis is therefore, beyond the scope of this thesis. Nevertheless, such an analysis, leading to more accurate associations, would improve the accuracy of the developed decision support system. It is therefore recommended for future research.

Association analysis from National Hospital Discharge Survey data

Initially, the association between diagnoses and possible telemedicine referrals were investigated, using statistical analysis of National Hospital Discharge Survey (NHDS) data sets from the USA, described in Chapter 4. Unfortunately, data from the NHDS were not suited for diagnosis-procedure association analysis, which resulted in unfeasible results. The analysis of NHDS data is documented in Appendix B. The NHDS analysis and results are excluded from the analysis chapter, since results are not feasible for the decision support system. Nevertheless, this investigation was valuable to this study, and should be included in future research.

Association analysis using diagnostic procedures

An alternative analysis was done, using acquired knowledge of telemedicine capabilities, in conjunction with diagnostic procedures of ICD diagnosis. Figure 14 shows the table that was used to map medical equipment (relevant to telemedicine) that might be necessary for the diagnosis of each ICD-10 code. The PubMed search engine and A.D.A.M. Medical Encyclopaedia were used to research the procedures and equipment necessary to diagnose each ICD-10 code. Equipment that could be helpful for diagnosis was marked with a “1” next to the code. Results of the analysis should be considered as a very conservative estimation, since equipment was listed even if there was only a possibility that it is applicable, as opposed to it being a requirement.

ICD10	Diagnosis Description	NOT TELEMED	Basic	Camera	Bronchoscope	Stethoscope	ECG	EEG	Endoscope	Ultrasound	X-ray	CT Scan	MRI	Retinal Camera	Otoscope	Ophtalmoscope	Spirometer
A01.0	Typhoid fever		1														
A03.9	Shigellosis		1														
A06.4	Amoebic liver abscess		1							1		1					
A07.1	Giardiasis [lambliasis		1						1								
A08.3	Other viral enteritis		1														
A09	Other gastroenteritis a		1														
A09.9	Gastroenteritis and co		1														
A15.0	Tuberculosis of lung		1			1					1						
A15.1	Tuberculosis of lung		1			1					1						
A15.3	Tuberculosis of lung		1			1					1						
A15.5	Tuberculosis of larynx		1			1					1						
A15.6	Tuberculous pleurisy		1			1					1						
A15.9	Respiratory tuberculos		1			1					1						
A16.0	Tuberculosis of lung		1			1					1						

Figure 14: ICD-Technology Associations

The data stored in the data mart are in a format that is ready for data analysis. In the next section, the methods used to manipulate and analyse the data are described in order to assess the benefits of telemedicine implementation.

5.3. Data Analysis

The main purpose of the needs assessment part of the decision support system is to determine the potential benefits that the implementation of telemedicine could include for a network of hospitals. As discussed earlier, this has to be done with limited data sources. In the previous section, the data available for analysis were explained, as well as the format in which it is stored for analysis. In this section, the methodology used to analyse the data is discussed.

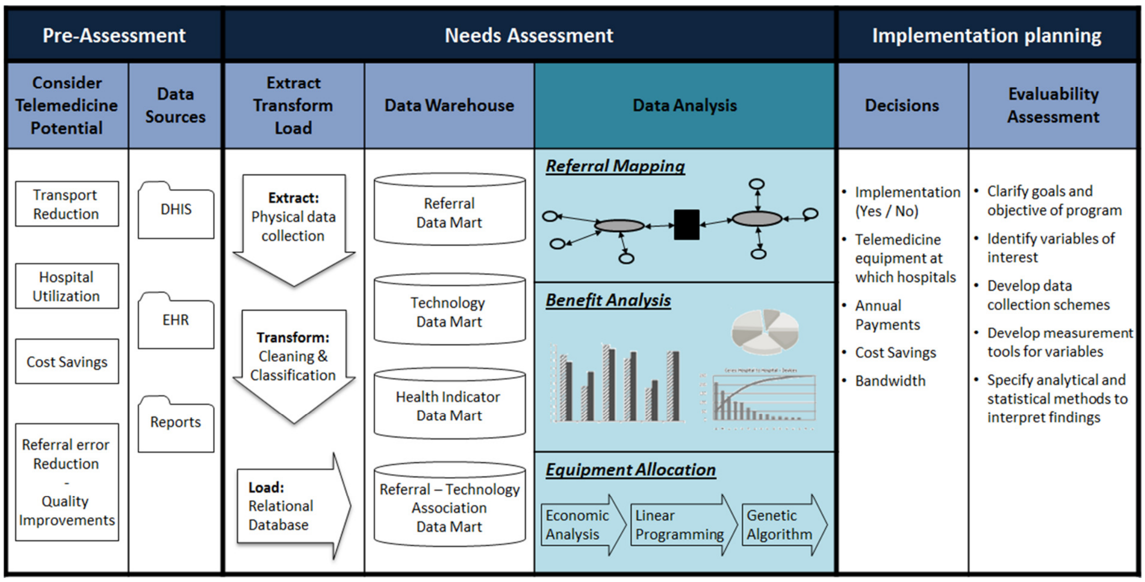

Figure 15: The DSS - Data Analysis

Data analysis, needed to determine telemedicine implementation benefits, is separated into three different sections (Figure 15). Firstly, referral patterns are mapped between the hospitals using EHR systems. This is done to identify the hospitals that refer, or receive, the most patients from other hospitals.

After analysing the referral patterns, data from the association data mart, referral mapping and indicator data mart are used to statistically estimate the potential benefits for telemedicine implementation. An equipment allocation algorithm concludes the analysis, by using the results from the benefit analysis and telemedicine implementation costs, in order to support financial implementation decisions. Table 13 shows the sequence in which the decision support system uses input data to analyse and the output that can be expected.

Table 13: Data Management and Analysis for a Telemedicine Needs Assessment

Input Data	Warehouse	Analyse	Output
Electronic Patient Records • Reason for referral • Name of hospital admitted • Name of hospital referred to • Length of stay	• Referral Data Mart	• Trends analysis • Referral pattern modelling • Calculations and comparisons between different hospitals	• Trend graphs • Travel distances • Referral patterns
Technology Data • Telemedicine systems • Peripheral devices • Technologies	• Technology Data Mart		
DHIS Data • Hospital utilisation • Patient day equivalent • Average length of stay • Transport distances	• Health Indicator Data Mart	• Transport reduction calculation • Hospital utilisation calculation • Reduced utilisation calculation	• Hospital utilisation reduction • Transport reduction • Referral cost savings
Financial data • Transport costs • Procedure costs • Hospital patient day cost	• Health Indicator Data Mart • Technology Data Mart	• Linear programming • Cost analysis • Genetic algorithm	• Equipment allocation results • Implementation recommendations

5.3.1. Referral Mapping

Decision makers need to have a system or network perspective, prior to assessing the benefits that telemedicine implementations could provide for a hospital or district. Telemedicine and referrals between hospitals influence not only one hospital, but an entire network of hospitals. It is thus, important that current referral patterns (without telemedicine) are assessed and compared to the alternative that telemedicine could provide.

In this section, data from the referral mart are analysed to map the referral patterns for 2010, between hospitals in the Eastern Cape Province (Figure 16). A variety of graphical illustrations is used to assist decision makers in obtaining a broad perspective on current referral trends in the province. Analysed referral patterns are subsequently used to calculate potential telemedicine referral patterns, discussed in the benefit analysis section.

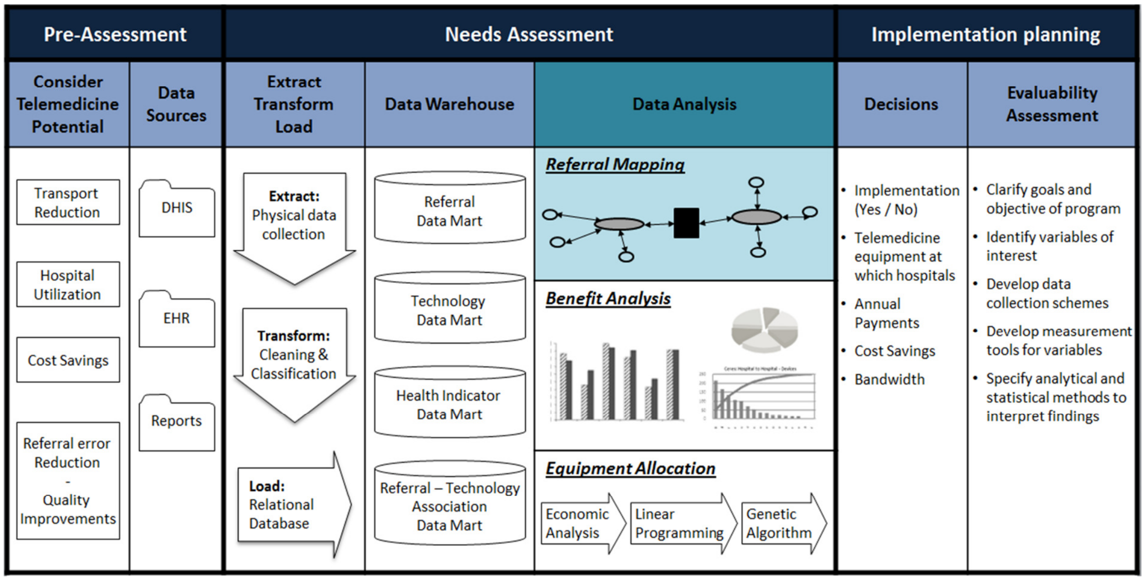

Figure 16: The DSS - Referral Mapping

5.3.1.1. Reason of Referral Pareto Analysis

According to the Pareto principle (also called the 20-80 rule), a limited number of tasks or costs (typically 20%), could accomplish a significant overall effect or benefit (typically 80%) (Allais, 1968). The referral ICD-10 codes follow the principle of Pareto. Figure 17 shows that for approximately 80% of the patients that were referred, 15% of the codes occurred.

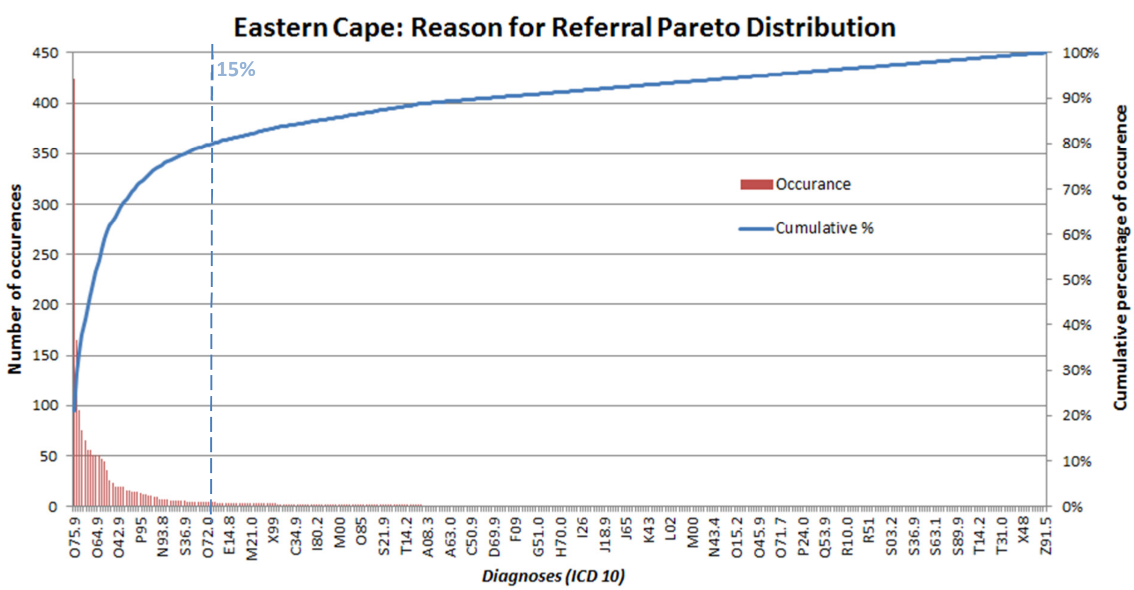

Figure 17: Pareto Graph for Referral Diagnoses - Eastern Cape 2010

Table 14 lists the top 10 leading diagnoses recorded as reason for referrals. The results from the Pareto analysis can be used to plan a telemedicine program to focus on the leading reasons for referral. The telemedicine program can therefore address 80% of the referrals by focussing on 15% of the diagnoses that are referred.

Table 14: Top 10 Reason for Referrals - Eastern Cape 2010

Rank	ICD	Description	Occurrence	%
1	O75.9	Complication of labour and delivery	480	24%
2	O14.0	Moderate pre-eclampsia	165	8%
3	S09.9	Unspecified injury of head	132	7%
4	O15.9	Eclampsia	95	5%
5	O75.7	Vaginal delivery following previous caesarean section	65	3%
6	C33.9	Malignant neoplasm of trachea	51	3%
7	O64.9	Obstructed labour due to malposition and malpresentation	51	3%
8	O60.1	Preterm spontaneous labour with preterm delivery	50	2%
9	O13	Gestational [pregnancy-induced] hypertension without significant proteinuria	47	2%
10	O82.9	Delivery by caesarean section	44	2%

5.3.1.2. Calculating the amount of referrals between hospitals

Discharge reports contain data that indicate the name of the hospital to which a patient was referred, as well as the name of the hospital from which a patient was referred. The Eastern Cape data set includes discharge reports from 7 hospitals using UniCare™. These 7 hospitals referred patients to a total of 46 hospitals during 2010. A Visual Basic Application was written in Microsoft Excel to count the number of referrals between the hospitals. The output of the application is a 'From-To' chart, indicating the number of referrals from the 7 hospitals where discharges were recorded, to the 46 hospitals, where patients were referred. A sample of the 'From-To' chart is shown in Table 15 below. As was described earlier, during the transformation process, 218 entries that did not contain hospital name information were deleted from the data set. Table 15 shows the totals after these incorrect entries were deleted from the data set.

Table 15: Eastern Cape Hospital Referrals From-To Chart (Sample)

		FROM:							
		Cecilia Makiwane	***Dora Nginza***	***Frere***	***Settlers***	***St Elizabeth's***	***St Patrick'***	***NMAH***	***Totals***
TO:	***All Saints***							145	**145**
	Bambisana					1		3	**4**
	Bedford					8	13	12	**33**
	…	..	…	…	…	…	…	…	**…**
	Tower	1							**1**
	Uitenhage		1						**1**
	Umthatha					6	3	42	**51**
	Zitulele							43	**43**
	Totals	**22**	**293**	**1**	**1**	**339**	**74**	**1742**	**2472**

The 'From-To' chart, illustrated in Table 15, can be used to illustrate the percentage of referrals from each hospital where discharge data were recorded. Figure 18 is an example of a pie graph that could be used to illustrate the distribution of where patients are referred to, from the hospitals included in the data set.

The purpose of this chapter is not to illustrate all the referral trends of each hospital in detail. Instead, it serves to illustrate the analysis and graphic tools that the decision support system could provide to assist decision makers in making informed decisions regarding, the implementation of telemedicine systems. The decision support system could draw similar pie charts for all the hospitals for which referral data are available. Figure 18 shows the referrals from St Elizabeth's Hospital to other hospitals.

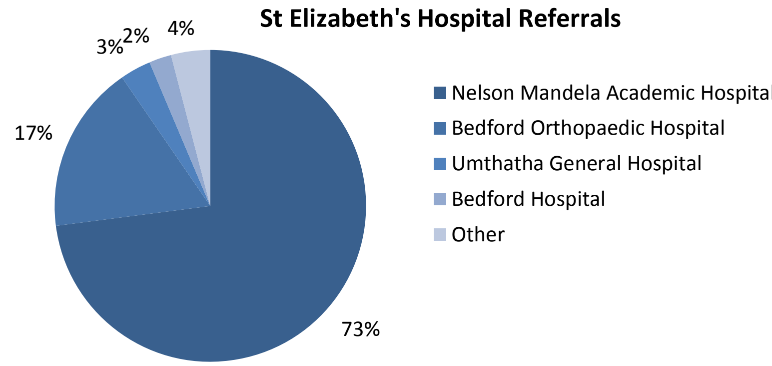

Figure 18: Referral Distribution for St Elizabeth's Hospital in 2010

In this graph it is clear that the majority of the 2010 referrals from St Elizabeth's Hospital went to Nelson Mandela Academic Hospital, followed by a smaller percentage to Bedford Orthopaedic Hospital and an even smaller percentage to Umthatha General Hospital. It is interesting to note that Nelson Mandela Academic Hospital, Bedford Orthopaedic Hospital and Umthatha General Hospital are all part of a hospital complex in Umthatha. The graph shows therefore, that only 6% of the referrals from St Elizabeth's Hospital were to hospitals outside of Umthatha.

The data set from the Eastern Cape Province includes only referral reports. The decision support system was therefore not able to analyse trends of admitted patients after being referred from other hospitals. Nevertheless, data from other provinces and EHR systems could contain data that could be analysed to assess admission trends of referred patients. This will be discussed in more detail in Chapter 7, where the decision support system is validated using data from the Western Cape Province, public health sector.

The ‘From-To’ chart in Table 15 is also illustrated graphically, as is shown in Figure 19, by mapping all the data available from all the referrals by the hospitals included in the data set. Hospitals, where referral data were available, are colour coded in the figure. Arrows between hospitals indicate the flow of patients between the various hospitals. A large amount of patient referrals are illustrated by a thicker line. The amount of patients referred, is also indicated on each referral arrow.

The referral map provides decision makers with a graphical illustration of referral patterns for a network of hospitals. Decision makers could use this map to identify the hospitals where alternative referral possibilities would most likely have a bigger effect. Data, illustrated in the referral map, are identical to that in the ‘From-To’ chart. Therefore, the map could be used as an illustrative tool, whereas the ‘From-To’ chart can be used to calculate indicators such as referral distances and costs.

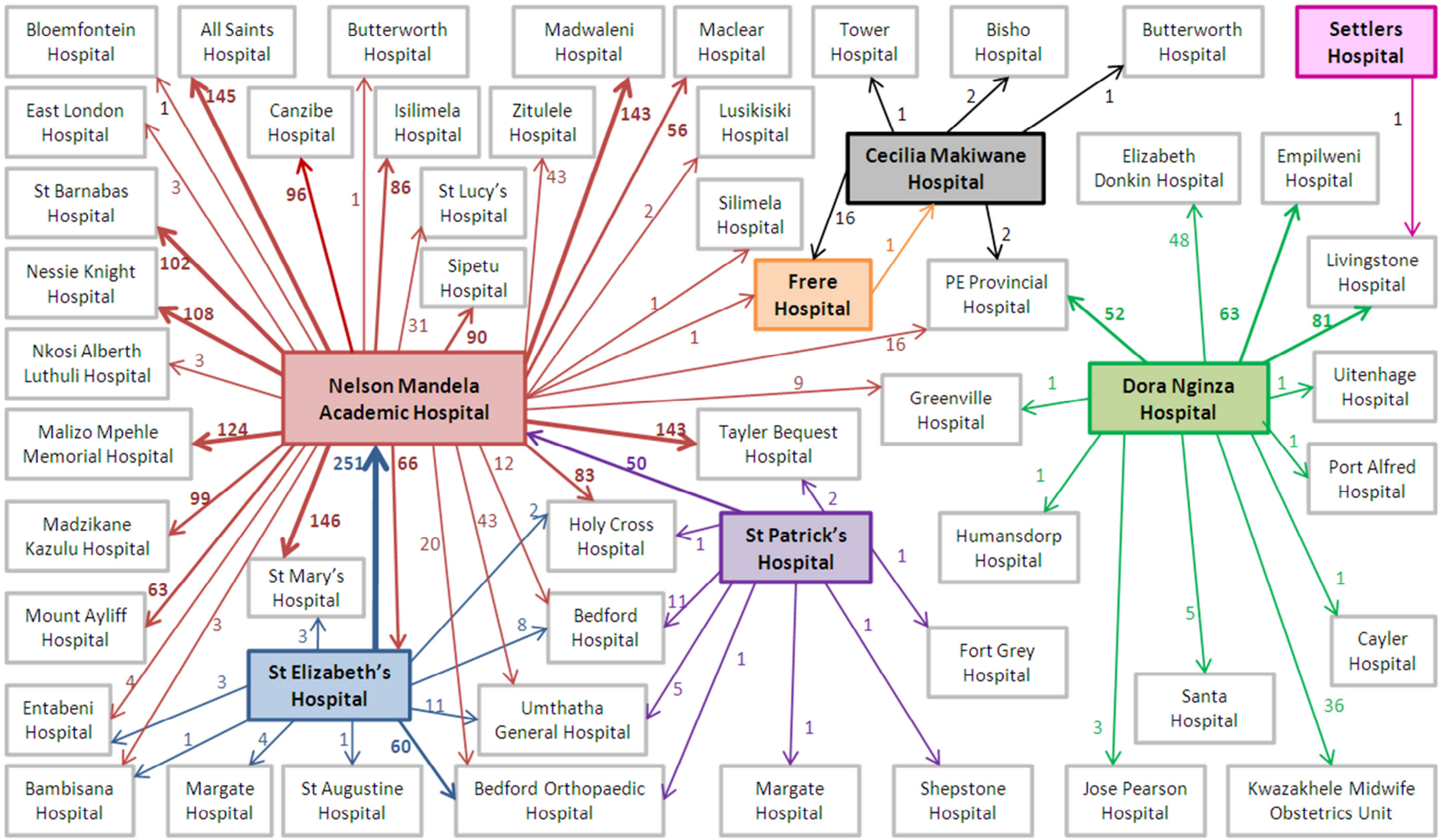

Figure 19: Referral Map for Eastern Cape Hospitals (Included in data set)

5.3.1.3. Calculating the distance between hospitals

Travel costs, related to hospital referrals, are widely considered to be the primary drawback of the hospital referral system. In regions where telemedicine is not available, transport costs are considered a necessary expense to deliver quality care. However, when considering telemedicine as a support system for referrals where transport is a factor, each referral that could be managed with telemedicine, would save on transport costs.

