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A Health Systems Engineering Approach to Meeting the Demand for Skilled Foetal Ultrasound Services in the Boland/Overberg Public Health District

by

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The final year project is presented in partial fulfilment of the requirements for the degree of Bachelors of Industrial Engineering at Stellenbosch University.

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October 2010

Declaration

I, the undersigned, hereby declare that the work contained in this report is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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Nina Uys Date

ECSA Exit Level Outcomes References

Exit level outcome	Section(s)	Page(s)
1. Problem solving	1.5 Problem statement 10 Conclusions and Recommendations	4 45
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4. Investigations, experiments & data analysis	Interviews were conducted, medical device evaluation was completed (see list of references in chapter 11) 6.2 Demand for Sonography Services	49, 50 24
5. Engineering methods, skills & tools, incl. IT	5.2 Information and Communications Technology audit 6.3.1 Analytic Hierarchy Process Process Flow Charts in Sections 3 and 8.3.1	19-22 25 14, 38
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Summary

In its Millennium Development Goals, the United Nations prioritizes the improvement of maternal health in developing countries. The World Health Organization argues that this can be done through improving the accessibility and quality of basic maternal health care, which includes ultrasound services. In South Africa, many clinics and hospitals have ultrasound machines, but there is a lack of skilled personnel to operate them and to provide safe and meaningful service.

The purpose of this project was to find an optimal combination of technology and business processes to meet the sonography skills shortage in South Africa in a sustainable way.

Alternative solutions to educating a nurse or midwife at a rural clinic in sonogram acquisitioning and interpretation were investigated. The technological requirements for each were identified. An information and communications technology audit was then done to determine if these solutions are technologically feasible. All of the systems were deemed feasible. These solutions were then tested for their economic feasibility through an analytic hierarchy process.

From these two feasibility studies, the most feasible solution was an asynchronous tele-ultrasound system. This system was developed by the Biomedical Engineering Research Group and the Department of Obstetrics and Gynaecology (OB/GYN) at the University of Stellenbosch, in collaboration with the Department of Bioengineering at the University of Washington. The system is composed of a portable ultrasound machine, a laptop and a server. It was evaluated in 2008 by a midwife in South Africa and three OB/GYN specialists in the United States of America. The midwife had low-level pre-existing ultrasound knowledge and interpretation skills.

The legal requirements for the implementation of the system in a Boland/Overberg public health district clinic were evaluated. Next, through process reengineering, the new system was designed to be incorporated in a typical consultation between a nurse and pregnant patient. Finally, the scheduling requirements to ensure the success evaluation and safety of the system were done.

It was found that overall this system is feasible within the Boland/Overberg health district. Further studies were recommended for the further implementation of the system.

Opsomming

In hul Millennium Ontwikkelingsdoelwitte, prioritiseer die Verenigde Nasies die verbetering van gesondheid tydens swangerskap in ontwikkelende lande. Die Wêreld Gesondheidsorganisasie beweer dat dit bereik kan word deur die toeganklikheid en gehalte van basiese gesondheidsdienste tydens swangerskap te verbeter. Dit sluit ultraklankdienste in. In Suid-Afrika het klinieke en hospitale meestal ultraklankmasjiene – maar daar is ’n tekort aan vaardige gesondheidswerkers wat dié masjiene kan gebruik om veilige en betekenisvolle dienste te lewer.

Die doel van hierdie projek was om die optimale kombinasie van tegnologie en besigheidsprossese te vind, om sodoende die tekort aan sonogramvaardighede in Suid Afrika op ’n volhoubare manier aan te spreek.

Alternatiewe oplossings is ondersoek om deur opleiding die sonogramvaardighede van ’n suster of vroedvrou by ’n landelike kliniek te verbeter. Die tegnologiese behoeftes vir elke oplossing is geïdentifiseer. ’n Informasie- en kommunikasietegnologie-oudit is toe gedoen om te bepaal of die oplossings tegnologies haalbaar is. Die oudit het gewys dat al die oplossings wel haalbaar is. Deur ’n analitiese hiërargieproses te gebruik, is die oplossings toe getoets vir hul ekonomiese haalbaarheid.

Vanaf die twee haalbaarheidstudies is die mees haalbare oplossing gevind, naamlik ’n asinchrone tele-ultraklank sisteem. Dit is ’n sisteem wat in 2008 ontwikkel is deur die Biomediese Ingenieurswese Navorsingsgroep en die Departement van Verloskunde en Ginekologie van die Universiteit Stellenbosch, in samewerking met die Departement van Bio-Ingenieurswese van die Universiteit Washington. Die sisteem bestaan uit ’n draagbare ultraklankmasjien, ’n skootrekenaar en ’n bediener. Dit is geëvalueer deur ’n vroedvrou in Suid Afrika asook drie verloskunde- en ginekologie-spesialiste in die Verenigde State van Amerika. Die vroedvrou het bestaande basiese kennis van ultraklank- en interpretasie-vaardighede gehad.

Die wetlike vereistes vir die implementering van die sisteem in ’n openbare kliniek in die Boland/Overberg-gesondheidsdistrik is toe geëvalueer. Daarna is proses- herbewerking gebruik om die nuwe sisteem in ‘n tipiese konsultasie tussen ‘n suster en ‘n pasiënt te inkorporeer. Om te verseker dat die skeduleringshaalbaarheid verseker is, is die vereistes vir sisteem-evaluasie en -veiligheid bewerkstellig.

Daar is bevind dat die sisteem haalbaar is in die Boland/Overberg- openbare gesondheidsdistrik. Voorstelle vir verdere studie is gemaak vir die implementering van die sisteem.

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Nomenclature and Abbreviations

3G	Third Generation – Third generation of digital mobile phone technologies
B/O Region	Boland/Overberg Region
CI	Consistency Index
DICOM	Digital Imaging and Communication in Medicine
EDGE	Enhanced Data rates for GSM Evolution – the final stage of the GSM standard for data transfer
EUR	Euro
GBP	Great British Pound
GPRS	General Packet Radio Service – Data transfer mode as part of the GSM phase 2
GSM	Global System for Mobile communications – also known as the second generation of digital mobile phone technologies
ICT	Information and Communication Technology
IFM	Infant Mortality Rate
INCOSE	International Council on Systems Engineering
JPEG	Joint Photographic Experts Group – compressed format for digital images
MDGs	Millennium Development Goals
MMR	Maternal Mortality Ratio
OB/GYN	Obstetrics and Gynaecology
RI	Random Index
SAMRC	South African Medical Research Council
SAQA	South African Qualifications Authority
SE	Systems Engineering

SITA	State Information and Technology Agent
Sonography	An ultrasound-based diagnostic imaging technique. In this report sonography refers to obstetric sonography used during pregnancy.
VAT	Value Added Tax
WHO	World Health Organization
ZAR	South African Rand

1 Introduction

1.1 Maternal Health Care in South Africa

1.1.1 The United Nations Development Goals

As part of their Millennium Development Goals (MDGs), the United Nations prioritizes the improvement of maternal health in developing countries. One target is to reduce by three quarters the Maternal Mortality Ratio (MMR) from 1990 to 2015. MMR is defined as the number of maternal deaths per 100,000 live births. South Africa has a relatively high MMR of between 300 and 549, compared to Europe and the United States of America where the MMR is less than 100. The second target of this MDG is to have universal access to reproductive health care by 2015. This includes ensuring the physical, mental and social well-being of women through pregnancy and childbirth. [1]

According to the World Health Organization (WHO) [2] the most common causes of maternal deaths can be made redundant by simply making health care services more accessible to pregnant women. This includes women seeking treatment without delays. These delays are caused by a lack of transportation and the knowledge on when to seek treatment. Even so, in South Africa, where care is available, women sometimes cannot afford it, and elsewhere only low-quality care is available.