The first step in assessing the effect that telemedicine systems could have on transport costs is to calculate the distances involved when patients are referred. Garmin MapSource software was used to map likely referral routes and to determine the distances included in these routes, as shown in Figure 20. Garmin MapSource is a GPS computer application that can be used to plan routes for travel planning and analysis. Maps of South Africa, that include road maps and places of interest, were uploaded to the program. Hospital locations were then mapped and the routes between hospitals connected. The software automatically calculated the best route between these hospitals, with the minimisation of travel time between the hospitals taking preference over the shortest distance. Thus, the routes were primarily plotted to include freeways and national roads, where speed limits are higher, and traffic flow better managed.

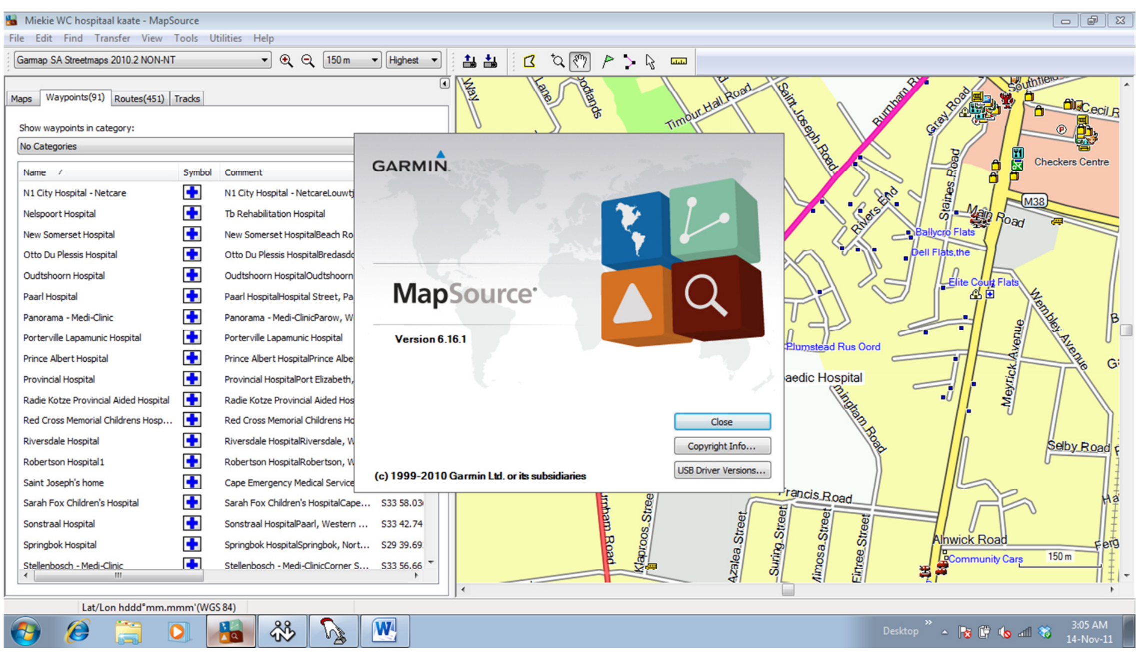

Figure 20: Screenshot of Garmin MapSource Software used to calculate referral distances

Figure 21 is a map of the Eastern Cape Province indicating the likely routes that were travelled to transport patients from the 7 hospitals, recorded in the data set, to other Eastern Cape hospitals. Different colours are used to illustrate the routes from each of the seven referral hospitals. This map could provide decision makers with an illustration on how the hospitals are connected through referrals, and how these referrals correspond to the distances travelled.

Figure 21: Likely patient transport routes for data set hospitals in the Eastern Cape

The route distances calculated by the Garmin MapSource software were recorded in a travel distance 'From-To' chart of which a sample is shown in Table 16. Travel distances were only recorded for hospitals where patients were referred in 2010. However, travel distances of all possible hospital travel distances in the Eastern Cape should be stored in the indicators data mart. This was not considered necessary for the development of the decision support system, but should be included in future work.

Table 16: A Sample of the From-To chart travel distances (in kilometres)

		FROM:						
		Cecilia Makiwane	***Dora Nginza***	***Frere***	***Settlers***	***St Elizabeth's***	***St Patrick's***	***NMAH***
TO:	***All Saints***							83.6
	Bambisana							127
	Bedford					504	602	376
	…	…	…	…	..	…	…	…
	PE Provincial	287	26.4					483
	Port Alfred		154					
	Sipetu							164
	St Augustine					323		

5.3.2. Benefit Analysis

The benefits of implementing telemedicine systems in a network of hospital are calculated in relation to the telemedicine potential that was identified in the pre-assessment phase of the decision support system. These benefits include transport reduction, hospital utilisation, cost savings and referral error reduction. Data from the data warehouse, as well as results from the referral mapping analysis, are used in the benefit analysis, as shown in Figure 22.

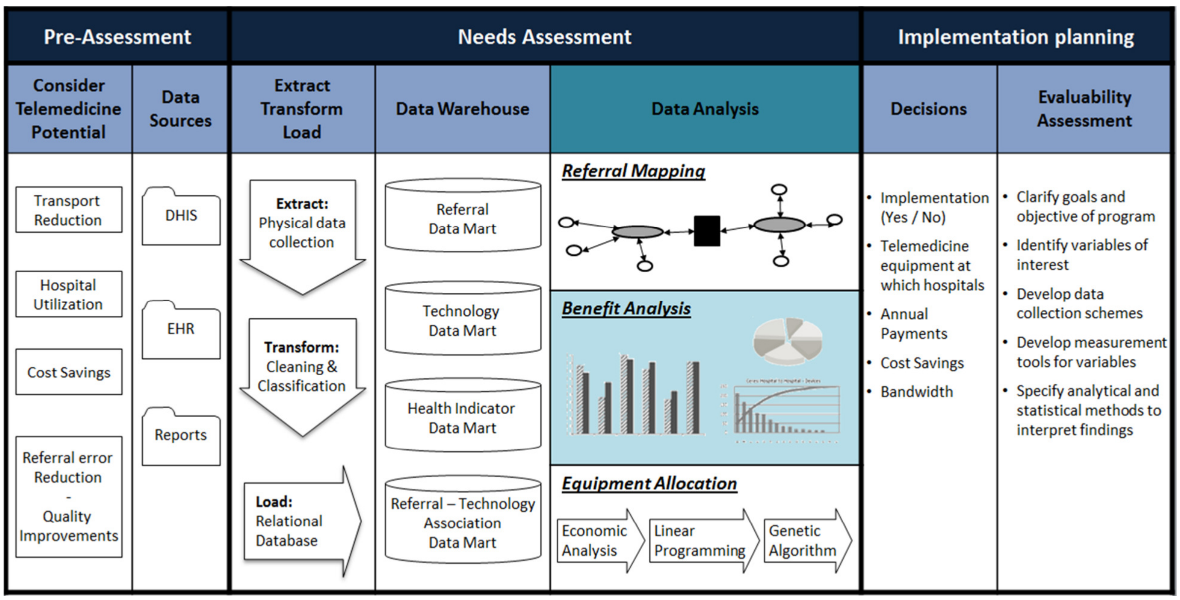

Figure 22: The DSS - Benefit Analysis

In this section, the potential of telemedicine to be used as a support to transfer referrals is analysed using hospital discharge data from hospitals, where telemedicine systems were not available. The data of referrals where asynchronous telemedicine systems would have had limited impact are excluded from the analysis. These data entries are:

- Referrals of patients in need of complicated surgeries
- Referrals of patients needing psychological treatment
- A percentage of referrals needing face-to-face consultations with specialists (in this case 30%)

It is likely that the referrals, of which the entries were excluded, could be synchronous telemedicine potential. Tele-robotic applications have been successful in assisting that complicated surgeries can be done over a distance. It is widely accepted that synchronous telemedicine is effective to facilitate long-distance face-to-face consultations, which also enables psychological treatment to be done with telemedicine. Nevertheless, as was previously discussed, due to current bandwidth restrictions in the South African public health sector, the scope of the decision support system is limited to asynchronous telemedicine. It is unlikely that telemedicine programs within this scope would be able to facilitate the referrals listed above. It is recommended that the exclusion criteria be reviewed if telemedicine programs are considered for regions where asynchronous telemedicine is feasible.

ICD-10 codes were used to identify patient referrals in need of surgical or psychological treatment. These entries were subsequently deleted from the analysis. The remaining data were used to calculate the number of referrals between hospitals. The 30% of the referrals, those requiring face-to-face consultations, were subtracted from the number of referrals calculated. The remaining number of referrals is considered to have the potential to be telemedicine referrals.

The available equipment for procedures is another factor that would significantly impact the potential of telemedicine to refer a patient. For example, some diagnoses require MRI scans, but an MRI machine is too expensive to be part of the equipment at district hospitals. It is therefore common practice for patients to be referred to tertiary hospitals for specialised procedures, such as MRI or CT scans. In this section, the influence of equipment is included in the percentage limitation of the analysis. This is done to support an implementation project where decision makers are not concerned with equipment but rather on implementing a general telemedicine workstation that includes basic telemedicine functionalities. The equipment allocation algorithm will focus on economic feasibility and choosing equipment according for cost-effective solutions.

Telemedicine only a potential substitute for lower-level to higher-level care

The Primary Health Care model is structured in such a way that generalised health services are able to be delivered in lower-level care facilities. It may be assumed that referrals from higher-level to lower-level care hospitals are not for diagnostic purposes, but for the general treatment of patients. It is therefore, improbable that telemedicine could prevent the transport of patients who were referred from higher-level to lower-level care hospitals.

It is likely that patients, referred from lower-level to higher-level care hospitals, were referred back to the lower-level care hospital after they had specialised treatment. It can thus be assumed that successful telemedicine referrals could prevent patient transfers to and from higher-level care hospitals. Ideally, the decision support system should not analyse data of referrals from higher-level to lower-level care hospitals, but should rather calculate the transport costs so that transport to and from the lower-level care hospital is included.

Using higher-level to lower-level referral data intelligently

Unfortunately the data sample from the Eastern Cape is limited. In addition, the exclusion of all referrals from higher-level to lower-level hospitals would cause a large reduction in data entries. Therefore, to demonstrate the analysis of Eastern Cape data, referral data from higher-level hospitals are also used. This is done under the assumption that patients were referred back to their local hospitals, the results therefore reflect on the referral that was done from the lower-level to the higher-level care hospital. Transport calculations include the referral to higher-level hospitals and the return from these hospitals.

5.3.2.1. Potential telemedicine referrals calculation

The small number of hospitals, as well as the number of unusable data entries in the Eastern Cape data set, limits the analysis that could be done for this province. The following aspects were considered to have had an influence on the data analysis: After the data were cleaned, only 1934 of the original 2690 referrals proved suitable for benefit analysis and 28% of the referral records were lost, due to inadequate data capturing. Figure 23 below, shows the amount of referrals that had the potential to be telemedicine referrals as well as the amount of referrals that were unsuitable. The 5 hospitals, listed on the horizontal axis of the graph, are the hospitals included in the data set that referred patients to other hospitals. The number of patients referred from these hospitals, is shown on the vertical axis.

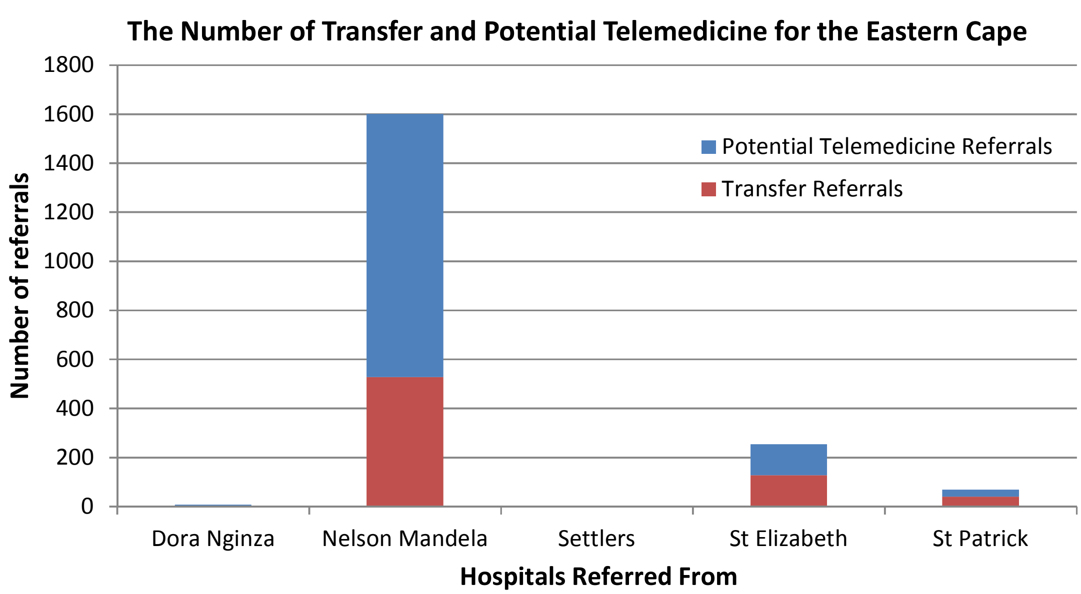

Figure 23: Trend Graph of Hospital Referrals and Potential Telemedicine Referrals

There is a significant difference in the referrals between Nelson Mandela Academic Hospital and the other hospitals. It should be noted that Nelson Mandela Academic Hospital is a tertiary and academic hospital (as the name suggests). Thus, it is expected that this hospital would receive a large number of referrals from other hospitals and subsequently refer patients back to their local hospitals. As discussed, although referrals from higher-level to lower-level care hospitals are not considered to be telemedicine potential, the data were analysed with the assumption that it could have been telemedicine cases when they were referred to Nelson Mandela Hospital. The number of referrals from the other four hospitals, especially Dora Nginza Hospital (regional) and Settlers Hospital (district) are much lower than would be expected. This is, in all likelihood, due to inadequate discharge report data entries at the hospitals.

This type of graph, illustrated with Eastern Cape data, can be used by decision makers to identify hospitals where telemedicine programs would have the most potential to be beneficial. Hospitals, with large numbers of referrals, many of which could have been telemedicine referrals, have much more potential for telemedicine programs than those showing small numbers of referrals. The graph in Figure 23 shows that Nelson Mandela Academic Hospital has much more potential for the successful implementation of a telemedicine program, than the other hospitals listed. It should however be noted, that due to it being a tertiary hospital, the telemedicine workstation would most likely be focused at receiving electronic data, thus not needing data capturing equipment such as cameras or digital x-ray machines.

5.3.2.2. Transport Reduction

The most notable benefit of telemedicine is the reduction in transport. In the previous analysis, the number of potential telemedicine referrals gave an indication of the benefits of implementing telemedicine. The potential referral trends are used together with travel distances, calculated in the referral mapping analysis, to measure the reduction in transport that would have been possible in the given scenario. The results of the potential travel distance that can be reduced by using telemedicine, as well as the transport necessary with telemedicine, are shown in Figure 24.

The distance, in multiples of 1000 kilometres, are shown on the vertical access, with the listed hospitals on the horizontal access. The total transport reduction for the 5 hospitals equals 395,441km. When comparing Figure 24 with Figure 23, similar trends in both transport and the number of referrals, can be seen. The minor differences between the trends are likely due to varying distances between hospitals.

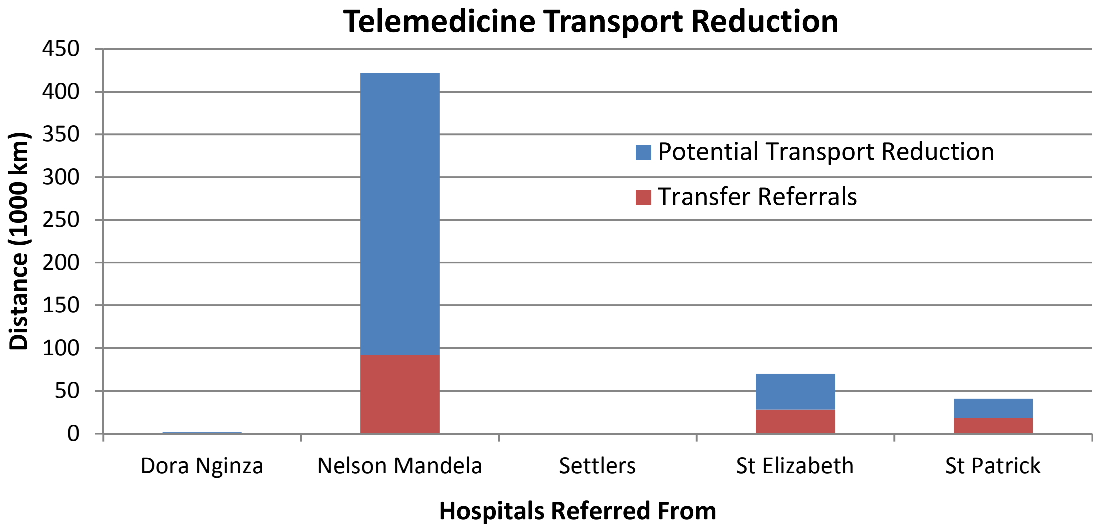

Figure 24: Trend Graph of Potential Travel Distance Reduction using Telemedicine

5.3.2.3. Hospital Utilisation

Hospital bed occupancy reflects on the quality of service delivery at that hospital. Bed utilisation rate (BUR) is an indicator that is calculated to assess the occupancy as a percentage. According to Eastern Cape Department of Health (2010), hospital utilisation is calculated by dividing the number of in-patient days by the number of usable bed days. The number of *in-patient days* is a measurement of the number of days spent at the facility for all admitted patients, over a period of time. The number of u*sable bed days* is a measurement used for the number of beds available in a facility over a period of time.

Another indicator that is associated with hospital utilisation is the average length of stay (ALOS) of a patient. Bed utilisation rate and average length of stay are used together to evaluate the performance of a hospital. A low ALOS is desired, indicating that patients are discharged regularly. High ALOS could indicate that there is a shortage of doctors to treat and discharge patients. However, an exceptionally low ALOS could be a sign of too many referrals, which is undesirable (Eastern Cape Department of Health, 2010).

The Primary Health Care model promotes hospitalisation at district hospital level, by adding value to higher bed utilisation rates at district level. Costs at district hospitals are lower than at higher-level care hospitals, so it is best to keep bed utilisation rates at higher-level care hospitals lower, if possible. However, there are less high-level than low-level care hospitals, making bed utilisation rates at these hospitals, generally higher.

Telemedicine keeps patients at lower-level care by reducing the need to transport and admit patients to higher-level care hospitals. It is therefore, expected that telemedicine would increase hospital utilisation rates at district hospitals, and decrease hospital utilisation rates at regional and tertiary hospitals.

The influence that potential telemedicine referrals could have had in 2010 can be analysed by calculating the equivalent in-patient days, in the 'referred from' hospital, as opposed to the 'referred to' hospital. This is done by multiplying the number of potential telemedicine referrals to the ALOS at both the hospitals 'referred from' and 'referred to'. The in-patient days are then subtracted from the 'referred to' hospitals and added to the 'referred from' hospitals. The analysis is concluded by recalculating the bed utilisation rate for all hospitals included in the data set.

5.3.2.4. Cost Savings

Potential transport reductions and hospitalisation in lower-level care hospitals promise cost savings. Transport cost savings are calculated by multiplying the total distance, reduced by the appropriate ambulance fees for patient transfer. Ambulance fees for the public sector were published in 2008 and 2009. In 2009, the cost for long distance patient transport was R14.10/km, R1.30/km more than in 2008. For this study it is assumed that the cost increased by the same margin from 2009 to 2010, making it R16.50/km for 2010.

It is assumed that not all patients that were referred used transport provided by the hospital. Furthermore, it is possible that more than one patient was referred in the same ambulance. For accurate cost saving results, a separate study should be done to determine how many ambulance trips are made with respect to the number of patients referred. The decision support system takes this into account by assuming that a percentage of the referrals were transported with ambulances, and calculating transport distances and costs accordingly. This percentage can be chosen by the decision maker. The total reduction in transport distance for the hospitals in data data set is 395,441km. The total cost savings, of cases, which would not have been necessary to travel, if telemedicine systems were implemented is estimated at R6, 524,776.50.

As was described earlier, telemedicine was considered for referrals from lower-level to higher-level care hospitals. Patient costs per day are generally lower in district hospitals than in regional and tertiary hospitals. The difference in cost between a higher-level care hospital (to which a patient was referred) and the lower-level care hospital (where a patient is staying, due to telemedicine) is multiplied by the equivalent in-patient days that were calculated in the bed utilisation analysis. In

Table 17, the potential cost savings were calculated. It should be noted that owing to limited data, only few results are shown for demonstration purposes.

Table 17: Hospitalisation cost savings for Eastern Cape Hospitals

		From:			
		Dora Nginza	***Settlers***	***St Elizabeth***	***St Patrick***
To:	***Frere***				
	Livingstone	R 778.40	R 1,651.20		
	Nelson Mandela Academic			R 312,972.80	R 84,572.80
	PE Provincial	R 2,744.00			
	St Patrick's				
	Totals	R 3,522.40	R 1,651.20	R 312,972.80	R 84,572.80

5.3.2.5. Quality Improvements

Ideally, the decision support system could calculate the number of referral errors that were made. A type 1 error, where a patient was referred, but the referral was not necessary, could be detected by matching admission and referral data for the same patient. In this analysis, the referral diagnosis and admission diagnosis are compared. If a patient was referred for diagnostic purposes, and the diagnosis at the 'referred to' hospital is the same as the diagnosis at the 'referred from' hospital, it is considered an unnecessary referral and thus a type 1 error.