1.1.2 The Medical Skills Shortage in South Africa

According to Government literature, “skills” refer to both qualifications and experience. Scarce skills are classified as either absolute or relative. Absolute scarcity refers to situations where adequately skilled people are not available, whereas relative scarcity refers to skilled people who are available, but do not meet employment criteria. Examples of relative scarcity include people who do not meet Black Economic Empowerment criteria, or skilled people available in urban but not rural areas. [3]

In their case study, Wildschut and Mgqolozana [4] argue that one of the most pressing problems of medical skill shortages in South Africa is the maldistribution of skilled people. This is a relative scarcity between the various provinces, urban and rural areas as well as the private and public sector.

Sonography is a specialization of radiography and is an absolute and relative scarce skill in South Africa. Even though most urban areas and the private sector enjoy quality sonography services, there are not enough skilled people to service both the rural areas and public sector adequately. In 2008, the South African Qualifications

Authority (SAQA) introduced a new qualification, namely a Bachelor of Radiology: Ultrasound. The rationale behind this was given as follows:

"There is a national shortage of qualified sonographers to operate Ultrasound equipment in order to provide safe and accessible service to the public. Many hospitals and clinics, especially in the Government sector, have ultrasound machines but lack the operators with the necessary skills to provide a safe and meaningful service or are using personnel to operate these units who have not undergone formal training and assessment... [Ultrasound] is particularly useful in the assessment of pregnant patient and foetal well-being." [5]

Thus, in accordance with the UN development goals mentioned above, more sonographers and a more even distribution of sonography services in South Africa are required.

1.2 Telemedicine

The South African Medical Research Council (SAMRC) [6] defines telemedicine as "the use of Information and Communication Technology (ICT) to provide and support healthcare activities, when distance separates the participants". It can take many forms and use various technologies. Examples range from telephone calls between medical practitioners consulting on a case, to health tools integrated with the internet to send data asynchronously or in real time. The goal of telemedicine is to create and aid coherent health service information and resource management programmes.

Telemedicine has shown various benefits, including improving accessibility to information, providing care not possible with previous traditional health care methods, improving professional education and reducing health care costs [7].

In rural areas, the professional development of health care workers can be deterred because of their isolation. The reach of specialist care to patients is also limited. An educative telemedicine system can help overcome this by providing training opportunities and consultations with a specialist. These systems can also reduce the cost, travel time and staff absences experienced with traditional training programmes. [8]

1.3 Maternal Health Care Telemedicine Projects in South Africa

The Biomedical Engineering Research Group and the Department of Obstetrics and Gynaecology (OB/GYN) of Stellenbosch University, in collaboration with the Department of Bioengineering at the University of Washington, completed a pilot project in 2008 to improve the quality of maternal health care in South Africa. The following section summarises their project and findings. [9]

The goal of the project was to extend the reach of expert advice to local clinicians where OB/GYN specialists are not available and to improve the clinicians' ultrasound acquisition and interpretation skills.

During the project, a web-based asynchronous telemedicine ultrasound system was developed. The system is composed of a portable ultrasound machine, a laptop and a server. It was evaluated in 2008 by a midwife in South Africa and three OB/GYN specialists in the United States. The midwife had low-level pre-existing ultrasound knowledge and interpretation skills.

The workflow for a patient started with the midwife taking the ultrasound image and transferring it unto the laptop. She then (as far as possible) recorded the patient's health record on a website. After making annotations and adding explanatory text to the image, she uploaded the images and requested a consultation with a specialist. A specialist then logged in when he or she had time and responded to the request. This process iterated until all of the midwife's questions in regard with the patient was answered. Of the 91 women studied, the specialists noted 25 "high-risk" conditions.

The researchers' findings suggest that:

- The service is technically feasible and could expand the availability of prenatal ultrasound to areas where these services have been limited.
- A midwife can be successfully educated to better acquire ultrasound images and interpret them with a web-based asynchronous educative system (or e-learning platform).

The feedback from the users was positive, and the proof of concept deemed successful. They believe that this system could contribute to the goal of reducing maternal mortality in developing countries.

1.4 Health Systems Engineering

A desk-top review by the Department of Health indicates that only 32 of the 86 established telemedicine sites in South Africa were functional at the beginning of 2010 [10]. A need thus exists to provide evidence-based solutions before the implementation of telemedicine systems. In order to evaluate possible solutions, the principles of health systems engineering can be followed.

The International Council on Systems Engineering (INCOSE) [11] defines systems engineering (SE) as "an interdisciplinary approach and [a] means to enable the realization of successful systems". Health systems engineering can thus be defined as the use of SE to meet the health care needs of a target population.

INCOSE states that the value added by a system as a whole, beyond that contributed by its parts, is primarily created by the relationship among the parts. A system's success thus lies in how its elements, namely people, hardware, software, facilities, policies and documentation, are interconnected. [11]

When evaluating a system, it is important to evaluate the viability of all the aspects of the system's elements. This evaluation can be done through a feasibility study, which tests a proposed system's technological, economic, legal, operational and scheduling feasibility. If the proposed system is then deemed successful, a comprehensive implementation plan can be delivered.

1.5 Problem Statement

In the above mentioned ultrasound project, the technology was developed and deemed successful. However, the evaluation of the system was done in controlled circumstances with willing participants. It can thus not be assumed that the system would be accepted by all users, or that the adequate Information and Communication Technology (ICT) infrastructure exists within a typical South African rural clinic.

In their literature study, Broens *et al*. [12] suggest moving from a prototype telemedicine project to small-scale implementation. However, due to the high failure rate of telemedicine systems in South Africa, the need for evidence based solutions before implementation is required [10]. The problem is that the targets of the Millennium Development Goals will only be reached if sustainable solutions are investigated and implemented [13].

1.6 Project Purpose and Research Methodology

The purpose of this project is to find an optimal combination of technology and business processes to meet the sonography skills shortage in South Africa in a sustainable way.

The research map is illustrated in Figure 1.

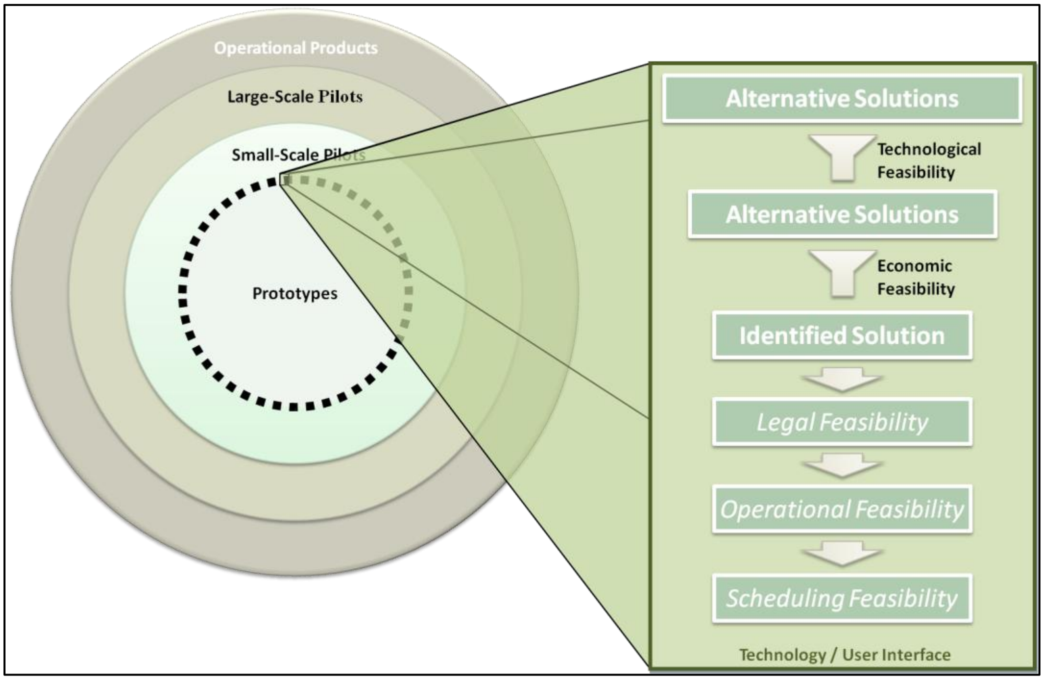

Figure 1: Layered Implementation Model (Source Broens *et al*.) with the Proposed Technology/User Interface Layer

To accomplish this, the following research objectives are set:

- Investigate alternative solutions to address the sonography skills shortage in South Africa.
- Conduct interviews with practicing sonographers, OB/GYN specialists and health district officials.
- Analyse the current obstetric sonography service system of the Boland/Overberg health district.
- Define possible solutions to increase the number of available skilled sonographers in South Africa.
- Evaluate all the possible solutions in terms of their technological feasibility.
- Evaluate all the possible solutions in terms of their economic feasibility.
- Select the most feasible solution.
- Consider the legal implications of the selected solution.
- Develop the business processes and change management strategies to facilitate sustained implementation of the system.
- Propose an implementation framework to ensure the constant evaluation and sustainability of the proposed system

The following subjects will not be included in the scope of the project:

- The purpose of this project is directed towards increasing the number of skilled sonographers in the South African public health sector. For the purpose of this project, only the Boland/Overberg health district status quo sonography service system was evaluated. This is due to the availability of skilled sonographers in this district who can minimise the medical risks involved in introducing a new system. Thus, if a pilot project to increase the available services for an increasing demand is to be tested there and it fails, skilled sonographers are available who can continue delivering services as normal. When selecting feasible solutions however, their roll-out capability to the rest of the country will be evaluated.
- If a patient is diagnosed with a "high-risk" pregnancy, she is referred to either her nearest district hospital or to Tygerberg Hospital. The patient flow after the referral is excluded from this project. Also, this project is mainly concerned with the trainee nurse or midwife role in the system. This is because the need for the system was identified by the specialists at the referral sites, and their user acceptance is thus assumed.
- This project does not include the development of any new technology, even though some suggestions may be made to improve the current system.
- Where medical legislation is discussed, notes on possible areas for concern will be made, but no new policies will be suggested.

1.7 Document Overview

The contents of the remaining chapters in this report are documented as follows:

Chapter 2 shows the literature study that supports the research methodology of this project. The determinants are discussed for how to incorporate systems engineering for successful telemedicine implementation.

In Chapter 3, the current patient flow for the B/O region's foetal sonography services is shown.

Chapter 4 provides the alternative possible solutions to increasing sonography skills levels.

Chapter 5 shows the ICT audit of the ultrasound systems. The technological requirements and the feasibility of each system are discussed.

In Chapter 6 the current economic demand for sonography services in the B/O region is calculated. The economic objectives are discussed for alternative systems to meet an increased demand effectively. The analytic hierarchy process being followed to identify the most effective solution is then shown.

In Chapter 7 the legal feasibility regarding patient consent and data security is discussed.

Chapter 8 shows the operational requirements for the identified system. The process reengineering and human factor considerations to meet these requirements are then discussed.

In Chapter 9 the scheduling plan is presented for the small-scale pilot project. This will include the constant re-evaluation plan for the system.

In Chapter 10 the conclusion of the research and results of the project are presented.

Appendix A shows the project plan for meeting all of the set objectives.

In Appendix B the poster that was presented at the first South African Telemedicine Conference is shown.

2 Literature Study

2.1 Determinants for Successful Telemedicine Implementations

According to Broens *et al*. [12], "telemedicine implementations often remain in the pilot phase and do not succeed in scaling-up to robust products that are used in daily practice". Their study identified the common determinants for successful telemedicine implementations. These were classified in five overhead categories, namely technology, acceptance, financing, organization as well as policy and legislation. Technology and acceptance were the two most reported determinants (66%).

In Figure 2, the proposed layered implementation model for telemedicine systems according to Broens *et al*. [12] is shown. They suggest that during the implementation of a telemedicine system, different determinants should gain focus through the development life cycle phases. This does not indicate that the other determinants should be ignored. It is argued that as a telemedicine system gains maturity from an individual prototype to large scale implementation, the determinants shift from being specific to more generic. This philosophy states that for successful implementation, one should "start small, think big" [12]. DeChant *et al*. [13] echoes this philosophy by suggesting one starts with small telemedicine evaluations and follow it up with larger comprehensive evaluations.

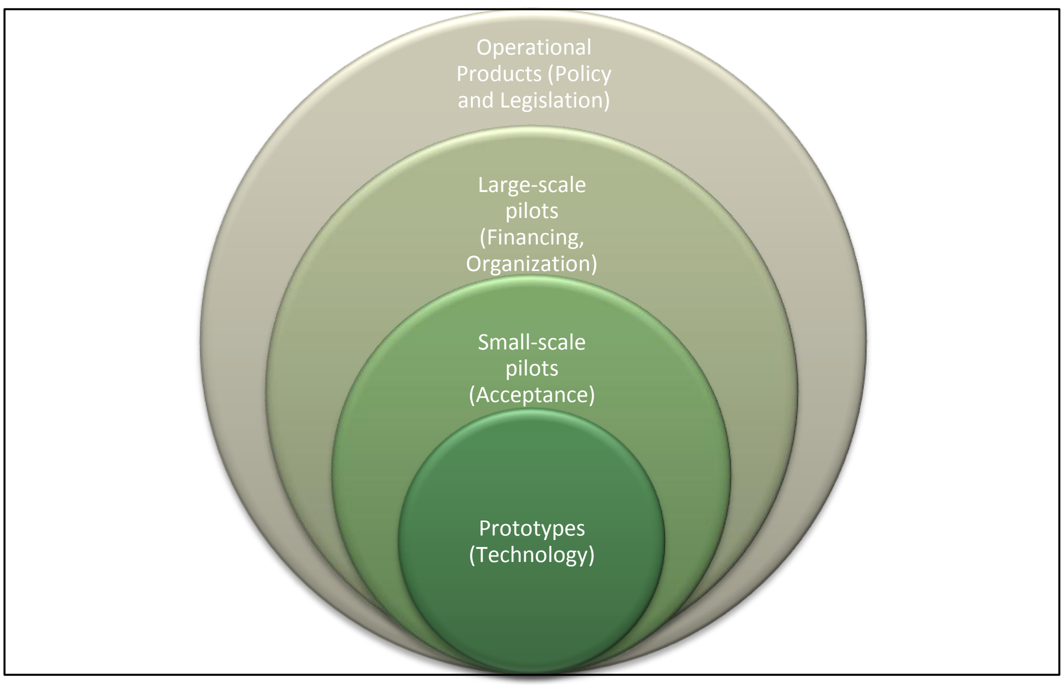

Figure 2: Layered Implementation Model (source: Broens *et al.*)

2.2 Systems Engineering

As mentioned in Chapter 1, systems engineering (SE) is "an interdisciplinary approach and [a] means to enable the realization of successful systems" [11]. One important concept of SE is systems thinking. This requires a systems engineer to look at a system as a whole, and to consider always how the various interconnected parts fit into that whole [15].

The United States Defence System [15] states that with SE one can:

1. Transforms a system's operational needs into descriptive performance parameters.
2. Optimize the total system by ensuring physical and functional compatibility.
3. Integrate reliability, maintainability, safety and other important factors while ensuring that the system meets cost, schedule, supportability and technical requirements.