Type 1 errors hold no medical risk for patients, but result in unnecessary cost. A type 2 error, where a referral was necessary but the patient was not referred, are not measured by the decision support system, as there are no EHR data available that could calculate such errors. The Eastern Cape data set did not include admission EHR data, therefore the quality improvements analysis could not be demonstrated for the Eastern Cape.

5.3.3. Equipment Allocation

The benefit analysis was developed to provide an overview of potential telemedicine benefits without considering the influence of specific telemedicine devices. The equipment allocation algorithm (Figure 25) was developed to guide decision makers towards choosing telemedicine devices according to a proven need and benefit. Economic analysis, linear programming and metaheuristics (genetic algorithm) are tools used by the system to calculate unique solutions for the decision makers' implementation profile. The system guides the decision makers to consider the entries included in the "decisions" section, in the implementation planning phase of the system.

The equipment allocation algorithm is subject to user input that specifies limitations regarding capital investment and bandwidth, as well as the available current digital equipment that could be used in the telemedicine program. The algorithm could therefore be executed repeatedly to explore proposed decisions for different capital investments and bandwidth limitations.

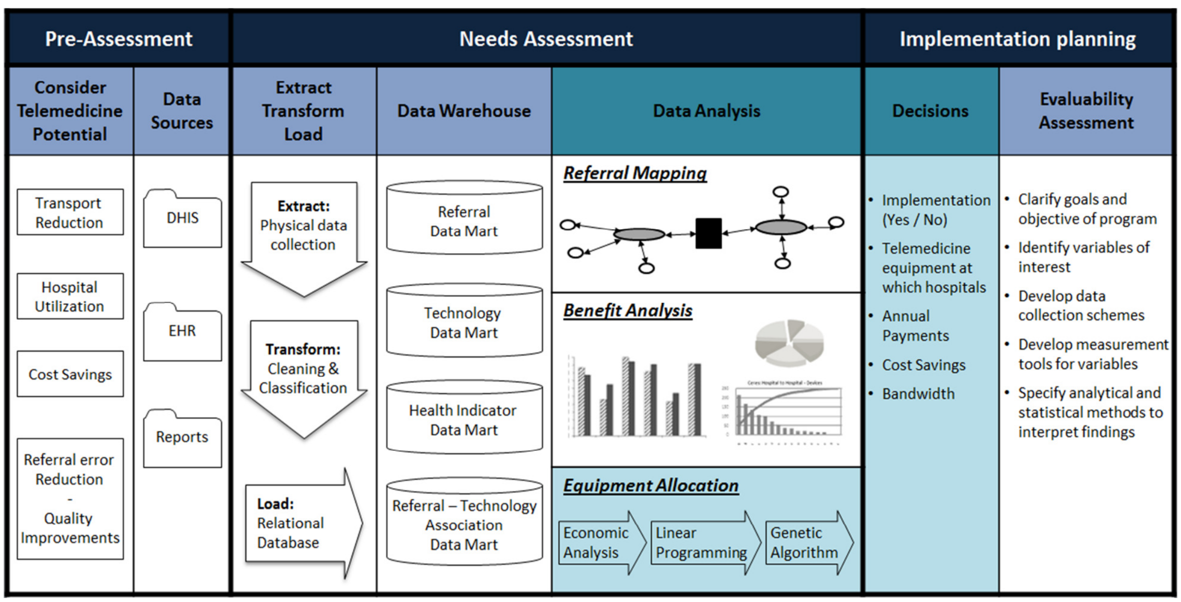

Figure 25: The DSS – Equipment Allocation Algorithm

5.3.3.1. Economic Analysis

As was discussed in chapter 3, literature reviews have shown that it is a complex procedure to accurately calculate telemedicine cost benefits in terms of referral cost between primary healthcare facilities. There are many factors that need to be taken into consideration, for example, transport cost per distance unit, the distance travelled for referrals, specialists' salaries, specialists' time spent on the case, hospitalisation costs, administration costs *et cetera*.

Saving costs is one of the most important measurable benefits when considering telemedicine implementation. Nevertheless, the purpose of the decision support system is not to provide results with perfect accuracy, but rather to determine, as accurately as possible, whether or not implementation would be beneficial. Hence the costs that are considered by the decision support system are categorised as follows: an annual payment cost to implement and maintain the equipment, annual transport savings and annual saving on hospitalisation.

Table 18, shows the prices, lifetime and data requirements of the devices as obtained from the technology data mart. The annual payments are calculated on the basis of the new price being divided into equal payments, for the lifetime of the device. The total annual cost is a sum of the running costs and the annual payments. All costs listed in this table are estimations for illustrative purposes. For accurate results, up-to-date figures need to be regularly entered on the technology data mart by the decision makers.

Table 18: Annual Payment Cost to Implement and Maintain Telemedicine Devices

Telemedicine	Data	Bandwidth	Lifetime	Price New *	Annual Payments	Running costs	Annual Cost
Basic workstation	Text	Low	5	R 50,000.00	R -12,522.82	R 2,000.00	R -14,522.82
Camera	Image	Medium	5	R 10,000.00	R -2,504.56	R 1,000.00	R -3,504.56
Bronchoscope	Image	High	5	R 30,000.00	R -7,513.69	R 1,000.00	R -8,513.69
Stethoscope	Text	Low	5	R 3,000.00	R -751.37	R 1,000.00	R -1,751.37
ECG	Text	Low	5	R 60,000.00	R -15,027.39	R 1,000.00	R -16,027.39
EEG Unit	Text	Low	5	R 40,000.00	R -10,018.26	R 1,000.00	R -11,018.26
Endoscope	Image	Medium	5	R 25,000.00	R -6,261.41	R 1,000.00	R -7,261.41
Ultrasound	Video	High	5	R 50,000.00	R -12,522.82	R 2,000.00	R -14,522.82
X-ray (Digital)	Image	Medium	10	R 100,000.00	R -25,045.65	R 5,000.00	R -30,045.65
CT Scan	Video	High	10	R 1,200,000.00	R -300,547.75	R 10,000.00	R -310,547.75
MRI	Video	High	10	R 3,000,000.00	R -751,369.36	R 15,000.00	R -766,369.36
Retinal Camera	Image	Medium	5	R 25,000.00	R -6,261.41	R 1,000.00	R -7,261.41
Otoscope	Image	Medium	5	R 5,000.00	R -1,252.28	R 1,000.00	R -2,252.28
Ophtalmoscope	Image	Medium	5	R 25,000.00	R -6,261.41	R 1,000.00	R -7,261.41
Spirometer	Text	Low	5	R 10,000.00	R -2,504.56	R 1,000.00	R -3,504.56

** Prices are estimations from internet market research*

Travel and hospitalisation costs are dependent on the number of potential telemedicine referrals. These costs are calculated in an algorithm that determines the number of potential telemedicine referrals.

5.3.3.2. Problem for Optimisation

The calculation of potential telemedicine implementation savings becomes complex when there is an increase in the variety of telemedicine equipment and the amount of hospitals under consideration. A combination of devices influences the type of diagnostics that can be done using telemedicine systems. Decisions regarding the nature of telemedicine devices to be implemented should therefore, be integrated with specific reference to the influence on expected implementation costs and savings.

Linear programming is a deterministic mathematical modelling technique that is used for the optimization of a linear objective function. The linear programming model yields an optimal solution, guided by the mathematical model. This model contains an objective function in terms of maximised profit that is subject to given constraints represented as linear equations (Winston & Goldberg, 2004). The selection of telemedicine devices at a number of hospitals, in order to acquire maximum cost benefits, is modelled as a mixed integer programming problem and is formulated as follows:

Indexes:

$i = 1,2,3 \ldots n$ Device index

$j = 1,2,3, \ldots m$ Hospitals referred from index
(Hospitals for which referral reports were collected)

$k = 1,2,3, \ldots p$ Hospitals referred to index

$l = 1,2,3, \ldots q$ Diagnosis (ICD10) index

Decision variable:

$$x_{i,j} = \begin{cases} 1, & Device\ i \text{ is chosen to be implemented at hospital } j \\ 0, & Device\ i \text{ is not chosen to be implemented at hospital } j \end{cases}$$

Input parameters (independent of decision variable):

$$y_{i,j} = \begin{cases} 1, & Device\ i \text{ is already available at hospital } j \text{ when decision is made} \\ 0, & Device\ i \text{ is not already available at hospital } j \text{ when decision is made} \end{cases}$$

$$d_{i,l} = \begin{cases} 1, & Device\ i \text{ is required to diagnose a case recorded as ICD10 code } l \\ 0, & Device\ i \text{ is not required to diagnose a case recorded as ICD10 code } l \end{cases}$$

$h_{j,k,l} =$ Amount of times that diagnosis l was referred from hospital j to hospital k

$c_i =$ Annual payments to implement and maintain device i

$b_{j,k} =$ Difference in overnight cost if a patient stayed in hospital j and not hospital k

$t_{j,k} =$ Transport distance to transfer a patient from hospital j to hospital k

$u =$ Patient transport cost per km

$w =$ Total annual payment cost available to implement devices

$$g_{j,k} = \begin{cases} 1, & \textit{Hospital } j \text{ is of the same or lower level than hospital } k \\ 0, & \textit{Hospital } j \text{ is higher referral level than hospital } k \end{cases}$$

Variable parameters (influenced by decision variable):

1) Devices i that will be available at hospital j are a combination of what was available prior to implementation and the devices that are chosen to be implemented.

$$V_{i,j}\langle x_{i,j} | y_{i,j} \rangle = \begin{cases} 1, & \textit{Device } i \text{ will be available after implementation at hospital } j \\ 0, & \textit{Device } i \text{ will not be available after implementation at hospital } j \end{cases}$$

$$V_{i,j} = x_{i,j} + y_{i,j} \qquad i = 1,2,3, \dots n; \; j = 1,2,3, \dots m$$

2) The annual payments are calculated for the devices chosen at each hospital.

$C_{i,j}\langle x_{i,j} | c_i \rangle =$ Annual payment costs to implement device i at hospital j

$$C_{i,j} = x_{i,j} * c_i \qquad i = 1,2,3, .. n; \; j = 1,2,3, \dots m$$

3) The number of referrals that has the potential to be telemedicine referrals, with the chosen devices is calculated for each hospital *j*. Each ICD-10 case requires a unique combination of devices for diagnosis. Thus, a referral recorded in 2010, $h_{j,k,l}$ is only a potential telemedicine referral if all the devices at that hospital are available after implementation as required to diagnose *l*:

$R_{j,k}\langle V_{i,j} | d_{i,l} | h_{j,k,l} | g_{j,k} \rangle =$ Amount of telemedicine referrals from hospital j to hospital k

$$R_{j,k} = \begin{cases} 0, & V_{i,j} < d_{i,l}, \\ \sum_{l=1}^{q} h_{j,k,l} \cdot g_{j,k}, & V_{i,j} \geq d_{i,l} \end{cases} \qquad \textit{for all } i = 1,2,3, .. n$$

4) The expected travel cost savings between hospital *j* and hospital *k* is calculated as a product between the number potential referrals determined in (3), the transport distances and the cost per km.

$$T_{j,k}\langle R_{j,k}|t_{j,k}|u\rangle = \text{Travel cost savings from hospital } j \text{ to hospital } k \text{ with proposed devices}$$

$$T_{j,k} \;=\; R_{j,k} * t_{j,k} * u \qquad j = 1,2,3,..m; \;\; k = 1,2,3, \dots p$$

5) The expected savings that is credited to patients staying in hospitals with a lower daily cost is calculated as a product between the numbers potential referrals determined in (3) and the difference in hospitalisation costs between hospital *j* and hospital *k*.

$$B_{j,k}\langle R_{j,k}|b_{j,k}\rangle = \text{Hospitalisation savings, patients staying at hospital } j \text{ and not hospital } k$$

$$B_{j,k} \;=\; R_{j,k} * b_{j,k} \qquad j = 1,2,3,..m; \;\; k = 1,2,3, \dots p$$

Objective Function:

The objective is to maximise the cost savings (z) that can be expected, when choosing telemedicine devices, to be implemented in the various referral hospitals. The annual payment costs, transport cost savings and hospitalisation savings, are all functions of the decision variable. These costs and savings are therefore variables determined by the decision variable. The objective function is to choose a decision variable that will maximise the sum of the savings with the subtracted cost.

$$\max z = -\sum_{i=1}^{n}\sum_{j=1}^{m} C_{i,j} + \sum_{j=1}^{m}\sum_{k=1}^{p} T_{j,k} + \sum_{j=1}^{m}\sum_{k=1}^{p} B_{j,k}$$

Subjected To:

1. A device should not be implemented if it is already available at that hospital.

$$x_{i,j} + y_{i,j} \;\leq 1 \qquad i = 1,2,3, \dots n; \; j = 1,2,3, \dots m$$

2. The total annual payment cost is constrained.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} C_{i,j} \;\leq \mathrm{w}$$

5.3.3.3. Genetic Algorithm

Linear programming could be used to determine the optimal solution to the problem (Winston & Goldberg, 2004). However, for large problems with many different combinations of devices for a number of hospitals, linear programming would require an enormous amount of computing power to search through such a large amount of basic feasible solutions.

In this study, 15 different telemedicine devices are considered. In order to determine the feasibility of each device, there are 2^{15} (32768) possible device combinations. The combination of selected devices influences the number of diagnoses that can be made. Thus, for each unique combination, the corresponding benefit has to be calculated. The number of referral entries in the data set determines the time required to calculate the benefit. The algorithm requires a minimum of 60 seconds to calculate the benefit from a few thousand referral entries. In this time, the algorithm test whether each referral entry could have been diagnosed using the combination of devices. Therefore it will take at least 32768 minutes, per hospital, to find the optimal solution. Therefore, if there are 10 hospitals in the data set, linear programming would require a minimum of 228 days to find the optimal solution. It is therefore, not practical to use linear programming, even for a small data set of 10 hospitals.

Heuristic methods are good alternatives to solving problems for which exhaustive search methods are impractical. A genetic algorithm is a search-heuristic (metaheuristic) that mimics evolution principles by iteratively searching for the best solution to the problem. The genetic algorithm was chosen and developed specifically for the decision support system in order to find a solution to the formulated problem. Microsoft Excel was chosen as a computing platform, together with Visual Basic as programming language. The genetic algorithm is integrated with the rest of the decision support system, to provide better usability.

Optimization problems require both variety and progression. Natural phenomena, therefore, provide valuable principles for algorithms. Genetic algorithms mimic the biological theory of evolution, where plant and animal species breed to form new offspring with unique features. With the birth of a new offspring, a new generation is formed. The concept of evolution is that new generations possess different characteristics from the previous generation, with the capability of improved performance in the new environment. The ‘survival of the fittest’ principle is applied and, with the passage of time, new generations become stronger by abandoning weaker individuals. Mutations, that occur randomly, reduce the possibility of inbreeding and lower the chances of the population being trapped at a local optimum (Hillier & Lieberman 2005).

Initiation

The initial population consists of a number of feasible trial solutions. Each individual solution in the population is created randomly and repaired to meet the set of constraints. For example, a population for the decision variable $x_{i,j}$ would consist of a number of trial solutions that are repaired to ensure that a device is not chosen for a hospital where such a device is already available.

A basic feasible solution consists of a number of genes (with a value of 0 or 1), indicating the chosen devices for the hospitals. The genes determine the strength of the individual. Genes, that form combinations of devices, resulting in high cost savings and low implementation costs, would have a high fitness (value of the objective function) outcome. The fitness is calculated for each feasible member of the initial population.

Solving highly constrained problems with genetic algorithms can be complex. A reason for this is that the generation of new offspring does not allow for constraint consistency through crossover. Hence, through crossover, the birth of a new offspring does not necessarily allow for a new feasible solution. The new offspring has to meet with the requirements of the constraints before it can be considered a possible solution (Aickelin & Dowsland, 2003). Nevertheless, the formulated problem is not highly constrained, making the genetic algorithm a practical approach.

Iterations

During the iteration phase, new basic feasible solutions are created using characteristics of good existing solutions. Parents (basic feasible solutions in the population) are randomly selected and compete in a tournament to mimic natural selection. Two parents with relatively high levels of fitness are chosen and paired with each other in a multiple crossover process to form an offspring (new basic feasible solution). Crossover points are chosen at random, so if two parents were to pair more than once, different offspring would be created. Offspring inherit a combination of both parents genes, therefore, a different combination of genes from the same parents would result in a different child. Mutation occurs on a random basis to increase the stochasticity of the algorithm, allowing a new offspring to be generated with unique genes that do not belong to either parent.

New offspring are subject to the set of constraints, ensuring that it is a feasible solution. If a new offspring is created that does not fit the criteria, making it unfeasible, the solution (offspring) is repaired in the same way that the individuals of the original population were repaired. The fitness of each offspring is calculated. As the process evolves, the fitness of the population increases. This process of creating new offspring continues until the termination criterion is met.

Termination rule

Since there are a large number of feasible solutions, the algorithm will continue to search through the solution space until a stopping condition is met, indicating that it has found a near optimum. There are a number of different termination rules that can be used, such as a fixed computation time, a fixed number of iterations or a fixed number of consecutive iterations without improvement. If the algorithm is executed for an adequate time period, the entire population will have the same fitness. If no new offspring are created during a number of iterations, it can be assumed that the algorithm has found a near optimum solution. Therefore, when reaching the termination criterion, the solution space would have converged upon the final solution.

The algorithm that was programmed for the decision support system is a classic generic algorithm and follows the same methods as described. The algorithm stops after a number of consecutive iterations do not improve. This number can be changed if more certainty is required that the algorithm has reached its best solution.

Demonstrating the algorithm

The decision support system is validated, in Chapter 7, using a large data set from the Western Cape. The validity of the algorithm, as well as decisions that can be supported using the algorithm, are discussed. The third phase of the decision support system is included in the system to aid decision makers in using the results from the analysis for implementation planning. As was previously mentioned, it is recommended that decision makers use the equipment allocation algorithm and implementation planning decisions simultaneously, to ensure that decisions are based on evidence.

Chapter 6

Implementation Planning

The decision support system provides quantitative results on the benefits of telemedicine. The needs assessment phase of the decision support system may have shown that telemedicine could have several benefits, but decisions have yet to be made, regarding the implementation. Telemedicine implementation planning is more complex than making a single decision on whether, or not, to implement it. Choosing the appropriate system for a specific region, while at the same time standardising systems for an entire district, could be a challenge.

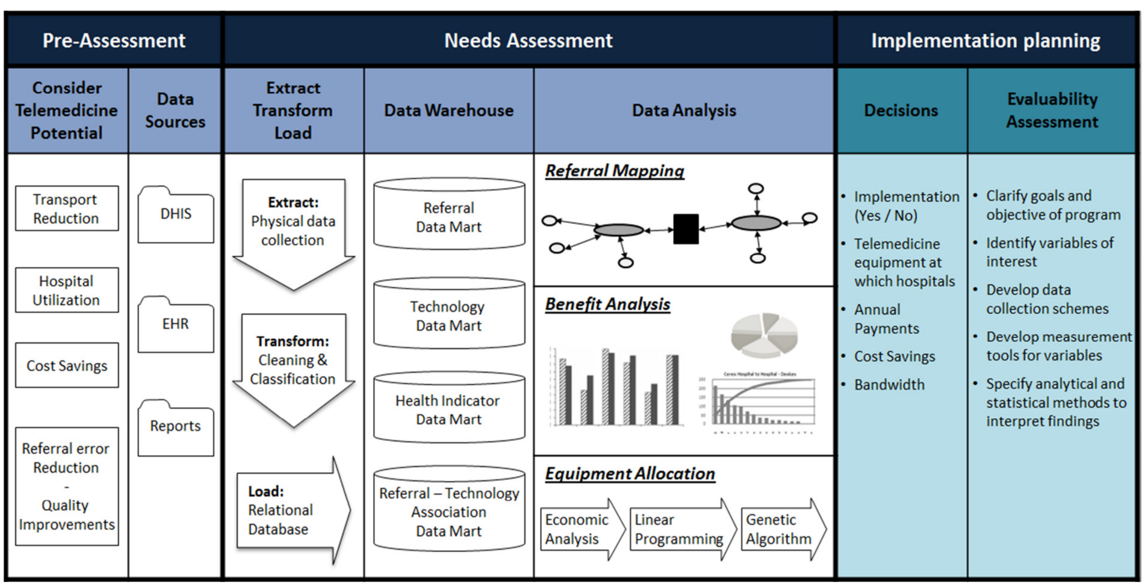

Figure 26: The DSS - Interpreting Results & Implementation Planning

6.1. Decision Making

The equipment allocation algorithm of the decision support system was designed to help decision makers with implementation decisions, as listed below. The algorithm can be repeated for different capital investments, bandwidth limitations and existing telemedicine equipment, thereby acquiring a profile for the specific network of hospitals. Answering the following questions would guide decision making for implementation:

- Should telemedicine be implemented or not?
- Which telemedicine equipment should be implemented at which hospitals?
- What are the annual payments required to implement the equipment?
- What is the net value of the cost savings?
- What are the bandwidth requirements for each hospital?

6.2. Evaluability Assessments

Once workstation specific decisions are made, the telemedicine program needs to be defined for future evaluation. Decision makers are recommended to use guidelines in the implementation planning phase of the DSS to assess how the program should be evaluated in the future.

6.2.1. Clarify Goals and Objectives of the Program

To implement a successful telemedicine program, the goals and objectives of the programs should be clearly defined. Results from the needs assessment could guide decision makers to set realistic goals. It is often wise to structure a program in such a way that opportunities for improvement remain. For example, when a telemedicine program is introduced for the first time at a facility, it might not be necessary to implement telemedicine in all the departments of the hospital. A department that is proven to have the most potential should be targeted first, after which, the program can be expanded into other departments.