The V-life cycle, as seen in Figure 3, can be used to describe the SE life cycle. The left hand of the "V" shows the decomposition and definition of the need for a system up to the final design. This includes the evaluation of alternative systems and their ability to meet system objectives. The right hand of the "V" shows the integration and recomposition of the final design towards the execution of the system. The life cycle is an iterative process as verification can cause changes in the analysis. [15]

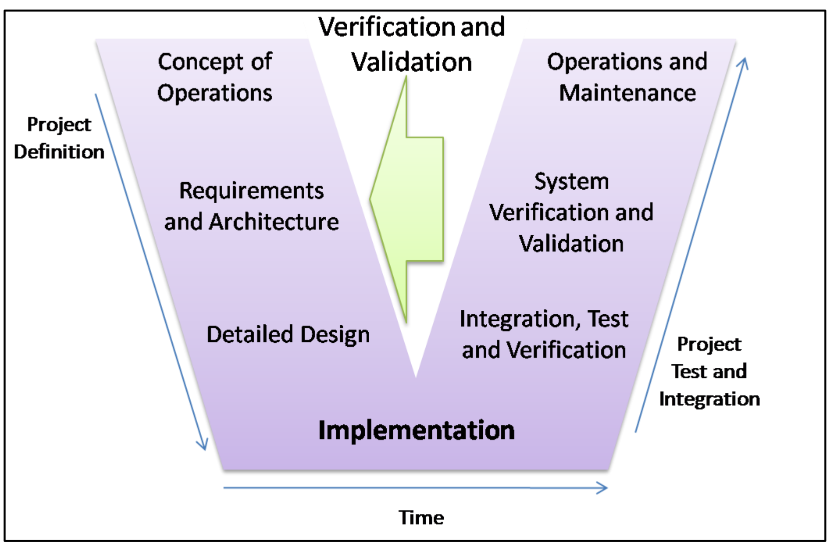

Figure 3: The V-Life Cycle for Systems Engineering
(Source: The Open Systems Engineering Environment, http://www.eclipse.org/osee/)

When optimizing a system, the sub-optimization of its parts is sometimes required. As in the "tragedy of the commons" dilemma, one part may drain resources that should be shared between sub-systems [17]. In health care for example, one service or district may run optimally if it receives plenty of funding from the health care resource pool. This will however be detrimental to other services and districts who then receive little funding.

When applying SE to the service industry, the distinctive aspects of services - compared to manufacturing- should be considered. Firstly, services are information driven. The design of a service system should thus focus on the creation, management and sharing of information. Also, services are user-centric, and a system should preferably be adaptable and customizable according to user needs. [15]

2.3 Feasibility Studies

2.3.1 Introduction

Huis in't Veld et al. state that "there is a lack of methodology to perform well-designed research on the cost- and clinical effectiveness of telemedicine interventions". They suggest that methodologies need to be developed in order to perform evidence-based telemedicine systems. [16]

In the above mentioned ultrasound project, the technology was developed and deemed successful. However, the evaluation of the system was done in controlled circumstances with willing participants. It can thus not be assumed that the system would be accepted by all users, or that adequate ICT systems exist within a typical South African rural clinic context. Also, the technology used is a means of providing a service and not the goal itself. The technological success of a system does not guarantee its success in the public health sector. There, many other factors contribute to a successful system.

Dr Sisira Edirippulige, who has implemented successful telemedicine systems in Queensland, Australia, states that these systems often fail in developing countries due to poor planning. This includes a focus on the technology, and not on stakeholder needs, as well as systems never being integrated into mainstream care. [19]

A feasibility study is a systematic evaluation of the desirability or practicality of a proposed action [18]. This is done by analysing the current mode of operation, defining the system requirements, evaluating alternative solutions and then deciding on the course of action [19]. This correlates with the left-hand side of the V-life cycle model in Figure 3, where successful design parameters for a system are defined.

The five categories of a feasibility study include the technical, economic, legal, operational and scheduling feasibility of the proposal [20]. These categories are discussed in the following sections.

2.3.2 Technological Feasibility

Technological feasibility is carried out to determine if a facility has the required hardware, software, personnel and expertise to initiate and implement a system. This can be done through an ICT audit. An audit is defined as "a methodical examination or review of a condition or situation" [21]. An ICT audit is thus a review of the available ICT infrastructure to support a system.

2.3.3 Economic Feasibility

An economic analysis is done to determine firstly if there is a demand for a system, and secondly to gauge how effectively a system meets those demands. Traditionally this is done through a cost-benefit analysis that determines whether the benefits of the system outweigh its costs. In health care systems however, this is quite often not used because it is difficult to put a monetary value to a patient's health, life or quality of life. Also the costs are not readily quantifiable. For example, there is a social cost related to inaction, in other words where health care systems are not present at all [13].

However, due to budget and human resource constraints, decisions have to be made on the best way to invest funds for public health services. The WHO suggests doing a cost-effectiveness analysis to evaluate interventions. This does not relate the system's costs to its benefits, but to the health gains of it solving the most pressing health problems [23].

2.3.4 Legal Feasibility

Legal feasibility studies look at what legislation may impact on a project and determines the possible extent of the impact on the project. Two areas of legal concern in most telemedicine projects are data security and patient consent [25].

2.3.5 Operational Feasibility

Operational feasibility measures how well a system functions within the daily operation processes of the facility it is implemented in [20]. It is thus mainly concerned with user acceptance [12]. Operational feasibility is studied by evaluating the various ways in which a system can be implemented.

2.3.6 Scheduling Feasibility

For a system to be successful, evaluation need be built into the system [13]. Evaluation in telemedicine includes the safety of using a system as well as its practicality [26]. These evaluation measurements need to be determined during a small-scale pilot to determine the roll-out scheduling feasibility of a system.

2.4 System Evaluation Roadmap

Based on the above mentioned health systems engineering and feasibility study principles, the system evaluation roadmap is illustrated in Figure 4. Alternative solutions are evaluated for their technological feasibility. Technologically feasible solutions then lead to the economic evaluation.

For the purpose of this project, it is assumed that a system that is technically and economically feasible can be implemented in such a way as to be legally and operationally feasible. Thus, from the technical and economic feasibility studies, the most feasible solution will be further evaluated. The conditions under which this identified system is legally and operationally feasible are then determined. Finally, the scheduling feasibility conditions are recommended.

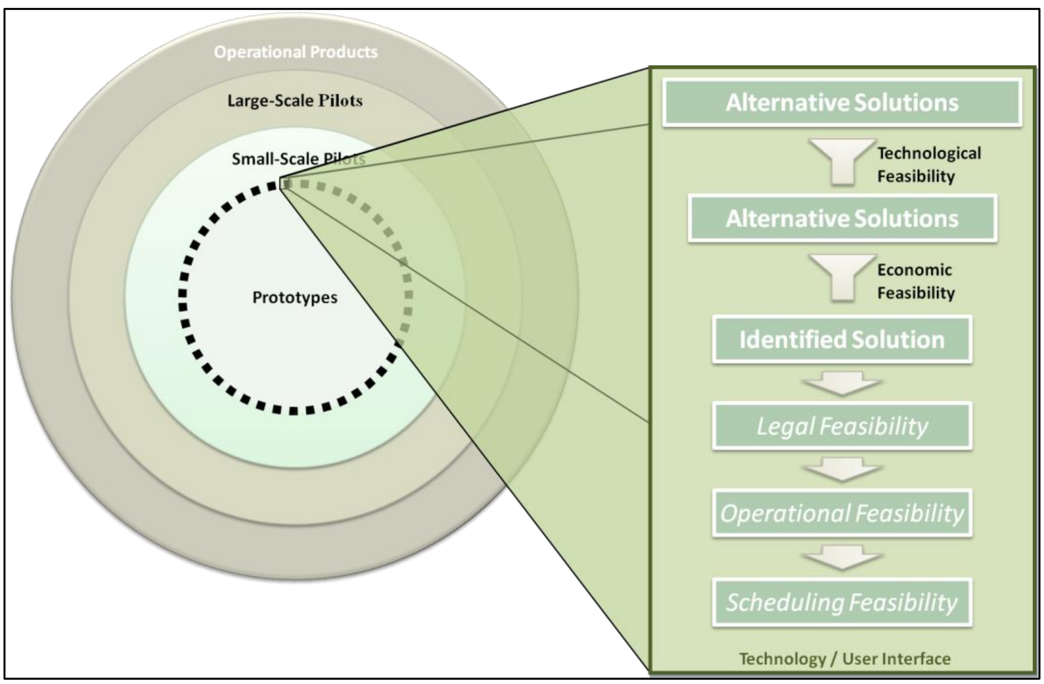

Figure 4: System Evaluation Roadmap

3 The Current Obstetric Sonography Service System (Status Quo System)

The current patient care process for pregnant women in the Boland/Overberg health district clinics can be seen in Figure 5. A patient arrives at her local clinic and consults with a nurse. The nurse captures the patient's health information on paper. If it is determined that she is under 24 weeks pregnant, the nurse makes an appointment for the patient to see the sonographer. (It is the protocol of the health district to give one free ultrasound examination to each patient before she is 24 weeks pregnant.) If she is over 24 weeks pregnant, she only visits the clinic nurse again every 4 – 6 weeks until giving birth. In this case the nurse only takes the fundal

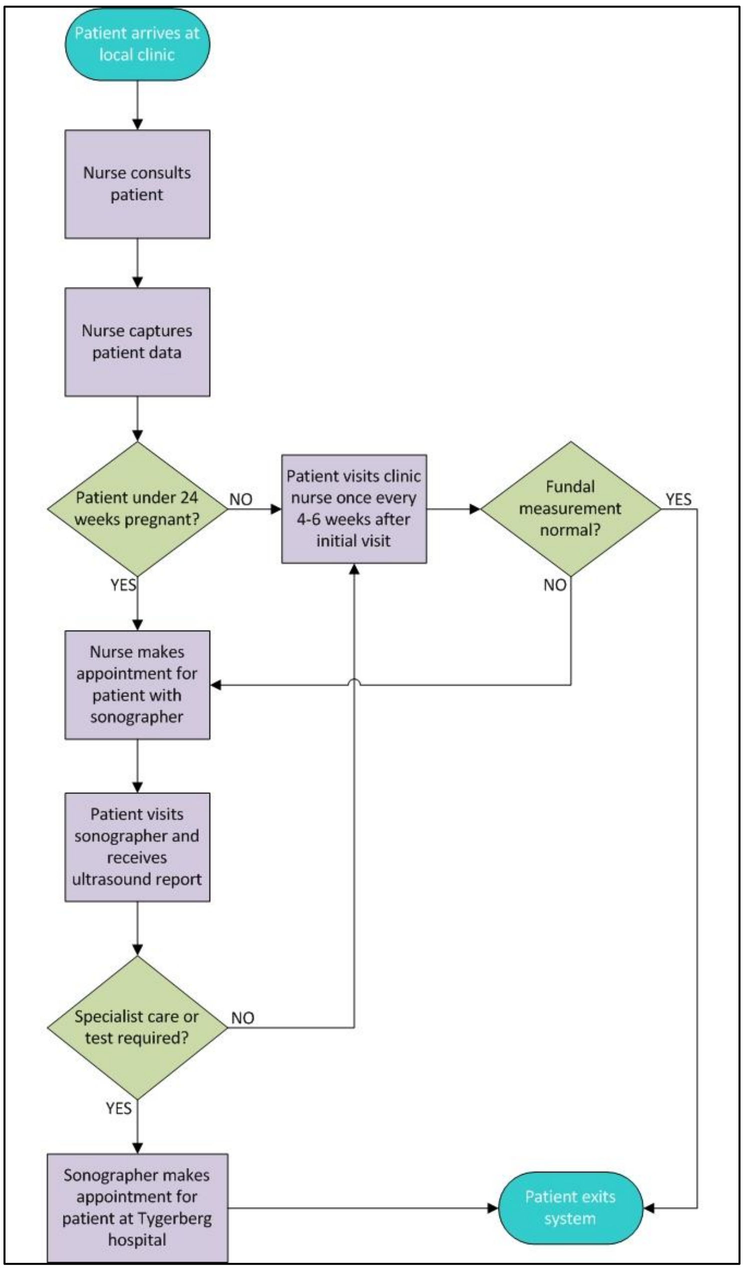

Figure 5: Current Patient Care Process

measurement (a measurement from the pelvis bone to the top of the uterus) to see if the foetal growth is normal. If the growth is not normal, or there are other symptoms of anomalies, the nurse makes an appointment for the patient with the sonographer. At some clinics the patient is tasked with keeping her health information paper and taking it to her sonographer or specialist appointment. At others the health record is filed at the clinic. [32]

Currently, there is one sonographer who serves the entire Boland and Cape Winelands health district, and one who serves the Overberg region. Each sonographer travels with a portable ultrasound machine according to a predetermined schedule. They set up this schedule themselves according to the demands from each clinic. The sonographers visit one clinic per day for up to 6 hours. The nurses schedule their appointments for 5 patients per hour. [32]

After a patient has visited the sonographer, she receives a report detailing all the relevant foetal information. If there are any areas of clinical concern, the sonographer refers the patient to Tygerberg Hospital for tests. The necessary skilled personnel and equipment to perform these tests are not available at the clinics or the district hospitals. [32]

4 Alternative Ultrasound Solutions

4.1 Introduction

As discussed in Chapter 1, the success of a system within controlled circumstances does not prove its feasibility in real-world applications. The system's feasibility is also relative. Other system may be more feasible under certain conditions. For these reasons, alternative systems from the asynchronous ultrasound system pilot project are being evaluated to ensure that the most feasible solution is chosen to meet the sonography service demands in South Africa. This is illustrated in Figure 6. These alternative systems are described in the following sections.

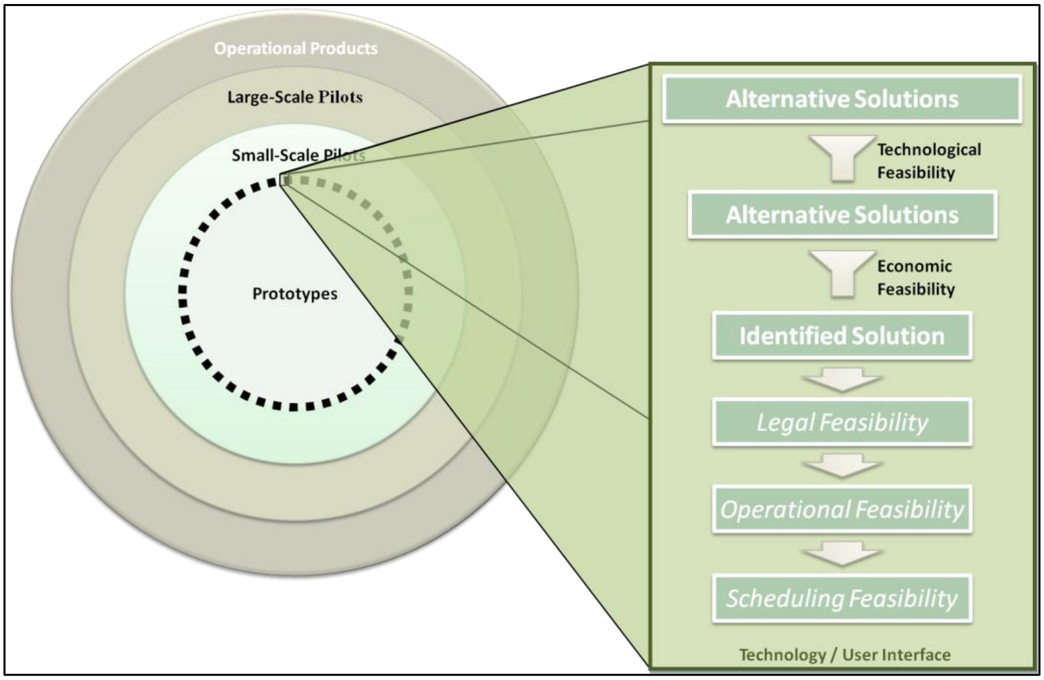

Figure 6: System Evaluation Roadmap

4.2 Telemedicine Systems

4.2.1 Introduction

As mentioned in section 1.3, telemedicine can occur either in real-time or asynchronously. The pilot project described in Chapter 1 was tested as an asynchronous system. In the following sections, other telemedicine systems are discussed.

4.2.2 Synchronous Ultrasound Systems for Individual Training

The main advantage of synchronous telemedicine is that it delivers real time results. Patients do not have to leave the clinic and return for follow-up visits [28]. In South Africa this is especially advantageous because of patients' lack of transportation [2]. However, the disadvantage is that the consulting specialist and the remote clinician have to be available at the same time [27]. In the South African public health sector where patients generally do not make appointments beforehand to see a clinic nurse, the availability of a specialist can thus not be guaranteed. Scheduled follow-up visits are thus often required, which nullifies the advantage originally mentioned.