6.2.2. Identify Variables of Interest

The continuous assessment of programs is essential for the promotion of on-going improvement. Variables of interest in program evaluation should be defined before the program is formally implemented. This would enable evaluation to take place from the start of the program. Evaluation could play an integral role in change management, ensuring that the program is driven towards tangible results. The variables of interest are likely to include the quantitative variables used in the needs assessment.

6.2.3. Develop Data Collection Schemes and Measurement Tools

Like needs assessment, evidence based evaluation depends on the scientific analysis of relevant data. Qualitative and quantitative data can be used for evaluation. The data collection and measurement tools that were used in the needs assessment can be modified and applied to evaluation studies. The data warehouse, developed for the needs assessment, is designed in such a way that it can be modified for continuous assessment. The results from the needs assessment serve as a benchmark for further evaluation and are therefore kept separate from the evaluation studies.

6.2.4. Specify Methods to Interpret Findings

Analytical and statistical methods, such as trends analysis, are used to evaluate the performance of the telemedicine program. During an evaluability assessment prior to implementation, the analytical and statistical methods, which could be used during the process and outcome evaluation, are specified and developed. Hence, a toolbox for evaluation is created to evaluate the performance of the telemedicine program.

Chapter 7

Case Study: Telemedicine in the Public Sector of the Western Cape

The Eastern Cape is known as one of South Africa's most rural provinces and, as one might expect, this has a negative influence on healthcare delivery. The Western Cape Province, on the other hand, is known as one of the leading South African provinces, with regard to healthcare service delivery (Coovadia, *et al*., 2009). These two provinces represent different strengths and challenges to healthcare delivery. The provinces were chosen specifically to investigate the applicability of the decision support system on divergent populations.

In Chapters 5 and 6, the modelling of the decision support system were demonstrated using EHR data from the Eastern Cape Department of Health. The purpose of this chapter is to validate the decision support system, using Western Cape data. The same methodology, discussed in Chapters 5 and 6 was followed in this chapter, but the emphasis is on the results and interpretation.

The pre-assessment phase of the decision support system was discussed in Chapters 2, 3 and 4. If Western Cape telemedicine implementation decision makers use the decision support system, it is recommended that they familiarize themselves with telemedicine and health informatics theory, as outlined in the pre-assessment phase of the decision support system. For this thesis, the approach is similar to decision making on a national level, where the same decision makers consider both provinces. Since the pre-assessment phase is not province-specific, it is not necessary to repeat the pre-assessment phase in one overarching study. The validation of the decision support system therefore starts at data collection in the needs assessment phase of the decision support system, as illustrated in Figure 27.

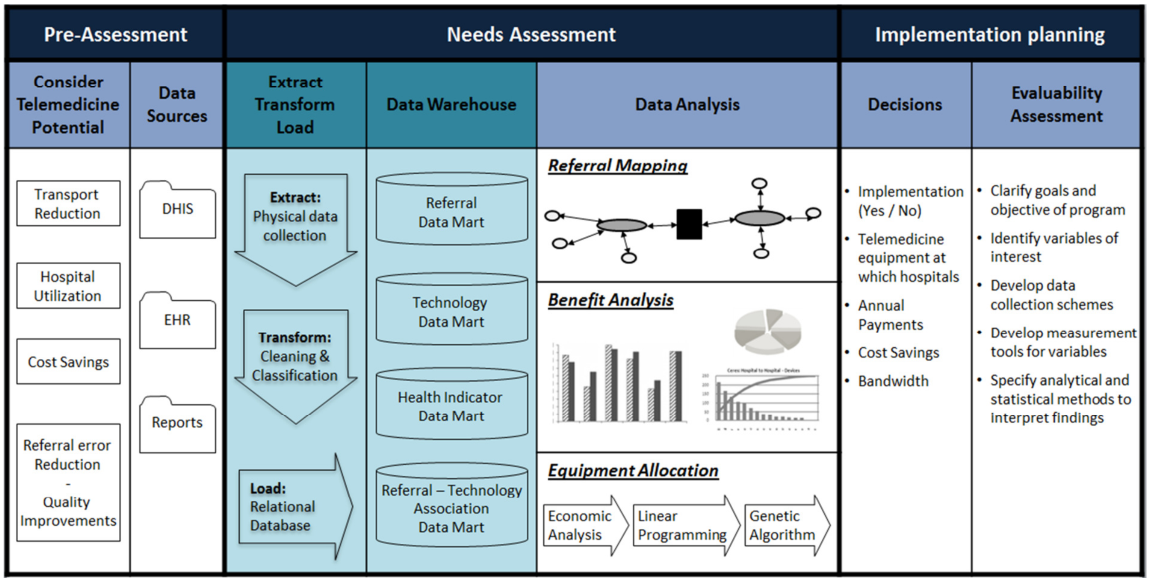

Figure 27: Data Collection and Warehousing for the Western Cape

7.1. Data Collection and Warehousing

Table 19 below shows an overview of the data that were used to validate the decision support system. A similar table, outlining data used from the Eastern Cape was discussed in Chapter 5.

Table 19: Outline of Western Cape data used to validate the Decision Support System

	Health Indicator Data	Referral Data	Admission Data
Description	Indications of the size and workload of the hospital	Data of patients referred from one hospital to another	Admission data of patients admitted to tertiary hospitals
Population	Western Cape Department of Health Hospitals: DHIS, Clinicom	Western Cape Department of Health Hospitals: DHIS, Clinicom	Sampled hospitals from the USA discharge survey
Collecting methods	Request extraction from Clinicom database	Request extraction from Clinicom database	Request extraction from Clinicom database
Sample	Indicator data from all hospitals in the WC using Clinicom, for 2010	Referral data from all hospitals in the WC using Clinicom, for 2010	All hospital admissions at the 3 WC Tertiary hospitals, 2010
Data Attributes	• Number of beds • Patient Day Equivalent • Cost per patient day • Bed utilization rate • Transfer distances • Patient transfer cost	• Diagnosis • "Referred to" hospital name • Date of discharged • Patient Date of birth • Patient Gender • Patient Suburb • Length of stay	• Diagnosis • Patient Date of Birth • Patient Suburb • Patient Language • Date admitted • Patient Financial bracket • Patient Ethnic origin
Analysis	• Economic Analysis	• Statistical Analysis • Referral Mapping	• Statistical Analysis • Referral Mapping
Data Mart	Health Indicator Data Mart	Referral Data Mart	Referral Data Mart

In the development of the DSS, some limitations were faced by the small data sets from the Eastern Cape. However, these limitations are alleviated in the Western Cape case study, since data sets from the Western Cape are much larger. Another advantage of the Western Cape data was that it contained no free text fields. The Eastern Cape data included 'reason for referrals' as a free-text field, with very little recorded ICD-10 codes. The Western Cape data contained no free-text fields and therefore no 'reason for referral' fields were available. However, ICD-10 codes were available for all referrals and admissions at tertiary hospitals.

The difference in data quality and fields recorded between the two provinces necessitated the development of complementary analyses, for the decision support system. Admission data were collected from the three tertiary hospitals in the Western Cape (see Table 19), primarily to determine the diagnoses of referrals. By matching referrals and admissions, it was possible to measure the potential that telemedicine systems could have in reducing the amount of referral errors. This will be explained in more detail in the data analysis section of this chapter.

7.1.1. Referrals Data Mart - Electronic Health Records

The Western Cape Department of Health is implementing EHR systems in a growing number of hospitals. The Clinicom system, managed by the Department of Health, is fully operational in all three of the tertiary hospitals in the province. The amount of regional, district and specialised hospitals that are using Clinicom is growing rapidly as a result of the Department of Health's plan to implement these systems in all hospitals. There are still other EHR role-players in the Western Cape, like Ethnics (Delta 9). Nevertheless, it is expected that the Western Cape Department of Health will eventually to integrate EHR between hospitals, and thus opt for the use of Clinicom in all Western Cape hospitals.

Similar to the UniCare^{TM} system of Ethniks (Delta 9), the Clinicom system is designed to capture and store patient records for hospital management. In this way, the Clinicom system is able to manage hospital processes, such as admissions, financial calculations, discharges, and so on. The decision support system requires referral data, as well as admission data, that can be used to analyse the need for telemedicine systems in different hospitals in the province.

Extract

The Western Cape Department of Health complies with the same ethical guidelines as the Eastern Cape Department of Health. It was therefore compulsory to apply for formal approval before the data, necessary for this study, could be extracted.

Ethical considerations and approval

The Western Cape validation study was added to the scope of the study after initial ethical clearance was received by Stellenbosch University's Health Research Ethics Committee. An amendment was made to the original research protocol and was submitted to the ethics committee for approval. The amendment was accepted by the committee with a formal letter, included in Appendix A. The research protocol and ethical clearance letters were then submitted to the Western Cape Department of Health who approved the data collection. The same guidelines, as for the Eastern Cape data, were followed to protect patient confidentiality.

Data Specifications

The amount of hospitals in the Western Cape, using EHR systems, is much larger than in the Eastern Cape. Data were extracted from all the hospitals in the Western Cape where Clinicom was operational in 2010. Table 20 lists the names of the hospitals, their level and the amount of referrals that were captured in 2010.

Table 20: Hospital Referral Data in the Western Cape Data Set

Hospital Level	*Amount*	*Hospital Names*	*Referral Amount*
Central	3	Tygerberg Hospital	3891
		Red Cross War Memorial Children's	2818
		Groote Schuur Hospital	2604
Regional	4	Somerset Hospital	1682
		Worcester Hospital	1635
		George Hospital	1090
		Mowbray Maternity Hospital	626
District	11	Helderberg Hospital	2205
		GF Jooste Hospital	1992
		Karl Bremer Hospital	1127
		Victoria Hospital	1108
		Wesfleur Hospital	673
		Eerste River Hospital	669
		False Bay Hospital	645
		Stellenbosch Hospital	599
		Khayelitsha Hospital	565
		Montagu Hospital	398
		Robertson Hospital	350
Psych	4	Lentegeur Hospital	169
		Stikland Hospital	167
		Valkenberg Hospital	105
		Alexandra Hospital	20
TB	4	DP Marais Hospital	268
		Brooklyn Chest Hospital	144
		Brewelskloof Hospital	30
		Harry Comay Hospital	22
Rehab	1	Western Cape Rehabilitation Centre	108
Total	**27**		**25310**

As with the Eastern Cape data, the following referral discharge fields were included in the reports, extracted from the Clinicom system:

- ICD-10 codes (optional)
- Date and time of discharge (referral)
- Name of hospital referred to (not free-text)

Transformation and Loading

Since the Western Cape data did not contain any free-text field, it was not necessary to clean data and code the 'reasons for referral' field. However, the following fields were included in Eastern Cape discharge reports, but were not included in the Western Cape data set.

- Reason for referral (free-text)
- Speciality of diagnosis (free-text)
- Date and time of hospital admission

The absence of the 'reason for referral' field in the Western Cape data, necessitated an alternative method be used, to determine why patients were referred. Unlike the Eastern Cape data, the data from the tertiary hospitals in the Western Cape had ICD-10 entries for almost all the patients that were admitted to these hospitals in 2010. It was therefore, possible to match referrals to admissions during 2010, at these hospitals.

To protect patient confidentiality, unique patient identifiers (ID numbers) were not made available for the study. However, by using a combination of patient specific data, it was possible to match the referral discharge entry of a patient, referred to a tertiary hospital, with the admission entry the same patient at the tertiary hospital. In this way, the ICD-10 codes of the referral reasons were obtained. Referral discharge and admission entries were considered matches if the following were true:

- The name of the tertiary hospital referred (referral report) was the same as the name of the hospital admitted to (admission report)
- The birth date on both reports were the same
- The discharge date (referral report) and admission date (admission report) were within a week of each other
- Patient residence suburbs were the same (on both reports)
- Patient residence post code were the same (on both reports)

- Patient gender were the same (on both reports)
- Language was the same (on both reports)
- Ethnic origin was the same (on both reports)

Entries were matched and coded for storage, using a Visual Basic Application in Microsoft Excel written for this purpose. The admission ICD-10 codes and dates were included in the referral reports to tertiary hospitals. After transformation was completed, patient referral data were loaded into the referrals data mart using Microsoft Excel.

7.1.2. Health indicators and Technology Data Marts

Health indicator data formats are standard for all the provinces in South Africa. The data for the Western Cape were therefore extracted and transformed in the same way as was done for the Eastern Cape data. Data fields include hospitalisation cost per patient day equivalent, bed utilisation and number of beds available per hospital. Data was loaded into the health indicator data mart for storage and analysis.

The technologies that are considered by the decision support system are not province specific; the same data mart can be used for any district. However, for decision support to be effective, decision makers have to update the data marts regularly. The data that are currently stored in the technology data mart are mostly estimations, and are thus suitable for high level decision making. For more accurate results, market research on equipment should be done frequently and the data marts updated accordingly.

7.1.3. Referral – Technology Association Data Mart

In Chapter 5, a follow up study was recommended to determine accurate associations between ICD10 codes and telemedicine technologies. However, the association analysis, discussed in Chapter 5, was considered satisfactory for this study and the data mart, populated in Chapter 5, was used in the validation study without any further amendments.

7.2. Data Analysis

The larger data set of the Western Cape allowed referrals from 27 hospitals to be analysed for potential telemedicine implementation at these hospitals. The large data set yielded more evidence upon which to base decisions. Western Cape data were analysed according to the three different phases of analysis as shown in Figure 28. The remainder of this chapter is devoted to a demonstration of each three of the respective analyses shown in this figure:

- Referral Mapping (Section 7.2.1)
- Benefit Analysis (Section 7.2.2)
- Equipment Allocation Algorithm (Section 7.2.3)

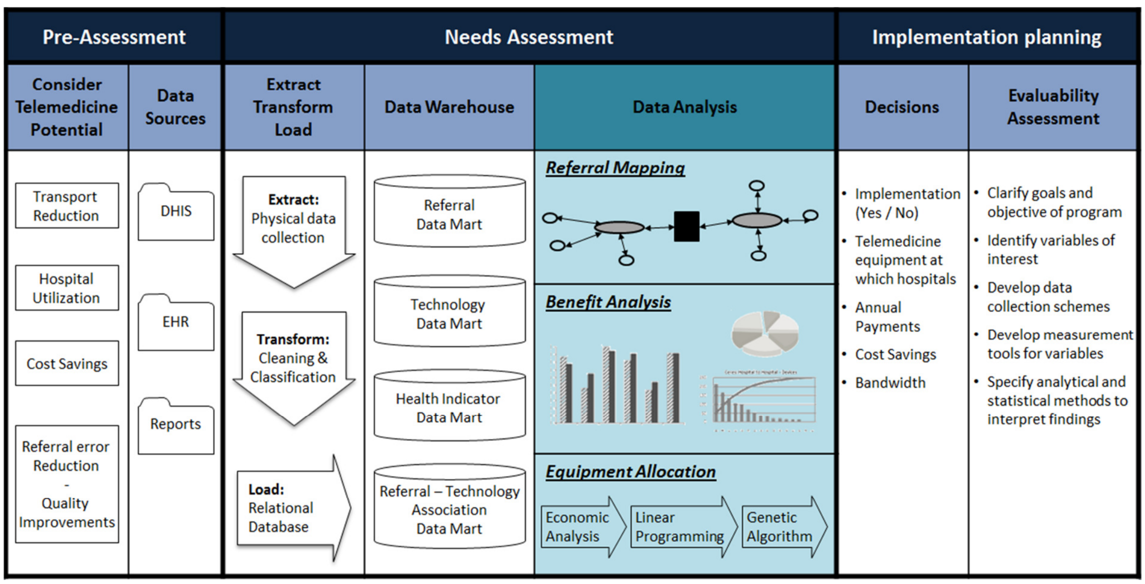

Figure 28: Analysing data for Validation

7.2.1. Referral Mapping

Decision making on district or provincial level, require a broad perspective as well as detail indicators. Referral mapping allowed decision makers to obtain a broad perspective on referral patterns between hospitals (included in the data set) of the province. In addition, referral mapping analyses and illustrates the trends of referrals, irrespective of their telemedicine potential. Diagnosis trends, referral patterns and distances travelled are indicators included in this analysis and are explained in this section.

7.2.1.1. Referral Diagnoses Pareto Analysis

The Pareto analysis on the referral diagnoses provided an overview of the top 15% of the diagnoses, documented for 80% of the referrals. The distribution is shown in Figure 29 with the Top 10 codes listed in Table 21. This Pareto analysis supported decisions concerning the selection of telemedicine programs, but was not directly used in calculating the potential benefit of telemedicine. Nevertheless, it is important for decision makers to take note of the most frequent reasons for referrals so that future telemedicine programs can focus on these referrals, thus reducing transport and saving costs.

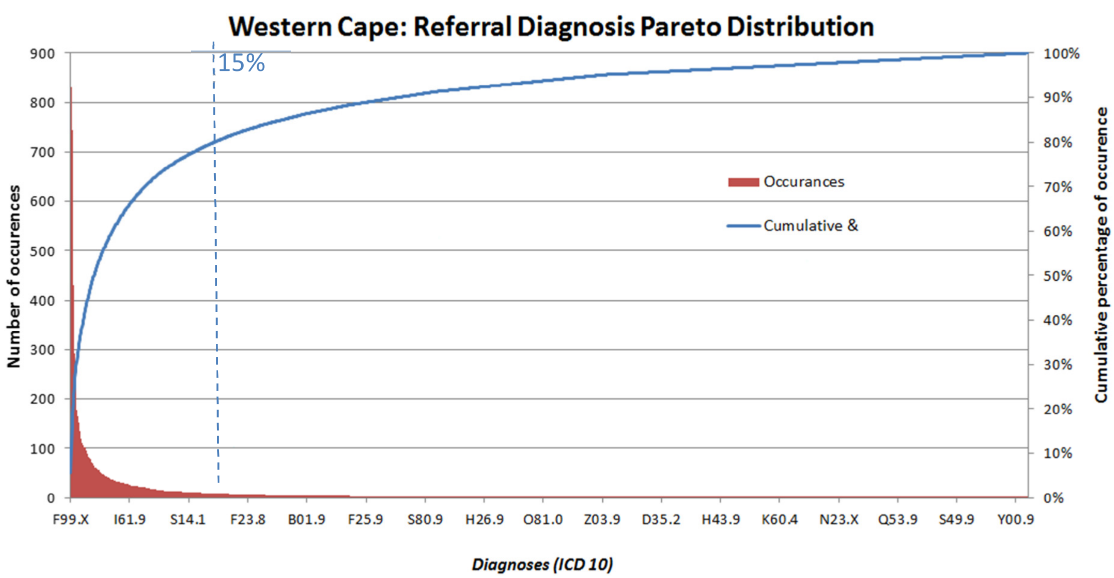

Figure 29: Pareto distribution of all referral diagnoses in the Western Cape, 2010

The left vertical axis of the Pareto graph shows the number of times that the ICD10 codes (on the horizontal axis) occurred as referrals, in the data set. The right horizontal axis indicates the cumulative percentage of the diagnoses to the total number of referrals. The graph shown in red is a bar chart that shows the number of times a diagnosis occurred, while the blue graph represents the cumulative percentage trends of the Pareto distribution. The vertical dotted line shows that 15% of the diagnoses occurred 80% of the time.

Table 21 below lists that mental disorders were the leading reason for referrals. 5.6% of all referrals in the province were classified under the F99 diagnostic code. Gastroenteritis and pre-term infants were also leading reasons for referrals.

Table 21: Top 10 Reason for Referrals – Western Cape 2010

Rank	ICD	Description	Occurrence	%
1	F99	Mental disorder	830	5.6%
2	A09	Gastroenteritis and colitis of unspecified origin	828	5.6%
3	P07.3	Other preterm infants	743	5.0%
4	J18.0	Bronchopneumonia	430	2.9%
5	O80.0	Spontaneous vertex delivery	312	2.1%
6	O82.9	Delivery by caesarean section	293	2.0%
7	B05.9	Measles without complication	289	2.0%
8	J18.9	Pneumonia	277	1.9%
9	O80.9	Single spontaneous delivery	193	1.3%
10	A16.9	Respiratory tuberculosis unspecified	177	1.2%

7.2.1.2. Calculating the amount of referrals between hospitals

The decision support system interprets referral reports in order to calculate the amount of referrals from all hospitals (included in the data set) to listed hospitals. The Visual Basic application, written for this analysis, was used to map the 25310 referral entries in a 'from-to' chart. The 'from-to' chart contains referral amounts from 27 hospitals to 100 hospitals.

Figure 30 shows the total number of patients that were referred from the hospitals in the Western Cape data set. The three tertiary hospitals (Tygerberg, Red Cross and Groote Schuur) of the province referred the most patients in 2010. Tygerberg Hospital referred 3891 patients in that year, an average of between 10 and 11 patients daily. Tertiary hospitals have the most referrals because they receive patients from district and regional hospitals. Tertiary hospitals provide high-level care and would typically send patients back to their local hospitals for lower-level treatment.

The hospitals that had the least amount of referrals were Alexandra, Harry Comay and Brewelskloof. These hospitals are all specialised hospitals; Alexandra is a psychiatric hospital and Harry Comay and Brewelskloof are TB hospitals. Patients are generally referred to specialised hospitals to receive longer term specialised treatment, not offered at the referred-from hospital. It is therefore, to be expected that since patients are sent to specialised hospitals for longer term treatment, it is unlikely that they would be sent back to the hospital from which they came.