The University of Queensland published a study in 1999 in which they calculated the minimum requirements for remote real-time foetal tele-ultrasound consultations. During the test, three experienced clinicians evaluated the quality of a live ultrasound feed transmitted from a remote location. Various bandwidths were tested for the diagnosis of foetal anomalies. The specialists deemed the second level that used a 384kbit/s link as adequate for most diagnoses. There was only a slight improvement of evaluation at the third bandwidth level of 1 Mbit/s. [30]

It should be noted though that during this study only the real-time images were received and no verbal communication took place between participants. The required bandwidth will be more if the participants were to communicate using the same data channel that transfers the sonogram feed.

4.2.3 Synchronous Virtual Classrooms

The School of Nursing and the Department of Telehealth at the University of Kwazulu Natal are currently setting up video conferencing venues for teaching student nurses at remote sites. The project is made available through donor funding. Two venues were identified, one to hold 24 students and the other to hold 50 students. Even though they did experience technical difficulties and delays in setting up adequate internet connections, the project is so far deemed successful. [29]

The advantage of a system as described above is that it is a cost-effective way of educating groups in a few remote areas. This keeps the students in their workplace and saves travel time and money [29]. Web-conferencing software such as Adobe® Connect™ [30] needs only one software package for meetings with up to 100 participants. There are also many free open source tools available [31]. However, when the aim of distance education is to synchronously teach single learners at a large number of remote facilities, the solution is less cost-effective. The hardware costs (including internet connection, adequate personal computers and any simulator skill sets) increase linearly with each remote site added.

The minimum required bandwidth for audio and video conferencing is between 300 and 400 kbit/s [32]. These requirements can be more for the web conferencing host, depending on the software used [30].

4.3 On-site Ultrasound Training Systems

4.3.1 Ultrasound Simulators

Simulation technologies can be used by medical institutions to train health care professionals in a risk free way. Simulation can range from simple documentation describing symptoms of a real medical case, to intricate mannequins replicating patients. It is used to train and then judge the competencies of health sciences students during examinations and also for the continuing education of health care professionals. [33]

Advantages of medical simulation include patient safety, repetition for students to gain confidence and the development of critical thinking and decision making skills. Students have however described simulation technology as intimidating. This is due to their unfamiliarity with the specific hardware and software functionality. Simulation also requires critical and disciplined self reflection if a senior advisor is not available to monitor a student's progress. [26]

With ultrasound, the main advantage of simulation is that common and rare anomalies that ultrasound is intended to detect can be simulated. This gives health care workers the opportunity to familiarise with and prepare themselves for these cases without having to find suitable volunteers. [27]

One example of a simulation training product is the Schallware Ultrasound Simulator. It has various modules that focus on various ultrasound applications, including gynaecology and obstetrics. An OB/GYN module consists of a pregnant female dummy torso, up to 12 pre-recorded patient cases, the OB/GYN specific ultrasound probe and a LINUX Personal computer with Schallware software. At the time of this project, such a system cost 24,500EUR excluding VAT (approximately 233,000 ZAR). This excludes the additional (but necessary) options that can be seen in Table 1. [28]

Option	Price (excluding VAT) in EUR	Approximate price (excluding VAT) in ZAR
Module Training	1,500	14,300
Transportation Case	1,200	11,400
Support Services (per year)	1,500	14,300

Table 1: Extra Options Prices for Schallware Ultrasound Simulator
(Source: http://www.schallware.de/downloads/schallwarede.pdf)

Another commercially available simulator is the UltraSim Ultrasound Training Simulator. This product currently does not have a model to simulate pregnancy. The cost of this simulator, with the required dummy and probe, is approximately 36,000 GBP including VAT (approximately 393,000 ZAR). [33]

Other simulators for pregnancy are being developed by institutions such as the Fraunhofer Institute the Polytechnical University of Stralsund, both in Germany, and Saint George's Hospital in London [29]. However, despite academic publications, these simulators seem to be not yet available commercially. It is thus assumed that the above mentioned example is the present price one can expect of an ultrasound pregnancy simulator.

4.3.2 Asynchronous Ultrasound Training without Data Transfer

A possible solution is to use the pilot project concept but without transferring the data. Images can be stored on a computer at each clinic and then evaluated when a sonographer visits the clinic. This can reduce ICT costs and provide the trainee the opportunity to receive feedback from the sonographer in person. This system will however only work where sonographers or specialist are readily available.

5 Technological Feasibility

5.1 Introduction

Technological feasibility is concerned with hardware, software, personnel and expertise requirements. For the purpose of this project, technology training of personnel is discussed under the operational feasibility. It is assumed that any new technological system requires adequate personnel training. The purpose of this section is to identify the systems that are feasible within a South African context. As seen in Figure 7, only the technologically feasible systems will be evaluated further.

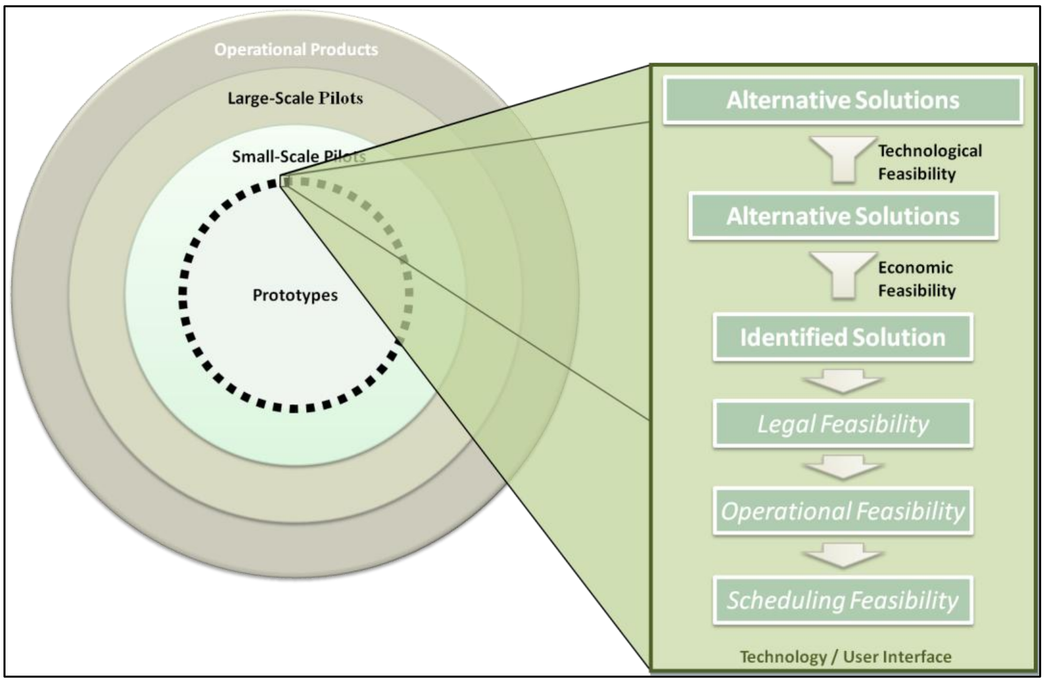

Figure 7: System Evaluation Roadmap

5.2 Information and Communication Technology Audit

5.2.1 Ultrasound Machines

In medical imaging, the standard image format is Digital Imaging and Communication in Medicine (DICOM). It was developed in 1993 to ensure compatibility when displaying, producing, storing, sending and retrieving medical images. An ultrasound machine uses its proprietary software to batch compress acquired images to JPEG (an abbreviation of Joint Photographic Experts Group for which the format is named) which can be viewed on most personal computers. The DICOM to JPEG compression is lossless, and thus the quality of an image remains the same even though the image size decreases. The mean compression ratio of DICOM to JPEG compression is 3.81. Ultrasound images are greyscale, and thus each pixel requires 16 bits. [37]

Currently, the ultrasound machines in use in most of the B/O clinics and hospitals are not USB compatible and cannot digitise images. Since these machines were acquired before 1993, they also do not use the DICOM image standard. [31]

The Department of Health's B/O region is, at the time of this project, acquiring new ultrasound machines for its clinics and hospitals. A timeline for the installation of these machines was however unavailable. It can be assumed though that these new machines will comply with modern industry standards and thus be USB compatible and use the DICOM standard.