If one looks at the high number of referrals in Figure 30, it seems logical to implement referral reducing initiatives at tertiary and other high scoring hospitals. However, when considering telemedicine implementation, it is important to note that most of the patients at tertiary hospitals are likely to be referrals. The calculation of potential telemedicine referrals are included in the benefits analysis, where these results can be used in a comparison so as to consider the broader perspectives on patient referrals.

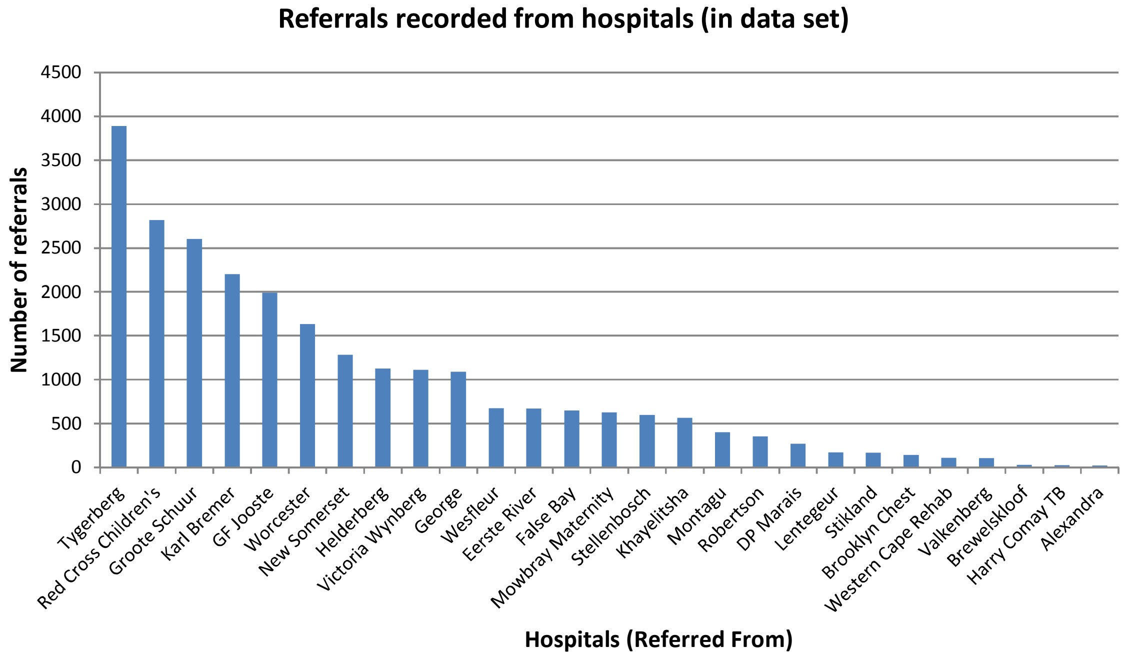

Figure 30: Referral Totals for Western Cape Hospitals

7.2.1.3. Calculating the distance between hospitals

The distances between the hospitals, included in the data set, were calculated using Garmin MapSource Software, as discussed in Chapter 5. The software takes the coordinates of the hospitals into consideration and then calculates the distance and time required to travel the fastest route between the hospitals. The distances travelled for transfers between hospitals, were recorded in a 'from-to' chart. The 'from-to' chart is stored in the referrals data mart in order to be accessible for the benefit analysis.

Figure 31 below shows the mapped routes, used to calculate the distances. Hospital locations are marked with a blue cross on the map. The red roads indicate the routes that ambulances are likely to travel when transporting patients between the hospitals in the data set. In the upper left hand corner, the Cape Town Metro district is emphasised, to show that there are many referrals which take place between the hospitals situated close to each other.

It can be observed from the map, that patients were referred to hospitals in the Eastern Cape, Gauteng and Northern Cape Provinces. However, the majority of the routes are in the Western Cape, with a large number of hospitals in the Cape Town area. It is expected that telemedicine systems would have more potential for cases where long distances separate the hospitals. The costs involved in patient transfers are discussed in the benefit analysis.

Figure 31: Transport Routes between Hospitals

7.2.2. Benefit Analysis

Data from tertiary hospitals in the Eastern Cape were analysed as if these referrals had telemedicine potential. It was assumed that referrals from tertiary hospitals were originally telemedicine referrals. These assumptions were not necessary for the Western Cape. The larger size of the Western Cape data set allowed for analysis to be done using the data as is, without the need for interpreting it for additional use. The following exclusions were made to remove referral data that had little or no potential of becoming telemedicine referrals.

- Referral entries that had no ICD-10 code
- Referrals of patients in need of complicated surgeries
- Referrals of patients needing psychological treatment
- Telemedicine only a potential substitute for lower-level to higher-level care
- A percentage of referrals needing face-to-face consultations with specialist (in this case 30%)

7.2.2.1. Potential telemedicine referrals

The referral data set were cleaned of entries with no ICD-10 code. This was done because diagnostic codes were not necessary to determine whether a referral could have been managed with telemedicine. The remaining data were separated into two categories: the first category included all referrals that had the potential to be telemedicine referrals, and the second category included those that were excluded due to the previously discussed reasons.

The potential telemedicine referrals are the red bars in Figure 32, and the excluded referrals (transfer referrals) are the blue bars. The three tertiary hospitals have significantly more transfer referrals than the potential telemedicine referrals. This is due to the exclusion criteria of referrals from higher-lever to lower-level care hospitals being unlikely to have telemedicine potential. Nevertheless, although not measured, it can be assumed that if the referrals from lower-level to higher-level care are reduced, the referrals back to the lower-level hospitals will also be reduced.

The district and regional hospitals including Karl Bremer, GF Jooste, Helderberg, Khayelitsha and Worcester show promise of telemedicine potential. The total numbers of referrals are much lower than at the tertiary hospitals, but the amount of potential telemedicine referrals are in general higher than at the tertiary hospitals. The specialised hospitals had few referrals, making it unlikely that telemedicine implementations at these hospitals would be beneficial.

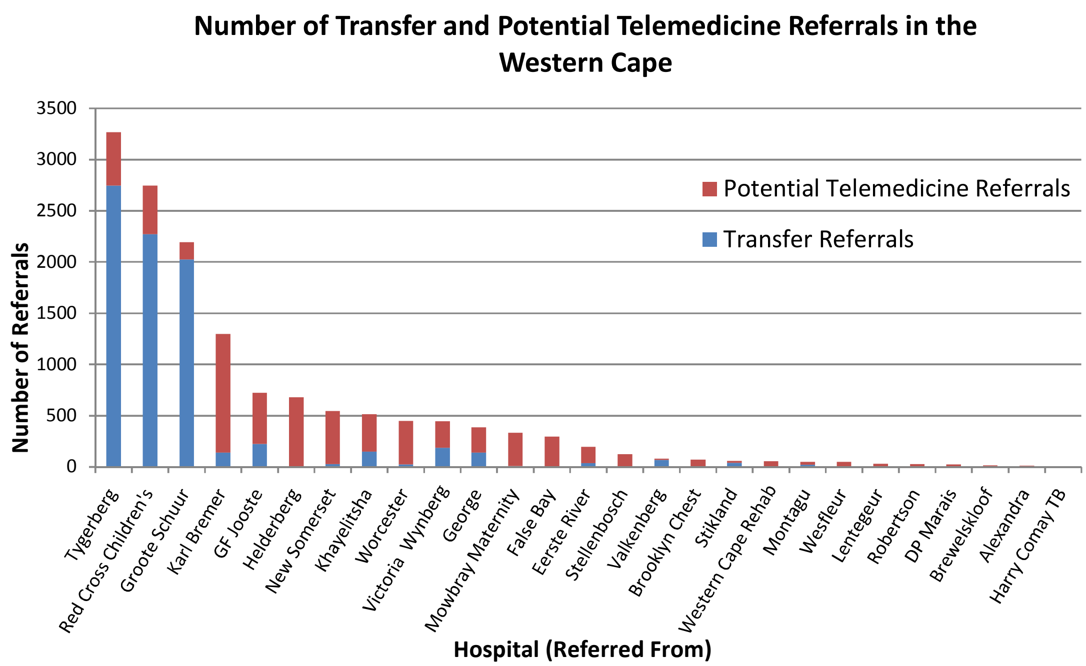

Figure 32: Number of Transfer and Potential Telemedicine Referrals in the Western Cape

7.2.2.2. Transport Reduction

Transport reduction is measured in terms of the distance that is reduced due to potential telemedicine referrals. The 'from-to' chart for the travel distances, together with the 'from-to' chart for the amount of potential telemedicine referrals, is used to calculate the potential distance reduction. The distance between the hospitals is multiplied by the number of potential telemedicine referrals between them and the total distance between the hospitals, which is reduced, is then calculated. Another 'from-to' chart is calculated for the total distance reduced between the hospitals.

In Figure 33, it is clear that implementing telemedicine at George Hospital has the highest potential of reducing transport. The reason for this is a combination of the facts that George is far from the tertiary hospitals in the Western Cape and because George Hospital is a secondary hospital, with a larger amount of referrals than district hospitals.

The graph in the figure shows the transport reduction, in millions of kilometres, for all hospitals included in the data set. According to the analysis, if telemedicine was available at George Hospital in 2010, 67519 km of travelling could have been avoided. Total transport reduction of 165740km could have been achieved in 2010 if telemedicine were implemented at all the hospitals.

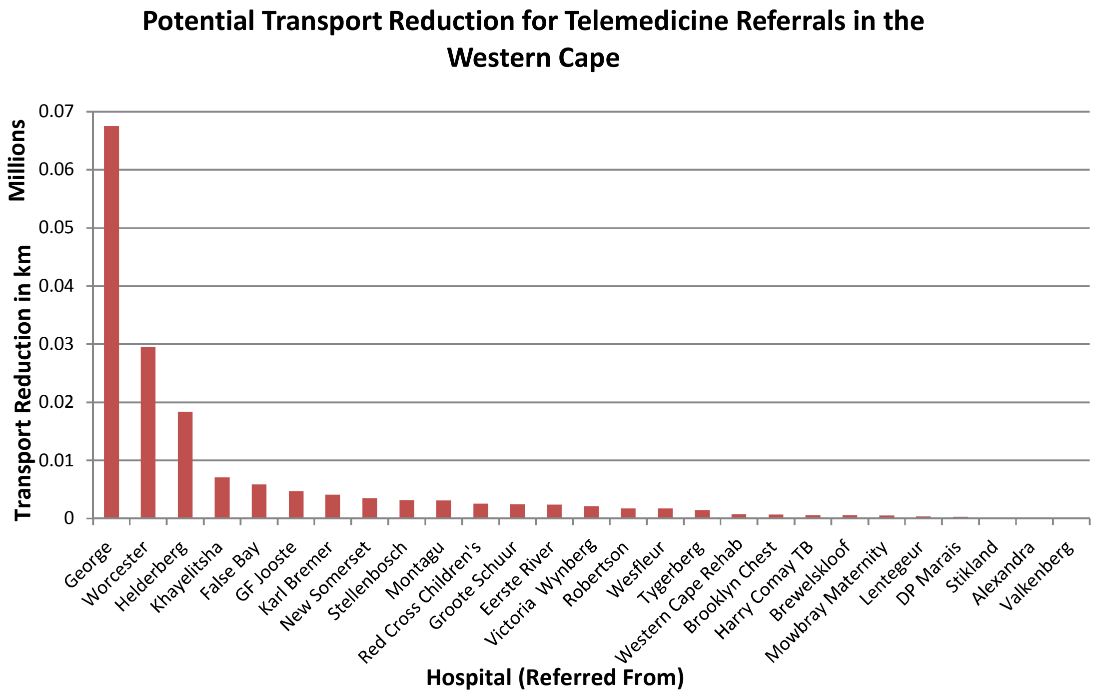

Figure 33: Potential Transport Reduction for Telemedicine Referrals in the Western Cape

7.2.2.3. Hospital Bed Utilisation

The effect that telemedicine could have on hospitals' utilisation of resources is calculated using health indicator data from the health indicator data mart. A potential telemedicine referral can also be interpreted as a patient staying at a lower-level care hospital as opposed to being referred and admitted to a higher-level care hospital. The bed utilisation of lower-level care hospitals would be expected to rise, whereas higher-level care hospitals occupancy would decline.

As previously discussed, the bed utilisation rate is calculated using indicators such as; the number of in-patients days, average length of stay of patients and number of beds in the hospitals. The number of potential referrals, multiplied by the average length of stay of patients (at that hospital), is calculated to determine the reduction of in-patient days at 'referred to' hospitals and increase inpatient days at the 'referred from' hospitals. The new indication on in-patient days was subsequently used to calculate the expected bed utilisation indicators. The reduction and increase in in-patient days influence hospital expenditure, and were used to calculate hospitalisation cost savings.

7.2.2.4. Cost Savings

Both transport reductions and hospital utilisations have cost benefits. The results from the transport reduction and hospital utilisation analysis were used, with cost estimations, to determine the cost benefit that could be expected with the implementation of telemedicine. The patient day equivalent cost indicators, which were used to determine hospitalisation cost benefit, was calculated using the total annual hospital expenditure, divided by the total annual patient day equivalent. The cost therefore reflects the total cost of the hospital (including overhead costs) per patient day.

The effect of patients being hospitalised in lower-level care facilities does not influence overhead costs. A percentage of the patient day equivalent cost was considered as part of overhead costs and excluded from the cost savings. For more accurate results, overhead cost indicators could be included in the indicator data mart and used in this analysis.

Figure 34 shows the potential transport and potential hospitalisation cost savings. The cost savings are shown in millions of Rands, as shown on the vertical axis. The 'referred from' hospitals are listed and sorted on the horizontal axis. Helderberg Hospital is listed on the left, as the hospital with the highest total potential cost savings, and Groote Schuur Hospital is listed on the right, with the lowest.

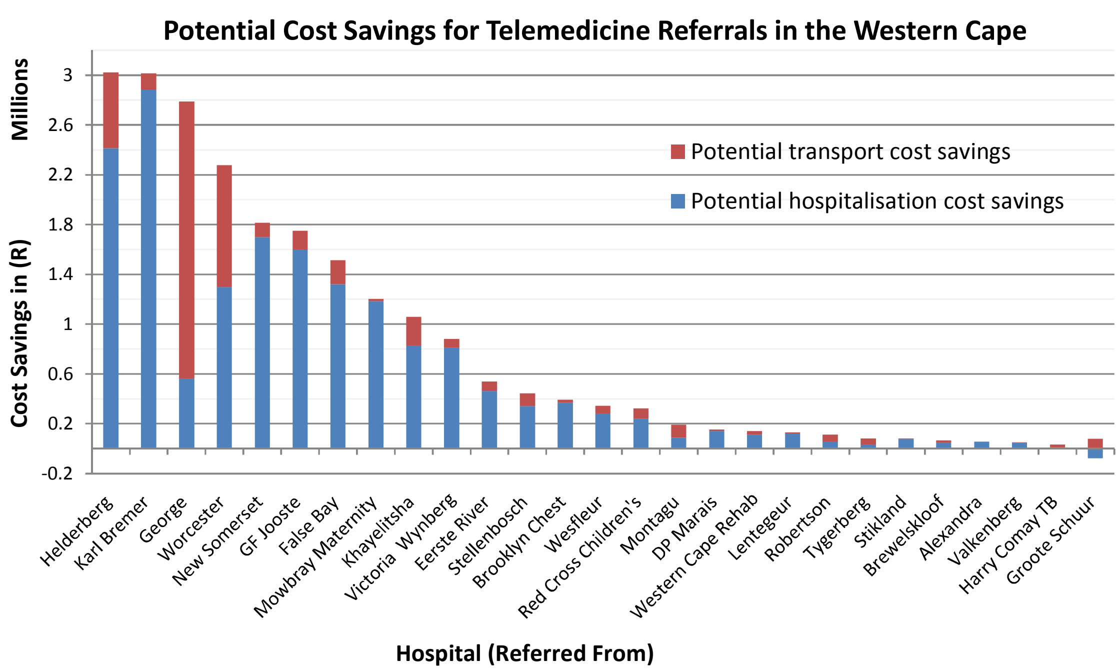

Figure 34: Potential Transport Cost Savings for Telemedicine Referrals in the Western Cape

At the majority of the hospitals, the potential cost savings, due to patients being hospitalised in hospitals with lower expenditure, have a larger influence than the transport cost savings. George Hospital and Groote Schuur Hospital are the only two hospitals where the transport cost savings are more than the hospitalisation cost savings.

The figures at George Hospital can be explained by the fact that it is a secondary hospital and is situated approximately 430km from all three tertiary hospitals. The patient day equivalent cost differences between secondary and tertiary hospitals are less than between district and tertiary hospitals. Therefore, the savings due to lower-level hospitalisation are less than for district to tertiary referrals.

Groote Schuur Hospital is the only hospital that has negative hospitalisation cost savings. The reason for this is that Groote Schuur Hospital is a tertiary hospital, and referrals to lower-level care hospitals are not considered to have telemedicine potential. Therefore, only referrals from Groote Schuur Hospital to other tertiary hospitals are considered as potential telemedicine referrals. Groote Schuur Hospital has the lowest hospitalisation cost of all the tertiary hospitals. Referring patients from Groote Schuur Hospital to other tertiary hospitals would thus result in higher costs and therefore negative cost savings.

7.2.2.5. Quality Improvements

Telemedicine has the potential to improve the quality of referral diagnostics by reducing the number of patients' referral errors. As previously discussed, type 1 referral errors are defined as unnecessary referrals, while type 2 referrals are when necessary referrals were not made. By combining and analysing referral and admission reports, the amount of type 1 referral errors can be measured.

The Western Cape data includes referral reports from 27 hospitals and admission reports from the 3 tertiary hospitals in the province. Data of patients that were referred to the three tertiary hospitals were combined with the admission data for the tertiary hospitals. The entries indicating admission at the tertiary hospital of a referred patient, over a short time period, were considered a match. This method of matching the entries, was discussed in the transformation and loading of the EHR, earlier in this chapter.

The results of the analysis are shown in Table 22. It should be noted that not all the referral entries could be matched with admission entries. Furthermore, reports for most of the hospitals that referred to the tertiary hospitals, did not include ICD-10 codes. As a result, only matched entries that had an ICD-10 code, in both the referral and admission report, could be used in the analysis. The percentages of useful data were 12%, 14% and 25% for Tygerberg, Groote Schuur and Red Cross Children's Hospitals respectively.

A referral was considered to be a type 1 error if the diagnosis at the tertiary hospitals remained the same as the referral diagnosis. Entries with ICD-10 codes, that indicate surgical or psychiatric cases, were excluded, since it is likely that treatment could not be done at the 'referred from' hospital.

Table 22: ICD-10 Code Matching for 'Referrals to' and Admissions at Tertiary Hospitals

		Tygerberg	Groote Schuur	Red Cross
a	**Number of referrals to tertiary hospital**	4740	3315	585
b	**Number of matches found**	3770	2920	501
c	**Number of ICD10 codes recorded in both referral and admission reports**	569	459	148
d	**Percentage data used in analysis (*c/a*)**	12%	14%	25%
e	**Number of times the ICD10 codes were the same**	139	113	28
f	**Number of surgical or psychiatric referrals**	3	10	0
g	**Number of type 1 errors**	136	103	28
h	**Percentage of times the codes were the same (g/*c*)**	24%	22%	19%

Limitations to the analysis

The analysis proved that it is possible to measure when the diagnosis remained the same, at the 'referred to' and receiving hospitals. However, in the analysis, the assumption was made that apart from surgical ICD-10 codes, all other referrals were made solely for diagnostic purposes. This is not an accurate reflection of reality, since the following factors could also necessitate a referral:

- Equipment to confirm diagnosis not available at a 'referred from' hospital
- The patient is in need of specialised treatment that the 'referred from' hospital cannot provide

In the analysis, 84% of the 'referred from' hospitals that referred type 1 errors, were tertiary hospitals, indicating a lack of data from district and regional hospitals. Therefore, the data used for the analysis (entries with ICD codes for both referral and admission reports) were clearly not representative of the population. The percentages are therefore not an accurate indication of referral errors to the tertiary hospitals.

It is recommended that the method of analysis should exclude referrals which are not made for diagnostic purposes. Future analysis should also ensure that ICD-10 codes are available in referral as well as in admission reports.

It is recommended that the method of analysis should consider exclusions indicating that referrals were not made for diagnostic purposes. Future analyses should also ensure that ICD-10 codes are available in referral reports as well as admission reports.

7.2.3. Equipment Allocation

The benefit analysis revealed that there are potential benefits associated with telemedicine implementation in the Western Cape. The benefit analysis considers telemedicine programs, and not specific telemedicine equipment. A limitation of the analysis is therefore, that it is not accurate in terms of referrals which could be done with telemedicine.

The equipment allocation algorithm provides a more detailed assessment of the equipment that should be implemented to achieve the best combination of benefits for the telemedicine program. The implementation and maintenance costs associated with telemedicine equipment, as well as cost saving benefits after implementation, are used to support decision making. Results from the algorithm are focussed to answer the following questions with regard to decision making:

- Should telemedicine be implemented or not?
- Which telemedicine equipment should be implemented at which hospitals?
- What are the annual payments required to implement the equipment?
- What is the net value of the cost savings?
- What are the bandwidth requirements for each hospital?

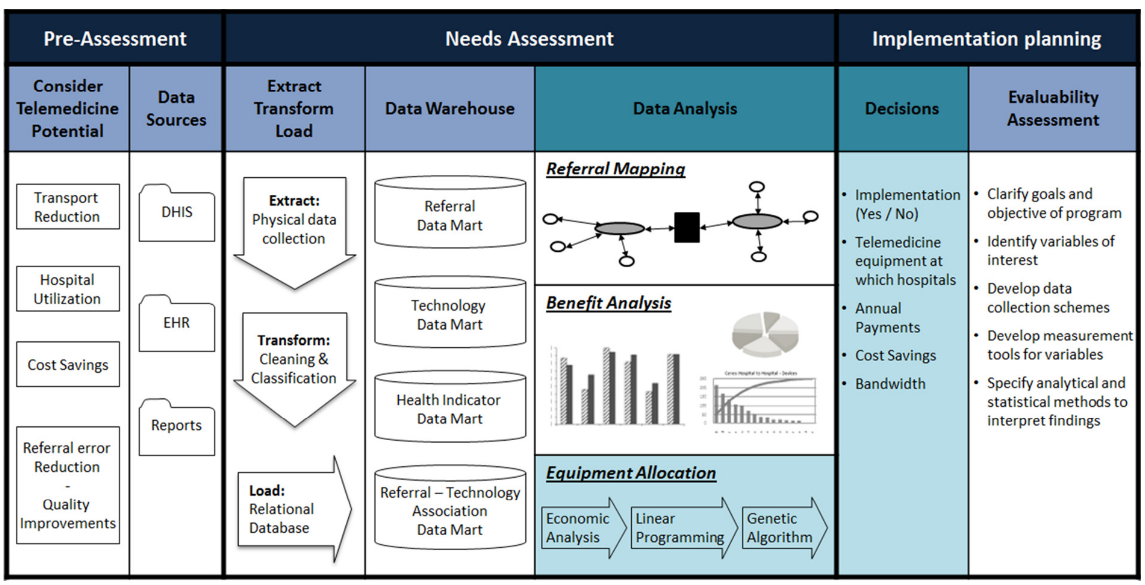

Figure 35: The DSS – Equipment Allocation

7.2.3.1. Economic Analysis

The list of telemedicine equipment that is considered for telemedicine implementation is the same for the Eastern and Western Cape provinces. It is therefore not necessary to repeat the analysis, unless updates are required, or specific equipment added to the list. The equipment allocation algorithm that was modified for the Western Cape used the same equipment as the Eastern Cape study. Therefore, the results from the economic analysis done in Chapter 5 are also used for the Western Cape. Table 18 shows the results of the economic analysis. The table shows the prices, lifetime and data requirements of the devices as obtained from the technology data mart.

Table 18: Annual Payment Cost to Implement and Maintain Telemedicine Devices

Telemedicine	Data	Bandwidth	Lifetime	Price New *	Annual Payments	Running costs	Annual Cost
Basic workstation	Text	Low	5	R 50,000.00	R -12,522.82	R 2,000.00	R -14,522.82
Camera	Image	Medium	5	R 10,000.00	R -2,504.56	R 1,000.00	R -3,504.56
Bronchoscope	Image	High	5	R 30,000.00	R -7,513.69	R 1,000.00	R -8,513.69
Stethoscope	Text	Low	5	R 3,000.00	R -751.37	R 1,000.00	R -1,751.37
ECG	Text	Low	5	R 60,000.00	R -15,027.39	R 1,000.00	R -16,027.39
EEG Unit	Text	Low	5	R 40,000.00	R -10,018.26	R 1,000.00	R -11,018.26
Endoscope	Image	Medium	5	R 25,000.00	R -6,261.41	R 1,000.00	R -7,261.41
Ultrasound	Video	High	5	R 50,000.00	R -12,522.82	R 2,000.00	R -14,522.82
X-ray (Digital)	Image	Medium	10	R 100,000.00	R -25,045.65	R 5,000.00	R -30,045.65
CT Scan	Video	High	10	R 1,200,000.00	R -300,547.75	R 10,000.00	R -310,547.75
MRI	Video	High	10	R 3,000,000.00	R -751,369.36	R 15,000.00	R -766,369.36
Retinal Camera	Image	Medium	5	R 25,000.00	R -6,261.41	R 1,000.00	R -7,261.41
Otoscope	Image	Medium	5	R 5,000.00	R -1,252.28	R 1,000.00	R -2,252.28
Ophtalmoscope	Image	Medium	5	R 25,000.00	R -6,261.41	R 1,000.00	R -7,261.41
Spirometer	Text	Low	5	R 10,000.00	R -2,504.56	R 1,000.00	R -3,504.56

** Prices are estimations from internet market research*

7.2.3.2. Optimisation Problem Demonstration

A generic mixed integer programming problem, that was models the allocation of equipment, was formulated and discussed in Chapter 5. In this section, the problem is applied to the Western Cape case study.

Indexes:

$i = 1,2,3 \dots 16$ Device index

$j = 1,2,3, \dots 27$ Hospitals referred from index
(Hospitals for which referral reports were collected)

$k = 1,2,3, \dots 87$ Hospitals referred to index

$l = 1,2,3, \dots 1609$ Diagnosis (ICD10) index

Decision variable:

$$x_{i,j} = \begin{cases} 1, & Device\ i \text{ is chosen to be implemented at hospital } j \\ 0, & Device\ i \text{ is not chosen to be implemented at hospital } j \end{cases}$$

Input parameters (From data marts):

The algorithm uses large amounts of data (from the data marts) to calculate the cost benefits of equipment combinations. The following data are used to calculate benefits:

- Referral reports

  $h_{j,k,l} =$ Amount of times that diagnosis l was referred from hospital j to hospital k

  $$g_{j,k} = \begin{cases} 1, & Hospital\ j \text{ is of the same or lower level than hospital } k \\ 0, & Hospital\ j \text{ is higher referral level than hospital } k \end{cases}$$

- Association of ICD-10 with telemedicine equipment

  $$d_{i,l} = \begin{cases} 1, & Device\ i \text{ is required to diagnose a case recorded as ICD10 code } l \\ 0, & Device\ i \text{ is not required to diagnose a case recorded as ICD10 code } l \end{cases}$$

- Annual payment costs of telemedicine equipment

  $c_i =$ Annual payments to implement and maintain device i

- Travel distance & cost (from-to chart)

  $t_{j,k} =$ Transport distance to transfer a patient from hospital j to hospital k

  $u =$ Patient transport cost per km

- PDE costs (from-to chart)

  $b_{j,k} =$ Difference in overnight cost if a patient stayed in hospital j and not hospital k

Input parameters (required from decision maker):

The decision support system requires specific input from decision makers for the equipment allocation algorithm. The reason that decision makers are requested to regularly enter data into the system, apart from the data marts, is because data, which is stored in the data marts, are fixed for a time period. The data entered by decision makers are subject to change and should therefore be updated before the algorithm can determine the solution.

It is required of decision makers to populate a data sheet similar to Table 23, with relevant indicators of equipment that is available at the 'referred from' hospitals at that time. Table 23 was populated with realistic but fictional data for demonstration and validation purposes of the equipment allocation algorithm. Table 23 is mathematically formulated in the problem as:

$$y_{i,j} = \begin{cases} 1, & Device\ i \text{ is already available at hospital } j \text{ when decision is made} \\ 0, & Device\ i \text{ is not already available at hospital } j \text{ when decision is made} \end{cases}$$

Decision makers should also provide the algorithm with a maximum total annual cost for all device implementations (formulated in the problem as *w*). If there is no maximum annual cost, the algorithm will have more freedom to choose devices. The annual costs related to implementation, would however still limit the number of devices that are chosen.

Table 23: Input – Equipment available at hospitals prior to implementation

	Basic	Camera	Bronchoscope	Stethoscope	ECG	EEG	Endoscope	Ultrasound	X ray	CT Scan	MRI	Retinal Camera	Otoscope	Ophtalmoscope	Spirometer
Alexandra								1							
Brewelskloof								1							
Brooklyn Chest					1			1					1	1	
DP Marais		1				1		1							1
Eerste River				1	1		1	1	1			1			
False Bay				1	1		1	1	1						
George		1	1				1	1	1	1					
GF Jooste							1	1	1						
Groote Schuur		1	1	1	1	1	1	1	1	1	1	1	1	1	1
Harry Comay TB					1	1		1				1			
Helderberg		1					1	1	1						1
Karl Bremer							1	1	1					1	
Khayelitsha				1	1		1	1	1					1	
Lentegeur		1						1							1
Montagu			1		1	1	1	1	1						
Mowbray Maternity							1	1	1	1		1			
New Somerset				1			1	1	1						
Red Cross Children's		1	1	1	1	1	1	1	1	1	1	1	1	1	1
Robertson		1				1	1	1	1					1	
Stellenbosch			1	1			1	1	1				1		1
Stikland					1			1							
Tygerberg		1	1	1	1	1	1	1	1	1	1	1	1	1	1
Valkenberg		1				1	1	1							
Victoria Wynberg					1		1	1	1					1	1
Wesfleur				1			1	1	1				1		
Western Cape Rehab					1			1							
Worcester	1	1	1	1	1							1		1	1

Calculated parameters (influenced by decision variable):

- Devices i that will be available at hospital j, are a combination of what was available prior to implementation and the devices that are chosen to be implemented.

$$V_{i,j}\langle x_{i,j}|y_{i,j}\rangle = \begin{cases} 1, & Device\ i \text{ will be available after implementation at hospital } j \\ 0, & Device\ i \text{ will not be available after implementation at hospital } j \end{cases}$$

$$V_{i,j} \ = \ x_{i,j} + y_{i,j} \qquad i = 1,2,3,\ldots n;\ j = 1,2,3,\ldots m$$

- The annual payments are calculated for the devices chosen at each hospital.

$$C_{i,j}\langle x_{i,j}|c_i\rangle = \text{ Annual payment costs to implement device } i \text{ at hospital } j$$

$$C_{i,j} \ = \ x_{i,j} * c_i \qquad i = 1,2,3,..n;\ \ j = 1,2,3,\ldots m$$

- The number of referrals that have the potential to be telemedicine referrals, with the chosen devices, is calculated for each hospital j. Each ICD-10 case requires a unique combination of devices for diagnosis. Thus, a referral recorded in 2010, $h_{j,k,l}$ only has the potential for telemedicine if all the devices at that hospital are available after implementation, as required, to diagnose l:

- $R_{j,k}\langle V_{i,j}|d_{i,l}|\ h_{j,k,l}\ |g_{j,k}\rangle =$ Amount of telemedicine referrals from hospital j to hospital k

$$R_{j,k} = \begin{cases} 0, & V_{i,j} < d_{i,l}\ , \\ \sum_{l=1}^{q} h_{j,k,l}.\, g_{j,k}\ , & V_{i,j} \geq d_{i,l} \end{cases} \qquad for\ all\ i = 1,2,3,..n$$

- The expected travel cost savings between hospital j and hospital k is calculated as a product between the number of potential referrals, determined in (3), the transport distances and the cost per km.

$$T_{j,k}\langle R_{j,k}|t_{j,k}|u\rangle = \text{Travel cost savings from hospital } j \text{ to hospital } k \text{ with proposed devices}$$

$$T_{j,k} \ = \ R_{j,k} * t_{j,k} * u \qquad j = 1,2,3,..m;\ \ k = 1,2,3,\ldots p$$

- The expected savings from patients staying in hospitals with a lower daily cost is calculated as a product between the numbers potential referrals, determined in (3), and the difference in hospitalisation costs between hospital j and hospital k.

$$B_{j,k}\langle R_{j,k}|b_{j,k}\rangle = \text{Hospitalisation savings, patients staying at hospital } j \text{ and not hospital } k$$

$$B_{j,k} = R_{j,k} * b_{j,k} \quad j = 1,2,3,..m; \ \ k = 1,2,3,...p$$

Objective Function:

The objective function maximises the sum of the savings with the subtracted cost.

$$\max z = -\sum_{i=1}^{n}\sum_{j=1}^{m} C_{i,j} + \sum_{j=1}^{m}\sum_{k=1}^{p} T_{j,k} + \sum_{j=1}^{m}\sum_{k=1}^{p} B_{j,k}$$

Subjected To:

1. A device should not be implemented if it is already available at that hospital.

$$x_{i,j} + y_{i,j} \leq 1 \qquad i = 1,2,3,...n; \ j = 1,2,3,...m$$

2. The total annual payment cost is constrained.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} C_{i,j} \leq \mathrm{w}$$

7.2.3.3. Genetic Algorithm Demonstration

The genetic algorithm programmed in Microsoft Excel Visual Basic, used data stored in worksheets to calculate benefits and costs (objective function) for each basic feasible solution (decision variable). A population of basic feasible solutions was created and solutions with high objective functions were used to produce stronger basic feasible solutions. Each new basic feasible solution created, forms a new iteration. Figure 36 shows the iterations and their objective functions (cost savings).

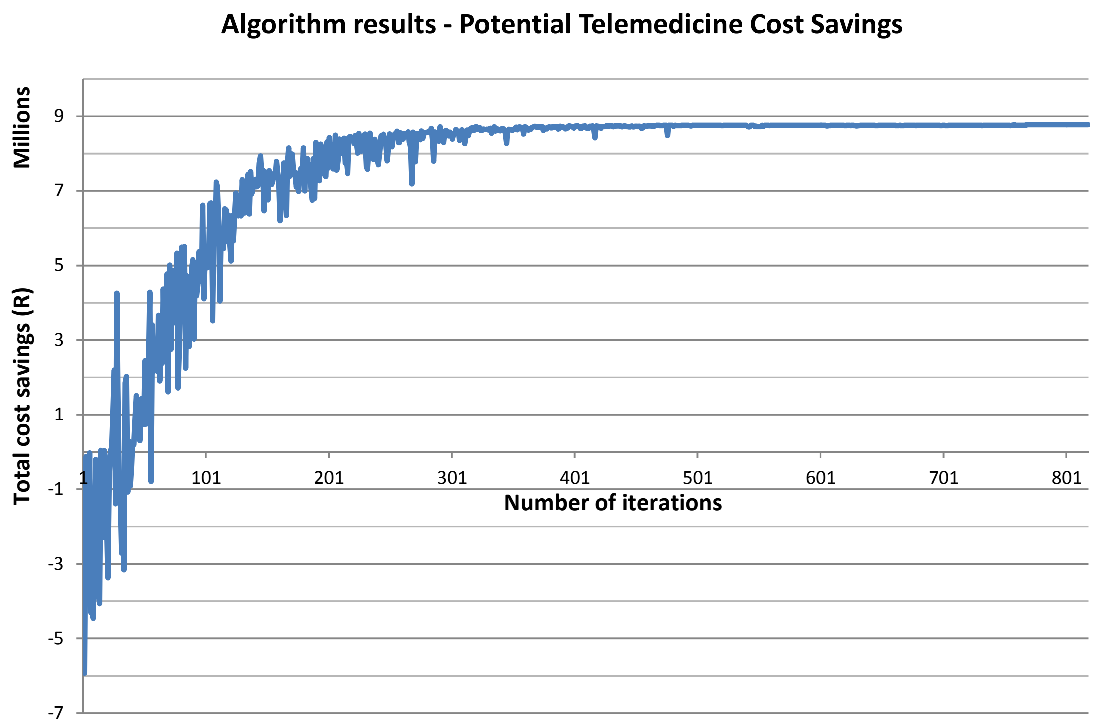

Figure 36: Algorithm Iterations and objective function

Between the 1st and the 200th iteration, there was a large stochastic element to basic feasible solutions (bfs) objective functions. The reason for this is that the genetic algorithm starts with a random population that is improved, by randomly pairing basic feasible solutions with high objective functions. As a result, as iterations increase, the stochasticity decreases and the objective functions increase.

The algorithm was programmed to stop after 200 consecutive iterations showed no improvement. The potential cost savings for all 27 hospitals totalled R 8,755,115.96. This is not necessarily the optimum solution; however, it is a good solution that strongly recommends implementation. Figure 37 shows the solution's cost savings, according to the type of saving per hospital. Table 24 shows the devices that were chosen to be implemented.

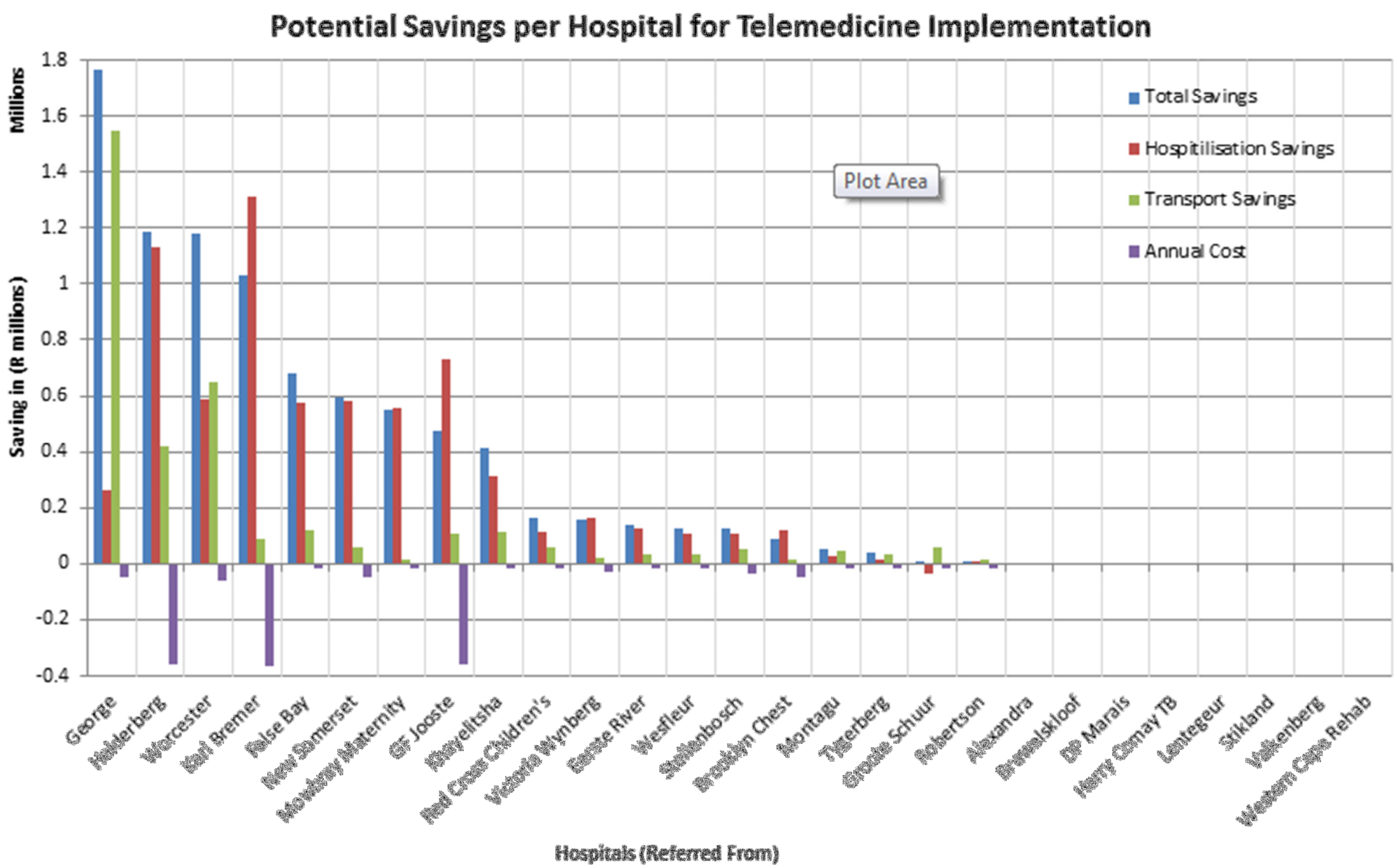

Figure 37: Algorithm Results on Potential Savings for Telemedicine Implementation

Table 24: Algorithm Implementation Decisions

	Basic	Camera	Bronchoscope	Stethoscope	ECG	EEG	Endoscope	Ultrasound	X ray	CT Scan	MRI	Retinal Camera	Otoscope	Ophtalmoscope	Spirometer
Alexandra															
Brewelskloof															
Brooklyn Chest	1			1					1						
DP Marais															
Eerste River	1	1													
False Bay	1	1													
George	1			1	1							1		1	1
GF Jooste	1	1	1	1	1					1			1		1
Groote Schuur	1														
Harry Comay TB															
Helderberg	1		1	1	1					1		1	1		
Karl Bremer	1	1	1	1	1					1		1	1		1
Khayelitsha	1	1													
Lentegeur															
Montagu	1	1		1											
Mowbray Maternity	1	1		1											
New Somerset	1	1	1		1										1
Red Cross Children's	1														
Robertson	1														
Stellenbosch	1	1			1										
Stikland															
Tygerberg	1														
Valkenberg															
Victoria Wynberg	1	1	1	1											
Wesfleur	1	1													
Western Cape Rehab															
Worcester	1	1	1	1	1							1		1	1

7.3. Implementation Planning

The third and final phase of the decision support system is applied to the Western Cape public sector, using the results from the previous section. Results from the benefit analysis and equipment allocation algorithm strongly motivate implementation of telemedicine in the Western Cape. For a total capital investment of R1.52 million, a total net cost saving of R8.77 million could have been expected for 2010. The devices recommended for implementation at the relevant hospitals and which are necessary for the provision of these cost savings, are shown in Table 24.

Execution of the equipment allocation algorithm could be repeated for different capital investments and devices, available prior to implementation. In this way, decisions could be based on different scenarios. It is also recommended that evaluability assessments are done as part of implementation planning, as discussed in Chapter 6. Evaluability assessments promote the use of benefit measurements to continuously assess the telemedicine program and manage it accordingly, in order to obtain the potential benefits, calculated by the decision support system.

Chapter 8

Conclusions and Recommendations

In this study, a clinical-pull approach to telemedicine implementation was proposed, using health informatics to determine the need for telemedicine before implementation. The decision support system was developed to support strategic implementation decisions concerning the potential of telemedicine as an alternative to hospital referrals, within the public health sector of South Africa. The system serves as a tool to identify, assess and use potential benefits of telemedicine systems in management implementation planning.