5.2.2 Hospital and Clinic Computer Use

Hospitals such as the Eben Donges Hospital in Worcester do use digital patient databases and have internet connections to send images and documents to specialist referral sites. Most clinics however still run on a paper based system. Even though the clinics own computers, they are often not used and not connected to the internet. [26]

5.2.3 Internet Connectivity in South Africa

5.2.3.1 Introduction

As mentioned above, rural clinics in South Africa do not have internet connectivity [26]. There are two options for internet access, mobile or wired connectivity. These are discussed in the following sections.

5.2.3.2 South African Mobile Data Coverage

There are various generations of standards for mobile telecommunications. A third generation (3G) modem, as was used in the pilot project, can transfer data using any of the previous generations of technologies. The data technology used for transfer depends on the data coverage of the location of the modem. The maximum data transfer rates of downloading data using these technologies are shown in Table 2. [38]

Technology	Maximum Transfer Rate (kbit/s)
GSM (2G)	9.6
GPRS (2.5G)	40
EDGE	128
3G	384

Table 2: Data Transfer Rate of Various Generation Technologies

(Source: http://www.gsm.org/technology/index.htm)

Figure 8 shows the data coverage in South Africa for 3G, GPRS/GSM and EDGE. It can be seen that 3G is rarely available in the rural regions and that the use of EDGE coverage is to be expected. Thus, when using mobile technologies, a maximum data transfer rate of 128 kbit/s can be expected.

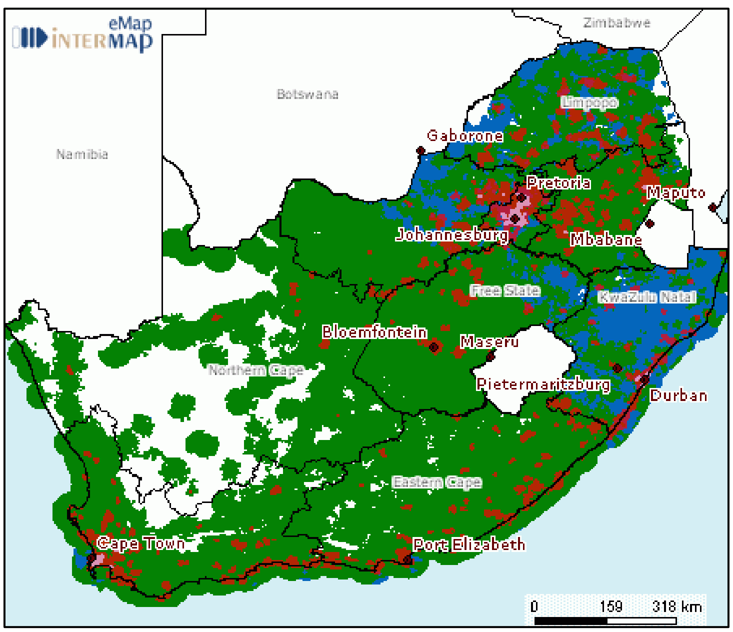

Figure 8: 3G (red), GPRS/GSM (blue) and EDGE (green) Data Coverage in South Africa

Source: http://www.vodamap.net/3g/

5.2.3.3 Wired Internet Connectivity

Broadband refers to internet data access at a greater data transfer speed than another standard. In South Africa, Broadband refers to speeds higher than 256kbit/s. Asymmetric Digital Subscriber Line (ADSL) is Broadband access that is a modem based communication technology that uses ordinary telephone lines. [39]

Commercially in South Africa, Internet Service Providers (ISPs) such as MWEB [40] and Telkom [39], provide ADSL connections at the following transfer rates:

ADSL Package	Download speeds (kbit/s)	Upload speeds (kbit/s)
Fast DSL	384	192
Faster DSL	512	256
Fastest DSL	4096	384

Table 3: Data Transfer Rates for ADSL Connectivity
(Source: http://www.mweb.co.za/productspricing/Portals/19/Pdf/MWEB_Uncapped_ADSL.pdf)

5.2.4 Data Server Audit

The State Information and Technology Agent (SITA) is a government institution that consolidates and coordinates the state's information technology resources. These include the sourcing, operation and support of data hosting and data centres on behalf of government departments. SITA can thus acquire a data server on behalf of the Department of Health if required. [34]

5.3 Technical Requirements Summary

The technical requirements for the possible ultrasound service systems are summarised in Table 4. Technically, all the solutions are feasible. This assumption is made under the conditions that the new ultrasound machines will be installed in time for implementation, and that SITA can meet all data server requirements.

In some cases, systems are considered technologically feasible even though the technological infrastructure is not yet available. For example if video conferencing or synchronous tele-ultrasound were to be implemented, wired connections would have to be installed to meet the required bandwidth requirements. This would incur extra costs that are taken into account in the economic feasibility evaluation in Chapter 6.

		Requirements			
Solution	Document Reference	DICOM or Digitally Compatible Ultrasound Machine Required?	Computer Use Required?	Internet Connectivity Requirements	Data Server required?
Status quo	Chapter 3	No	No	None	No
Asynchronous Tele-Ultrasound Pilot Project	Section 1.3	Yes	Yes	3G Mobile Modem	Yes
Synchronous Tele-Ultrasound	Section 4.1.1	Yes	Yes	Minimum 384 kbit/s connectivity	No
Synchronous Virtual Classroom	Section 4.1.2	No	Yes	300 – 400 kbit/s	Yes
Ultrasound Simulator	Section 4.2.1	No	Yes	None	No
Asynchronous Ultrasound Without Data Transfer	Section 4.2.2	Yes	Yes	None	No

Table 4: Technological Data Requirements for Possible Solutions

6 Economic Feasibility

6.1 Introduction

When implementing solutions that address health system inadequacies, it is difficult to put a monetary value on the added value of a system. A solution should be sustainable though, however effective it is in solving health system problems. For this reason, a economic feasibility study is completed to determine the most feasible solution for addressing an increasing demand for skilled sonography services in the B/O region. This is illustrated in the system evaluation roadmap in Figure 9.

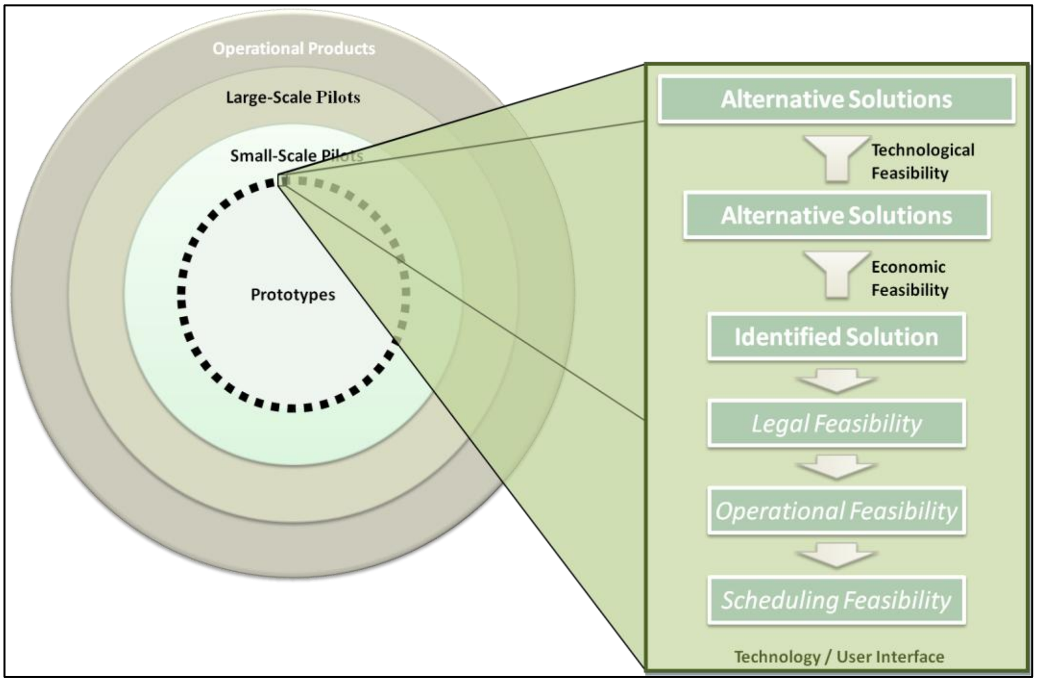

Figure 9: System Evaluation Roadmap

6.2 Demand for Sonography Services

In 2007, there were 10 191 births in the B/O region [44]. As was mentioned previously, it is in the protocol of the B/O region to give one free ultrasound for a woman under 24 weeks pregnant. This is however not ideal. Two ultrasounds are preferable for quality health care, one for the end of both the first and second trimester [31].