The novelty in using EHR data to measure potential benefits of telemedicine implementation called for an exploratory study to consider decision support systems, different applications of telemedicine and data sources available. The decision support system was subsequently based on a new concept of using patient discharge data to quantify potential benefits for implementation.

The mixed integer programming problem was formulated and solved using a genetic algorithm is a new approach that proved to be effective in choosing equipment for implementation that could provide high cost benefits for a network of hospitals. Future work could include using other heuristics to solve the problem. The problem could also be expanded to include other quantifiable benefits for telemedicine implementation.

This study originated in the Eastern Cape and for the majority of the research process, the data from the Eastern Cape was used in the development of this system. The Eastern Cape data set was sufficient in guiding the system development process. Fortunately, towards the end of this study significantly larger data set was sourced from the Western Cape Department of Health. Hence, it was possible to validate this system using the public health sector of South Africa as case study. The case study revealed that the system was effective in measuring: transport reduction, hospital utilisation and cost savings. However, the system had limited success in measuring quality improvements. This limitation could be attributed to a lack of data as well as the fact that service quality is difficult to quantify.

Health informatics has proved to be a valuable source of data for decision making. There are however still many improvements necessary in health information systems to be integrated with telemedicine. Ideally, the strategy for EHRs should be improved by restricting the information systems not to allow free-text in the discharge reports and requiring that ICD-10 codes are entered for all patients. If the 'reason for referral' was not a free-text field and ICD-10 codes were available for all entries, reports could have been drawn; indicating why patients are being referred. The relationship of telemedicine to ICD-10 codes can then be linked to the reasons for referral, allowing for telemedicine assessments to be been integrated into the system, allowing calculation to be done automatically by the information system.

The amount of South African hospitals that are using electronic health information systems are growing rapidly. As a result, the information available for analysis is increasing as more hospitals store patient data and other health indicators electronically. Furthermore, the introduction of the National Health Insurance would require improvement of medical coding systems at all hospitals. According to SA Department of Health (2011), "the reimbursement system for inpatient services will be according to disease related groups". Therefore disease codes will be collected for the majority of patients as opposed to the current state where only the minority of the patients have medical aid.

The increase in information will allow more decisions to be based on quantifiable evidence, thus leading to improved health decision making and ultimately improved quality healthcare. Therefore, as more hospitals are implementing EHR systems, the data set for the decision support system can be broadened. A larger data set will allow that the potential for telemedicine can be assessed for larger networks of hospitals. Thus leading to improved decision making and cost-effective telemedicine solutions.

As discussed in Chapter 5, the referral-technology association data mart requires a more accurate study to determine the relationship between conventional reason for referrals (ICD-10 codes) and telemedicine referrals. In this study the association were established from a method that produces conservative results. To calculate the probability that a telemedicine referral could be an alternative to a transfer referral, it is necessary to assign a probability that a telemedicine technology or device could prevent the transfer for each reason of referral (ICD-10 code). It is critical to the accuracy of the analysis, to have an accurate probability assigned between different technologies and reasons for referrals. However there is a lack of published studies that investigate these relationships. It is therefore recommended that a relation between diagnoses and telemedicine services are established prior to implementing the system.

The quantitative needs assessment should be supported by qualitative studies, assessing social and clinical perspectives of telemedicine implementation needs. The extent to which telemedicine improve aspects such as quality of care, equity of care, practitioner support and education, should be assessed using appropriate research methods. The inclusion of synchronous telemedicine applications should also be included in the system in future work.

This study contributed to telemedicine management in South Africa, by providing a tool that can be used to measure the needs and benefits tor telemedicine before implementation. The decision support system could assist decision makers to implement cost-effective solutions and thus improving healthcare delivery in the long term. Furthermore the study explored a new method to measure telemedicine benefits which could be used for telemedicine decision making, ranging from the implementation phase to continuous assessment. This new application of health informatics in telemedicine could lead to cost-effective hospital referrals and ultimately better quality healthcare for all.

Chapter 9

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Appendix A:

Ethical Approval documents

A.1. Stellenbosch University Health Ethics Committee Approval

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

11 October 2010 MAILED

Ms MJ Treurnicht
[illegible] Street
[illegible]
Stellenbosch
7600

Dear Ms Treurnicht

"A decision support system for telemedicine system implementation planning in the Eastern Cape, South Africa."

ETHICS REFERENCE NO: N10/10/330

RE: APPROVED

It is a pleasure to inform you that a review panel of the Health Research Ethics Committee has approved the above-mentioned project on 5 October 2010, including the ethical aspects involved, for a period of one year from this date.

This project is therefore now registered and you can proceed with the work. Please quote the above-mentioned project number in ALL future correspondence. You may start with the project. Notwithstanding this approval, the Committee can request that work on this project be halted temporarily in anticipation of more information that they might deem necessary.

Please note a template of the progress report is obtainable on www.sun.ac.za/rds and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly and subjected to an external audit.

Translations of the consent document in the languages applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372
Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No 61 2003 as it pertains to health research [illegible]

Please note that for research at primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Hélène Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

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Fakulteit Gesondheidswetenskappe · Faculty of Health Sciences

Verbind tot Optimale Gesondheid · Committed to Optimal Health
Afdeling Navorsingsontwikkeling en -steun · Division of Research Development and Support
Posbus/PO Box 19063 · Tygerberg 7505 · Suid-Afrika/South Africa
Tel.: +27 21 938 9075 · Faks/Fax: +27 21 931 3352

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot · your knowledge partner

Approval Date: 5 October 2010 Expiry Date: 5 October 2011

Yours faithfully

MRS MERTRUDE DAVIDS
RESEARCH DEVELOPMENT AND SUPPORT
Tel: [illegible] / E-mail: [illegible]
Fax: [illegible]

11 October 2010 11:07 Page 2 of 2

Fakulteit Gesondheidswetenskappe · Faculty of Health Sciences

Verbind tot Optimale Gesondheid · Committed to Optimal Health
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A.2. Western Cape Amendment Approval (Stellenbosch University)

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

18 April 2011 **MAILED**

Ms MJ Treurnicht
5 Uitsig Street
Rozendal
Stellenbosch
7600

Dear Ms Treurnicht

"A decision support system for telemedicine system implementation planning in the Eastern Cape, South Africa."

ETHICS REFERENCE NO: N10/10/320

RE : AMENDMENT

Your letter dated 1 April 2011 refers.

The Chairperson of the Health Research Ethics Committee approved the amended documentation in accordance with the authority given to him by the Committee.

The following amendments were approved:
1. Inclusion of data from the Western Cape Province.

Yours faithfully

MRS MERTRUDE DAVIDS
RESEARCH DEVELOPMENT AND SUPPORT
Tel: 021 938 9207 / E-mail: mertrude@sun.ac.za
Fax: 021 931 3352

18 April 2011 11:57 Page

Fakulteit Gesondheidswetenskappe · Faculty of Health Sciences

A.3. Eastern Cape Department of Health – Letter of Approval

From: To:0865828520 24/11/2010 10:19 #180 P.001/001

Re: A decision support system for telemedicine implementation planning in the Eastern Cape, South Africa

The Department of Health would like to inform you that your application for conducting a research on the abovementioned topic has been approved based on the following conditions:

1. During your study, you will follow the submitted protocol with ethical approval and can only deviate from it after having a written approval from the Department of Health.
2. You are advised to ensure, observe and respect the rights and culture of your research participants and maintain confidentiality of their identities and shall remove or not collect any information which can be used to link the participants.
3. The Department of Health expects you to provide a progress on your study every 3 months (from date you received this letter) in writing.
4. At the end of your study, you will be expected to send a full written report with your findings and implementable recommendations to the Epidemiological Research & Surveillance Management. You may be invited to the department to come and present your research findings with your implementable recommendations.
5. Your results on the Eastern Cape will not be presented anywhere unless you have shared them with the Department of Health as indicated above.

Your compliance in this regard will be highly appreciated.

DEPUTY DIRECTOR: EPIDEMIOLOGICAL RESEARCH & SURVEILLANCE MANAGEMENT

A.4. Western Cape Department of Health – Letter of Approval

DEPARTMENT of HEALTH
Provincial Government of the Western Cape

STRATEGY & HEALTH SUPPORT

[illegible]
[illegible]
3rd Floor, Norton Rose House, 8 Riebeek Street, Cape Town, 8001
[illegible]

REFERENCE: RP 91/2011
ENQUIRIES: Dr V Appiah - Boiden

5 Uitsig Street,
Rosendal,
Stellenbosch,
7600

For attention: **Maria J Treurnicht**

Re: <u>A Decision Support System for Telemedicine Needs Assessments in South Africa</u>

Thank you for submitting your proposal to undertake the above-mentioned study. We are pleased to inform you that the department has granted you approval for your research.
Please contact the following people to assist you with any further enquiries.

Director: Information Management	**Ian de Vega**	**(021) 483 8801**

Kindly ensure that the following are adhered to:

1. Arrangements can be made with managers, providing that normal activities at requested facilities are not interrupted.
2. Researchers, in accessing provincial health facilities, are expressing consent to provide the department with an electronic copy of the final report within six months of completion of research. This can be submitted to the provincial Research Co-ordinator (healthres@pgwc.gov.za).
3. The reference number above should be quoted in all future correspondence.

We look forward to hearing from you.

Yours sincerely

DR T NALEDI
DIRECTOR: HEALTH IMPACT ASSESSMENT
DATE: 16.08.2011

A.5. SU Department of Industrial Engineering Code of Conduct

Research in Health System Engineering by students from the Department of Industrial Engineering, Stellenbosch University

Health systems engineering is an academic discipline where researchers and practitioners threat the health care industry as complex systems, and further identify and apply engineering applications in health care systems. Many engineering applications, such as optimization, decision making, human factors engineering, quality engineering, information technology and communication, and knowledge discovery are currently employed in varied levels of health systems.

Students from the Department of Industrial Engineering, Stellenbosch University who are working in the field of health systems, should adhere to this code.

A.5.1. Surveys, Questionnaires, Interviews and Observations

Surveys, questionnaires, interviews, observation of/ with healthcare workers, clinicians, technology developers or managers

A.5.1.1. Each person surveyed, interviewed or observed will be presented with the same project protocol summary that was scrutinized by the research committee. After being informed, the data gathering will only commence once they have provided written consent.

A.5.1.2. Any persons who are quoted/ paraphrased will be presented with the relevant parts of the thesis or journal article, whilst still in draft format to confirm (or not) that they were appropriately quoted.

Surveys, questionnaires, interviews, observation of patients

A.5.1.3. In exceptional cases where interaction with patients is essential to accomplish the research goal, it will be clearly stated in the individual research protocol. Measures to be taken to adhere to the ethical guidelines will be outlined accordingly. Otherwise, data will never be directly gathered from patients.

A.5.2. Health Records

Electronic Patient Records

A.5.2.1. Third party health record managing agency will only extract health record data with permission of the respected provincial department of health.

A.5.2.2. No data will be provided by these health record management agencies that can be linked to specific individual patients.

A.5.2.3. Data will be kept on the computers of the researcher and the supervisor only. Both of these computers will be protected by the password system of Stellenbosch University. An additional and separate password will be used, before each file can be opened.

A.5.2.4. All data will be deleted upon completion of the study, unless permission is granted to be used for follow-up studies.

A.5.2.5. Trends and patterns with respect to specific groups (e.g. gender, age, geographical area, level of income) will only be published if it directly links to the research goals and objectives.

Physical Paper-based Files

A.5.2.6. If data from physical paper-based files are needed for the accomplishment of research objectives, data will only be extracted if it cannot be linked with any individual, including patients and healthcare workers.

A.5.2.7. Trends and patterns with respect to specific groups (e.g. gender, age, geographical area, level of income) will only be published if it directly links to the research goals and objectives.

A.5.3. Blood draws, bone marrow biopsy samples, other biopsies or the collection of tissues

A.5.3.1. In the very unlikely event that this type of data are required towards the accomplishment with the research goal, the study will be conducted in collaboration with (a) clinician(s) and the exact procedure will be indicated in the specific research protocol.

Appendix B:

Diagnosis – Telemedicine Association

B.1 National Hospital Discharge Survey (NHDS)

The lack of South African data that indicates the performance of telemedicine systems necessitates the use of another source of data. The U.S. Centre for Disease Control and Prevention annually publish the NHDS data sets on the internet. The data files are made freely available for research.

B.1.1 Extract

The published format of the data simplifies extraction, since data sets are uploaded on a server to enable researchers to download data sets independently. The data sets are also supported by a series of documents explaining the format of the data and other details necessary to understand the characteristics of the data.

Ethical considerations and approval

Patient identifiable information has been removed by the capturers, thus clearing the data sets from sensitive information that causes ethical concerns. Therefore using the NHDS does not require a permission process or an ethical clearance process.

Data specifications

Data from the 2005 until 2009 years were used to determine the association between diagnoses and procedures in the sampled hospitals of the NHDS from the United States. Each discharge record has a minimum or one recorded diagnosis and could have up to seven diagnoses. A patient could be discharges without having procedures done. Therefore a record could have none or up to four procedures listed. The decision support system uses data from the 2009 set, which includes 162,151 data entries.

Data files

Data files are available in as txt files that can be imported into data manipulation software, such as Microsoft Excel. Files were downloaded during April 2011 from the NHDS website, administrated by the Centres for Disease Control and Prevention. The original format of the data files is shown in Figure 38.

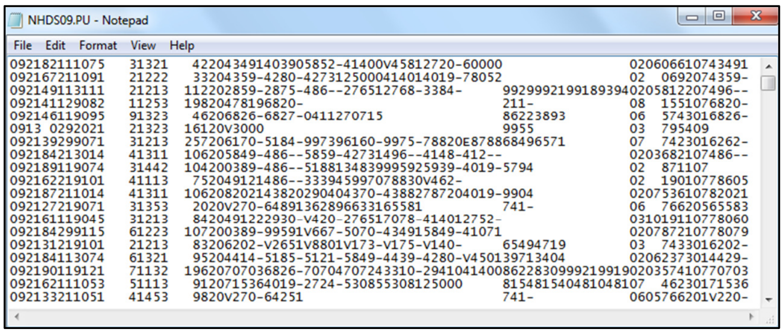

Figure 38: National Hospital Discharge Survey: Data Sample as Extracted

B.1.2 Transformation and loading

The data file, illustrated in Figure 38, includes 43 fields for each discharge. Although the data are already cleaned prior to it being published, it is saved in a format that does not separate these fields. NHDS guidelines that were published with the data files, includes instructions on how to separate data fields for analysis. To import the data into Microsoft Excel, it was necessary to separate the fields by inserting commas between fields using Notepad Software, as illustrated in Figure 39.

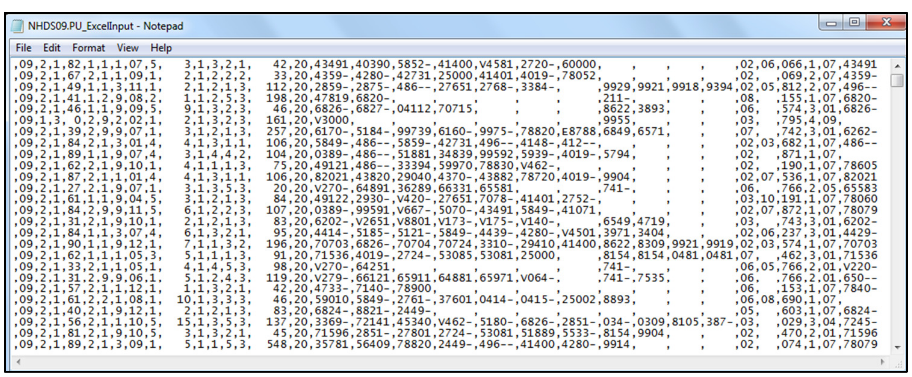

Figure 39: NHDS Data Transformed for MS Excel Import

After transforming data into the separate fields, data were imported in the Microsoft Excel for further transformation. Since the decision support system is only concerned with the diagnoses and procedures during a discharge, the other fields were deleted.

B.2 Analysis

Throughout this section the methodology is discussed that were used to determine the association that telemedicine might have with all possible diagnoses as coded in the ICD lists. As illustrated in Figure 40, the method of establishing the association between telemedicine and diagnoses are divided into four separate relationships. Likewise, each relationship is determined separately and discussed in the sequence as indicated from left to right in the figure.

To explain why the association between telemedicine and diagnoses are broken up in these four relationships, it is best to start at telemedicine and search for ways to link diagnoses with it. Telemedicine is considered as an alternative to hospital referrals. More specifically asynchronous telemedicine could replace referrals as longs as it is not emergency cases or for procedures that cannot be performed at the local hospital.

Hospital referrals are likely to differ according to the hospital levels of the two involved hospitals. The hospital services offered by the hospital would in turn influence the procedures that can be done in the hospital and together with the diagnosis determine if the patient are likely to be referred. The influence that these relationships have on the association of telemedicine with the ICD codes is explained in more detail using Figure 40 as roadmap.

Figure 40: Relationship between diagnoses and telemedicine

B.2.1 Diagnoses – procedures relationship

The first step in determining the association between telemedicine and diagnosis is to determine the association between diagnoses and procedures (Figure 41). It is logical that there should be consistency as to which procedures are done to determine or treat each diagnosis listed in the ICD list. Healthcare practitioners are trained specifically to diagnose and treat each diagnosis. Therefore a possible method to determine the association between diagnoses and procedures would be to use medical training material and literature to map the procedures done for each diagnosis. However, this study would require a vast amount of resources and time.

Figure 41: Diagnoses – Procedures Association

A different approach is to statistically analyse the procedures that were done to diagnose and treat diagnosis in the past. The USA National Hospital Discharge Survey contains diagnostic and procedure data of each discharge included in the data sets. Up to seven discharges and four procedures could be documented for each patient discharge. For each discharge there are at least one diagnosis documented, but it is possible that a patient were discharged without any procedures done. Figure 42 shows the data format of the diagnosis and procedure codes for each discharge entry.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Discharges	Diagnoses							Procedures			
2		DX1	DX2	DX3	DX4	DX5	DX6	DX7	PD1	PD2	PD3	PD4
3	1	V279-	64662	65961	59080	66411	6631	0414-	7569	734-		
4	2	V3001							640-			
5	3	0389-	5849-	5570-	70707	70709	45341	99591				
6	4	226--	49390	71690	V1749	V180-			652			
7	5	71595	V1209	24290	2809-	2825-	4279-	3051	8151	9904		
8	6	V270-	65971	64761	5889	V252-			740-	6629		
9	7	41071	5856-	45341	99812	40391	28981	2639-	387-	3723	8856	8853

Figure 42: NHDS: Data transformed in MS Excel

Statistical Analysis

The 162,151 discharge entries in the 2009 data set include 857,761 diagnoses and 215,066 procedures recorded. After the "remove duplicates" function was used in Microsoft Excel, it was calculated that the 2009 data set includes 7703 unique diagnosis codes and 2408 unique procedures. Unfortunately, no data sets could be found where procedures where specifically documented per diagnosis.

In the data set, as illustrated in Figure 42, a combination of diagnoses is listed per entry followed by a number of procedures. It is therefore not clear which procedures were done to treat or diagnose which diagnosis. Nevertheless, it is expected that by using a large data set, the overlapping of results could be excluded by mapping the primary diagnosis separate from the other diagnoses and performing an inference statistical analysis. Performing an inference of two populations' proportions hypothesis test was suggested by Professor Nel from the Centre for Statistics at Stellenbosch University. Montgomery and Runger (2007) were used as a reference to study and perform the statistical analysis.

Thus the matches between primary diagnosis called DX1 (in Figure 42) and all procedures were plotted in a matrix for all discharges. A separate matrix was calculated by plotting the remaining diagnoses (DX2 –DX7) and procedures for all the discharges. The large data set called for computer programming to compute a matrix containing the number of times each diagnosis was associated with each procedure. Visual Basic programming in Microsoft Excel was used to plot the cases where a specific diagnosis and a specific procedure were present in the same entry. A matrix was compiled with 7703 diagnoses and 2408 procedures as shown in Figure 43.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1				**Procedures**										
2	Diagnoses	Occurance (n_1)	Codes	3893	4525	4513	9904	9339	9671	9917	9919	9929	0003	...
3		7	0030-	3	2	1	1							
4		6	0031-	1				1	1	1	1	1		
5		0	00323											
6		0	00329											
7		0	0039-											
8		0	0043-											
9		0	0048-											
10		1	0049-		1									
11		4	0051-											
12		6	0059-		2							1		
13		1	0071-		1									
14		4	0074-		1	1								
15		4	00841	1	1				1					
16		3	00843		1									
17		0	00844											
18		341	00845	36	48	12	36	3	1	1	2	5		
19		0	00849											
20		4	0085-											
21		...	...											

Figure 43: DX1 Diagnoses-Procedure Occurrence Matrix Example

The inference of two populations' proportions test is explained briefly with reference to the analysis done on the data, using Figure 43 and Figure 45 as illustrations. The test is done for each match between procedure and diagnosis codes. The test is therefore done a total of 7703 x 2408 times including the procedures and diagnoses that did not match. Visual Basic applications were written to do all the calculations necessary in the statistical analysis.

Two independent samples are taken from the primary diagnosis (DX1) matrix and secondary diagnoses (DX2-DX7) matrix with sizes n_1 and n_2 (illustrated in Figure 43). Let x_1 and x_2 be the number of observations (times the specific diagnosis matched with the procedure) that belongs to the primary diagnosis (DX1) and secondary diagnosis (DX2-DX7) respectively (illustrated in Figure 43).

Furthermore, it is assumed the normal approximation to the binomial could be applied to both the primary diagnosis and secondary diagnoses populations; therefore the estimators of the populations' proportions have approximate normal distribution:

$$\hat{P}_1 = \frac{X_1}{n_1} \tag{1}$$

$$\hat{P}_2 = \frac{X_2}{n_2} \tag{2}$$

The population proportions for both populations were calculated by a Visual Basic application. The output is a proportion matrix as illustrated in Figure 44.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		**Procedures**											
2	**Diagnoses**	Codes	3893	4525	4513	9904	9339	9671	9917	9919	9929	0003	...
3		0030-	0.42857	0.28571	0.14286	0.14286							
4		0031-	0.16667				0.16667	0.16667	0.16667	0.16667	0.16667		
5		00323											
6		00329											
7		0039-											
8		0043-											
9		0048-											
10		0049-		1									
11		0051-											
12		0059-		0.33333							0.16667		
13		0071-		1									
14		0074-		0.25	0.25								
15		00841	0.25	0.25				0.25					
16		00843	0	0.33333									
17		00844											
18		00845	0.08798	0.14076	0.03519	0.0176	0.0088	0.00293	0.00293	0.00587	0.01466		
19		00849											
20		0085-											
21		...											

$\hat{P}_1$

Figure 44: Proportion Matrix of the Primary Diagnosis Population

The test statistic in equation (4) is distributed approximately N(0,1). An estimator of the common parameter p is shown in equation (3) and calculated using a Visual Basic application similar to the calculation of the in Figure 44.

$$\hat{P} = \frac{X_1 + X_2}{n_1 + n_2} \tag{3}$$

This leads to the test procedures described below:

Null hypothesis: $H_0: p_1 = p_2$

Alternative Hypothesis: $H_1: p_1 \neq p_2$

Test statistic:

$$Z_0 = \frac{\hat{P}_1 - \hat{P}_2}{\sqrt{\hat{P}(1-\hat{P})\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \quad 4)$$

Rejection Criteria: $z_0 > z_{\alpha/2}\ or\ z_0 < -z_{\alpha/2}$

The test statistic in equation 4 was performed using a Visual Basic application in MS Excel, for each diagnosis/procedure in the matrix. Z_0 values that were in the rejection criteria were rejected. Each diagnosis/procedure in the matrix that were not rejected, were accepted to have a possible association. In this way the influence that the multiple recorded diagnoses and procedures had on the results were tested, and those that did not correlate were ignored.

Limitations of the analysis

The statistical analysis of NHDS data to establish association between diagnoses and procedures has various limitations. The most notable limitation is the fact that multiple diagnoses and multiple procedures are recorded for each discharge. Although the statistical analysis test the influence of this, it is inevitable that the results are not perfectly accurate.

It can be assumed that there is a difference in service delivery between South African public hospitals and NHDS hospitals. Therefore, diagnoses and procedures trends are likely to differ between developed and developing countries, as well as between public and private healthcare facilities.

Despite some similarities between NHDS discharges and EHRs from South African public hospitals, there are various differences between these data sources that should be noted. The South African standard for EHRs is to use ICD-10 codes, whereas the NHDS use the USA modification to the ICD-9 codes called, ICD-9-CM. The difference could be bridged by transforming ICD-9-CM codes to ICD-10, in order for it to be compatible with South African systems. It should be noted that there are various issues related to code conversions. Anderson *et al.* (2001) provides comparability ratios that can be used to measure the effect of changes due to conversions. However, the use comparability ratios are not included in this study.

The transformation of ICD-10 codes to ICD-9-CM codes is necessary for EHR data sets where ICD-10 codes are used to record the diagnosis for the majority of referral cases. Nevertheless, as was discussed earlier in this chapter, diagnostic data from EHRs in the Eastern Cape Province were originally recorded as free-text. It was therefore feasible to directly transform the free-text fields to ICD-9-CM codes, hereby avoiding the transformation between ICD-9-CM and ICD-10 codes.

As previously mentioned, an in-depth analysis of the association between diagnoses and telemedicine referrals is considered beyond the scope of this thesis. The limitations of the analysis done for this study is acknowledged, but since an in-depth analysis is not included in this thesis, it is recommended that it should be attended to in further studies.

B.2.2 Procedures - Hospital services – Hospital Referrals Association

The procedures that could be done at a specific hospital are largely dependent on the services offered by that hospital. The South African Department of Health published norms and standards for district hospital services in 2002. In this document, standard services offered by district hospitals are discussed with relevance to some diagnoses and procedures. Using the association of diagnoses and procedures analysed in the previous section, hospital services could be linked with procedures or diagnoses (Figure 45).

Figure 45: Procedures – Hospital Services Association

The hierarchy level of a hospital determines which services are offered by the hospital. Figure 8 in Chapter 3.4 is repeated as Figure 46 below, and shows the hospital hierarchies and referrals of South African public hospitals.

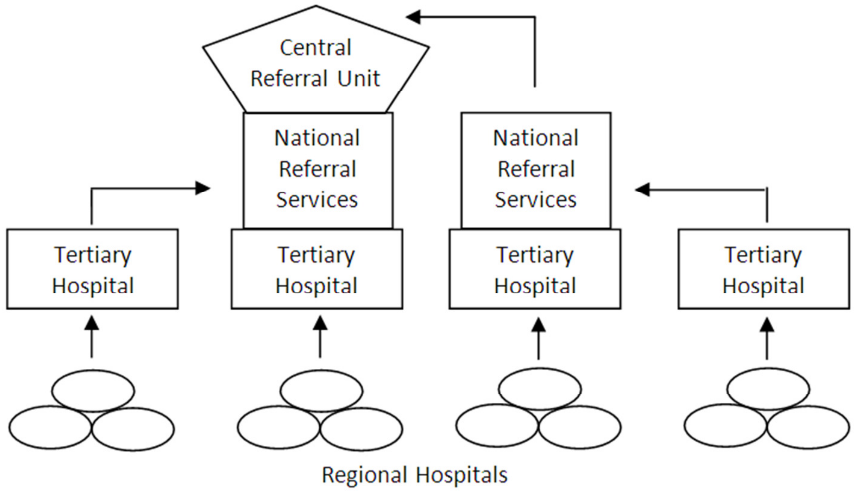

Figure 46: Referral Hierarchy in SA (Adapted from National Department of Health, 2003)

Tables obtained from Department of Health (2002) that indicate hospital services offered by the three hospital levels, could be used in the analysis.

B.2.3 Telemedicine potential with relation to hospital services

The hospital service tables and referral standards tables that were adapted from Department of Health (2002) were used to determine for which services and diagnoses, patients at district hospitals, are referred to either regional hospitals or tertiary hospitals. Nevertheless it is not necessarily a telemedicine referral if a patient is referred. This section is dedicated to determine when a telemedicine system could be used as an alternative to transport patient referrals (Figure 47).

Figure 47: Hospital Referrals - Telemedicine Association

Telemedicine technologies available at hospitals would play an important role in whether referring information of a patient could be an adequate alternative to patient transfer referrals. Asynchronous telemedicine systems are mostly used for diagnostic purposes, whereas synchronous telemedicine have more potential to enable procedures over a distance. Since this study is scoped to focus on asynchronous telemedicine, excluding synchronous telemedicine, hospital referrals that necessitate synchronous telemedicine are excluded from potential telemedicine referrals.

Emergency referrals as well as referrals that require procedures that cannot be done by local healthcare practitioners are not considered to have potential to be an alternative to transport referrals. An in-depth analysis of the referrals that could be done with telemedicine is considered beyond the scope of this study, and should be included in future work.

B.3 Discussion

The study to determine associations between diagnoses and telemedicine technology using NHDS data proved to be unfeasible. The National Hospital Discharge Survey data includes 7 diagnosis codes and 4 procedure codes. The statistical study used hypothesis tests to test if the first diagnosis would be representative of all the diagnoses. An association were only made if the primary diagnosis represented all 7 diagnoses. However, a similar issue due to the fact that there are also 4 procedures caused the result from the analysis to be unfeasible for the decision support system.

Each diagnosis was mapped for all four procedures. However it is unlikely that all four procedures were done for the primary diagnosis, if up to 7 other diagnoses could also be recorded. Therefore future analysis should either find a way to statistically discern between the procedures and the diagnoses. For the purposes of this study, it is suggested that the NHDS data are not suitable to determine the association between diagnoses and procedures. The mapping could however be done if a data set is found that records only one diagnoses per procedure.

Since the association analysis delivered faulty results, this analysis was excluded from the decision support system.

Appendix C:

Visual Basic Programming for Genetic Algorithm

```
Public Sub HospReferrals()

Dim i As Integer, j As Integer, k As Integer, m As Integer
Dim h As Integer, n As Integer
Dim Count As Integer, Cnt As Integer
Dim NumDiag As Integer, NumDev As Integer
Dim NumEntries As Integer
Dim NumHospFrom As Integer, NumHospTo As Integer
Dim CapDevCostSum As Double ', Goal As Double
Dim PopNum1 As Integer, PopNum2 As Integer, PopNum3 As Integer, PopNum4 As Integer
Dim TotalGoal As Double, PrevTotalGoal As Double

Dim NumIterations As Integer, NumPop As Integer

NumIterations = 1500
NumPop = 50
NumEntries = 1466
NumDiag = Sheets("DiagnosisDevices").Range("C1")
NumDev = Sheets("DiagnosisDevices").Range("C2")
NumHospFrom = Sheets("ExistingDevices").Range("C1")
NumHospTo = 87

ReDim DiagnosisDevices(1 To NumDiag, 1 To NumDev) As Integer
ReDim HospDevices(1 To NumHospFrom, 1 To NumDev, 1 To NumPop) As Integer
ReDim ExistingDevices(1 To NumHospFrom, 1 To NumDev) As Integer
ReDim FromToChart(1 To NumHospTo, 1 To NumHospFrom, 1 To NumPop) As Integer
ReDim TravelCostChart(1 To NumHospTo, 1 To NumHospFrom, 1 To NumPop) As Double
ReDim PDEcostsChart(1 To NumHospTo, 1 To NumHospFrom, 1 To NumPop) As Double
ReDim PDEcostsSum(1 To NumHospFrom, 1 To NumPop) As Double
ReDim TravelCostSum(1 To NumHospFrom, 1 To NumPop) As Double
ReDim PopChosenDev(1 To NumHospFrom, 1 To NumDev, 1 To NumPop) As Integer
ReDim SumChosenDev(1 To NumDev) As Integer
ReDim AnnualCost(1 To NumHospFrom, 1 To NumPop) As Double
ReDim Goal(1 To NumHospFrom, 0 To NumPop + 1) As Double

ReDim Parent1(1 To NumHospFrom, 1 To NumDev) As Integer
ReDim Parent2(1 To NumHospFrom, 1 To NumDev) As Integer
ReDim Offspring(1 To NumHospFrom, 1 To NumDev) As Integer
ReDim HospOffspringDev(1 To NumHospFrom, 1 To NumDev) As Integer
ReDim OffspringAnnualCost(1 To NumHospFrom) As Double
ReDim OffspringFromToChart(1 To NumHospTo, 1 To NumHospFrom) As Integer
ReDim OffspringTravelCostChart(1 To NumHospTo, 1 To NumHospFrom) As Double
ReDim OffspringPDEcostsChart(1 To NumHospTo, 1 To NumHospFrom) As Double
ReDim OffspringTravelCostSum(1 To NumHospTo) As Double
ReDim OffspringPDEcostsSum(1 To NumHospTo) As Double
ReDim OffspringGoal(1 To NumHospTo) As Double
ReDim Leastfit(1 To NumHospFrom) As Double
ReDim LeastfitCoord(1 To NumHospFrom) As Double
ReDim Maxfit(1 To NumHospFrom) As Double
ReDim MaxfitCoord(1 To NumHospFrom) As Double

Sheets("Result").Range("C3:AC90").ClearContents
Sheets("Result").Range("C3:AC90").Interior.Pattern = xlNone

For k = 1 To NumPop
For i = 1 To NumHospFrom
  For j = 1 To NumDev
    ExistingDevices(i, j) = Sheets("ExistingDevices").Range("C3").Offset(i, j)
    If Rnd > 0.5 Then
      PopChosenDev(i, j, k) = 1
    Else
      PopChosenDev(i, j, k) = 0
    End If
    If ExistingDevices(i, j) = 1 Then
      PopChosenDev(i, j, k) = 0
    End If
    HospDevices(i, j, k) = PopChosenDev(i, j, k) + ExistingDevices(i, j)
    AnnualCost(i, k) = Sheets("AnnualCost").Range("H1").Offset(j, 0) * PopChosenDev(i, j, k) + AnnualCost(i, k)
  Next j
Next i
```

```
For i = 1 To NumEntries
  If Sheets("Data").Range("B1").Offset(i, 0) < Sheets("Data").Range("E1").Offset(i, 0) Or Sheets("Data").Range("B1").Offset(i, 0) =
Sheets("Data").Range("E1").Offset(i, 0) Then
      j = Sheets("Data").Range("C1").Offset(i, 0)
      h = Sheets("Data").Range("H1").Offset(i, 0)
      Count = 0
      For m = 1 To NumDev
        If Sheets("DiagnosisDevices").Range("D3").Offset(h, 0) = 1 Then
          Count = 0
        ElseIf HospDevices(j, m, k) > Sheets("DiagnosisDevices").Range("D3").Offset(h, m) Or HospDevices(j, m, k) =
Sheets("DiagnosisDevices").Range("D3").Offset(h, m) Then
          Count = Count + 1
        End If
      Next m
      If Count = NumDev Then
        FromToChart(Sheets("Data").Range("F1").Offset(i, 0), Sheets("Data").Range("C1").Offset(i, 0), k) =
FromToChart(Sheets("Data").Range("F1").Offset(i, 0), Sheets("Data").Range("C1").Offset(i, 0), k) + 1
      End If
  End If
Next i

For i = 1 To NumHospFrom
For j = 1 To NumHospTo
TravelCostChart(j, i, k) = FromToChart(j, i, k) * Sheets("TravelDistance").Range("B3").Offset(j, i) * 16.5
PDEcostsChart(j, i, k) = FromToChart(j, i, k) * Sheets("PDEcosts").Range("D4").Offset(j, i)
TravelCostSum(i, k) = TravelCostChart(j, i, k) + TravelCostSum(i, k)
PDEcostsSum(i, k) = PDEcostsSum(i, k) + PDEcostsChart(j, i, k)
Goal(i, k) = PDEcostsSum(i, k) + TravelCostSum(i, k) + AnnualCost(i, k)
Next j
Next i
Next k

For n = 1 To NumIterations

For i = 1 To NumHospFrom
For j = 1 To NumHospTo
OffspringTravelCostChart(j, i) = 0
OffspringPDEcostsChart(j, i) = 0
OffspringFromToChart(j, i) = 0
Next j
OffspringTravelCostSum(i) = 0
OffspringPDEcostsSum(i) = 0
OffspringAnnualCost(i) = 0
Next i

TotalGoal = 0
For i = 1 To NumHospFrom
Maxfit(i) = -10000000
'Leastfit(i) = 10000000

For k = 1 To NumPop
If Maxfit(i) <= Goal(i, k) Then
Maxfit(i) = Goal(i, k)
MaxfitCoord(i) = k
End If
Next k
Next i

PopNum1 = Int(Rnd * NumPop) + 1
PopNum2 = Int(Rnd * NumPop) + 1
PopNum3 = Int(Rnd * NumPop) + 1
PopNum4 = Int(Rnd * NumPop) + 1

For i = 1 To NumHospFrom
For j = 1 To NumDev
If Goal(i, PopNum1) < Goal(i, PopNum2) Then
Parent1(i, j) = PopChosenDev(i, j, PopNum2)
ElseIf Goal(i, PopNum2) < Goal(i, PopNum1) Then
Parent1(i, j) = PopChosenDev(i, j, PopNum1)
End If
```

```
If Goal(i, PopNum3) < Goal(i, PopNum4) Then
Parent2(i, j) = PopChosenDev(i, j, PopNum4)
ElseIf Goal(i, PopNum3) > Goal(i, PopNum4) Then
Parent2(i, j) = PopChosenDev(i, j, PopNum3)
End If

If j < Int(Rnd * 3) + 1 Then
Offspring(i, j) = Parent1(i, j)
ElseIf j < Int(Rnd * 6) + 4 Then
Offspring(i, j) = Parent2(i, j)
ElseIf j < Int(Rnd * 9) + 7 Then
Offspring(i, j) = Parent1(i, j)
ElseIf j < Int(Rnd * 12) + 10 Then
Offspring(i, j) = Parent2(i, j)
Else
Offspring(i, j) = Parent1(i, j)
End If

If Rnd < 0.002 Then
If Offspring(i, Int(Rnd * 15) + 1) = 0 Then
Offspring(i, Int(Rnd * 15) + 1) = 1
ElseIf Offspring(i, Int(Rnd * 15) + 1) = 1 Then
Offspring(i, Int(Rnd * 15) + 1) = 0
End If

If Offspring(i, Int(Rnd * 15) + 1) = 0 Then
Offspring(i, Int(Rnd * 15) + 1) = 1
ElseIf Offspring(i, Int(Rnd * 15) + 1) = 1 Then
Offspring(i, Int(Rnd * 15) + 1) = 0
End If

End If
    If ExistingDevices(i, j) = 1 Then
      Offspring(i, j) = 0
    End If
    HospOffspringDev(i, j) = Offspring(i, j) + ExistingDevices(i, j)
    OffspringAnnualCost(i) = Sheets("AnnualCost").Range("H1").Offset(j, 0) * Offspring(i, j) + OffspringAnnualCost(i)
Next j
Next i

For i = 1 To NumEntries
  If Sheets("Data").Range("B1").Offset(i, 0) < Sheets("Data").Range("E1").Offset(i, 0) Or Sheets("Data").Range("B1").Offset(i, 0) =
Sheets("Data").Range("E1").Offset(i, 0) Then
    j = Sheets("Data").Range("C1").Offset(i, 0)
    h = Sheets("Data").Range("H1").Offset(i, 0)
    Count = 0
    For m = 1 To NumDev
     If Sheets("DiagnosisDevices").Range("D3").Offset(h, 0) = 1 Then
      Count = 0
     ElseIf HospOffspringDev(j, m) > Sheets("DiagnosisDevices").Range("D3").Offset(h, m) Or HospOffspringDev(j, m) =
Sheets("DiagnosisDevices").Range("D3").Offset(h, m) Then
      Count = Count + 1
     End If
    Next m
    If Count = NumDev Then
     OffspringFromToChart(Sheets("Data").Range("F1").Offset(i, 0), Sheets("Data").Range("C1").Offset(i, 0)) =
OffspringFromToChart(Sheets("Data").Range("F1").Offset(i, 0), Sheets("Data").Range("C1").Offset(i, 0)) + 1
    End If
  End If
Next i

For i = 1 To NumHospFrom
For j = 1 To NumHospTo
OffspringTravelCostChart(j, i) = OffspringFromToChart(j, i) * Sheets("TravelDistance").Range("B3").Offset(j, i) * 16.5
OffspringPDEcostsChart(j, i) = OffspringFromToChart(j, i) * Sheets("PDEcosts").Range("D4").Offset(j, i)
OffspringTravelCostSum(i) = OffspringTravelCostChart(j, i) + OffspringTravelCostSum(i)
OffspringPDEcostsSum(i) = OffspringPDEcostsSum(i) + OffspringPDEcostsChart(j, i)
OffspringGoal(i) = OffspringPDEcostsSum(i) + OffspringTravelCostSum(i) + OffspringAnnualCost(i)
Next j
```

```
PopNum5 = Int(Rnd * NumPop) + 1
If PopNum5 = MaxfitCoord(i) Then
PopNum5 = Int(Rnd * NumPop) + 1
End If

For j = 1 To NumDev
PopChosenDev(i, j, PopNum5) = Offspring(i, j)
Sheets("DSSResult").Range("F2").Offset(n, j + i * 22 - 22) = PopChosenDev(i, j, PopNum5)
Next j

AnnualCost(i, PopNum5) = OffspringAnnualCost(i)
TravelCostSum(i, PopNum5) = OffspringTravelCostSum(i)
PDEcostsSum(i, PopNum5) = OffspringPDEcostsSum(i)
Goal(i, PopNum5) = OffspringGoal(i)

Sheets("DSSResult").Range("B2").Offset(n, i * 22 - 22) = Goal(i, PopNum5)
Sheets("DSSResult").Range("C2").Offset(n, i * 22 - 22) = PDEcostsSum(i, PopNum5)
Sheets("DSSResult").Range("D2").Offset(n, i * 22 - 22) = TravelCostSum(i, PopNum5)
Sheets("DSSResult").Range("E2").Offset(n, i * 22 - 22) = AnnualCost(i, PopNum5)

TotalGoal = OffspringGoal(i) + TotalGoal

Next i

Sheets("DSSResult").Range("A2").Offset(n, 0) = TotalGoal

If PrevTotalGoal >= TotalGoal Then
Cnt = Cnt + 1
Else
Cnt = 0
End If

If Cnt = 50 Then
n = NumIterations
End If

Sheets("Sheet9").Range("B2").Offset(n, 0) = PrevTotalGoal
Sheets("Sheet9").Range("C2").Offset(n, 0) = TotalGoal
Sheets("Sheet9").Range("E2").Offset(n, 0) = Cnt
PrevTotalGoal = TotalGoal

Next n

For i = 1 To NumHospFrom
Sheets("Goal").Range("B2").Offset(i, 0) = Goal(i, PopNum5)
Sheets("Goal").Range("C2").Offset(i, 0) = PDEcostsSum(i, PopNum5)
Sheets("Goal").Range("D2").Offset(i, 0) = TravelCostSum(i, PopNum5)
Sheets("Goal").Range("E2").Offset(i, 0) = AnnualCost(i, PopNum5)

For j = 1 To NumDev
Sheets("Goal").Range("F2").Offset(i, j) = PopChosenDev(i, j, PopNum5)
Next j

Next i

End Sub
```