Assuming a uniform distribution of service demand throughout the year, the maximum available sessions per sonographer per year can be calculated as follows:

*52 * 5*	*Working days per year*	
- 12	*Public holidays per year*	
- 15	*Paid leave days per year*	
-12	*Sick leave days per year*	
- 44	*Administration days*	
= 177	***Available working days***	*(Eq. 6.1)*
** 6*	*Available working hours per day (excluding travelling time)*	
= 1 062	***Available working hours per year***	
**5*	*Available 12 minute sessions per hour*	
= 5 310	***Available 12 minute sessions per year per sonographer***	

This shows that if both sonographers work full time, they just cover the demand for the current protocol for sonography services. There is however very little room for ineffective scheduling or a maldistribution of patient visits throughout the year. Also, if the ideal protocol of two ultrasounds per pregnant woman is to be realised, more skilled sonographers are required.

6.3 Cost Effectiveness Analysis

6.3.1 Analytic Hierarchy Process

The analytic hierarchy process was developed by an American mathematician, Thomas Saaty [36]. He argues that in cases where solution objectives are not readily quantifiable, relative pair-wise comparisons of these objectives can aid decision making [37]. This process is used to evaluate which ultrasound system can meet the economic demands and objectives for sonography services in the B/O region most effectively.

6.3.2 Objectives

An effective telemedicine solution must be a sustainable one [13]. It is thus important to evaluate systems in the context in which they will be implemented. The following solution objectives will be taken into consideration when measuring the feasibility of meeting economic demands:

- Low cost: The public health sector delivers services to approximately 80% of the South African population, and the state contributes 40% of its expenditures [38]. In realising the MDG target of universal access to maternal health care [1], reducing the cost of quality health care is essential. This includes reducing the cost of human resources and travelling.
- Technological infrastructure availability: When implementing solutions, care should be taken to ensure that the existing ICT infrastructure meets the system requirements. As discussed in chapter 5, this can include acquiring data servers or wired internet connectivity.
- Quality of training or diagnosis: The MDG targets include improving access to maternal health care and reducing the MMR [1]. It is thus necessary to minimise medical errors and misdiagnoses due to inadequate training so that maternal deaths are avoided. It is thus important that trainees receive training relevant to the South African patient profile and gain skills experience. The quality of training also refers to the relevance of the training. For example, a typical South African patient profile differs from a typical European profile. In the Western Cape for instance, foetal alcohol syndrome and HIV/AIDS cases are more prevalent than they are in Europe. Thus, if case studies are used for training, typical South African profiles should be used [48].
- Ease of implementation: From an economic point of view, this refers to the ease with which solutions are acquired and implemented. This does not refer to possible resistance to change from users upon implementation. For example, most sonographers who get a BTech degree either enter private practise or emigrate [26]. This is due to the relatively poor salaries that the public health sector offers and the difficult working conditions. It is thus difficult to find graduates who are willing to enter the public health sector. Also, ease of implementation refers to the number of health care workers who must be available simultaneously for the system to be cost effective.
- Personnel Availability: In many rural sites across South Africa, sonogram services are performed by nurses and doctors who are unqualified to do this because qualified sonographers and OB/GYN specialists are unavailable [26]. Systems should thus not rely on the onsite availability of experienced sonographers or specialists, or take for granted that a specialist will be readily available for tele-consultations. This thus tests for the roll-out capability of a system.

The following referral system will be used for the objectives in the analytic hierarchy process:

Objective	Analyses Reference
Low cost	LC
Technology availability	TA
Quality of training	QT
Ease of implementation	EI
Personnel Availability	PA

Table 5: Objective References in the Analytic Hierarchy Process

6.3.3 Possible Solutions

The possible solutions to be that are evaluated is shown in Table 6.

Solution	Document Reference	Analyses Reference
Status quo with two new sonographers	Chapter 3	SON
Asynchronous tele-ultrasound pilot project	Section 1.3	AUS
Real-time tele-ultrasound	Section 4.1.1	RTC
Synchronous Virtual Classroom	Section 4.1.2	VCR
Ultrasound Simulator	Section 4.2.1	USS
Asynchronous Ultrasound Without Data Transfer	Section 4.2.2	AWT

Table 6: Possible Solutions to be Evaluated

6.3.4 Analyses

6.3.4.1 Relative Comparison of Objectives

The first step in the analytic hierarchy process is to determine the relative importance of the objectives of the ideal solution [45]. The relative importance of the objectives is mostly subjective. However, information gathered from interviews with the region’s current sonographers, OB/GYN specialists and health district officials, as well as a thorough study of the current system and the available literature resulted in a realistic ranking of the objectives.

Matrix A shows these pair wise comparisons. Entry a_{ij} (row i and column j) indicates how much more important objective i is than objective j. (Please refer to Table 5 for the objective references.) For example, the "low cost" objective is three times more important than "quality of training".

$$A_{Objectives} = \begin{array}{c} \\ LC \\ TI \\ QT \\ EI \\ PA \end{array} \begin{array}{c} \begin{array}{ccccc} LC & TI & QT & EI & OA \end{array} \\ \begin{bmatrix} 1 & 4 & 3 & 9 & 3 \\ 0.25 & 1 & 0.5 & 4 & 2 \\ 0.33 & 2 & 1 & 6 & 1 \\ 0.11 & 0.25 & 0.17 & 1 & 0.33 \\ 0.33 & 0.5 & 1 & 3 & 1 \end{bmatrix} \end{array}$$

By normalising Matrix A, the weight given to each objective can be calculated with the following formula:

$$w_i = \frac{\sum_{j=1}^{n} a_{norm_{ij}}}{n} \qquad \textit{(Eq 6.2)}$$

This results in a relative weighting as shown in Vector **w**:

$$w = \begin{array}{ccccc} LC & TI & QT & EI & PA \\ 0.47 & 0.16 & 0.2 & 0.04 & 0.13 \end{array}$$

6.3.4.2 Testing for Consistency of Objectives

The next step is to ensure that the comparisons are consistent. For example, "low cost" is four times more important than "technology infrastructure" and three times more important than "quality of training". Thus, "quality of training" should be more important when compared to "technology infrastructure". To check for consistency, the following steps are taken [45]:

1. Matrix A is multiplied by the transposed vector **w** to find A$\mathbf{w}^T$.

$$Aw^T = \begin{bmatrix} 1 & 4 & 3 & 9 & 3 \\ 0.25 & 1 & 0.5 & 4 & 2 \\ 0.33 & 2 & 1 & 6 & 1 \\ 0.11 & 0.25 & 0.17 & 1 & 0.33 \\ 0.33 & 0.5 & 1 & 3 & 1 \end{bmatrix} \begin{bmatrix} 0.47 \\ 0.16 \\ 0.2 \\ 0.04 \\ 0.13 \end{bmatrix} = \begin{bmatrix} 2.5 \\ 0.8 \\ 1.1 \\ 0.2 \\ 0.7 \end{bmatrix}$$

2. The following is calculating:

$$\frac{1}{n}\sum_{i=1}^{i=n} \frac{i^{th} entry\ in\ Aw^T}{i^{th}\ entry\ in\ w^T} \qquad \text{(Eq 6.3)}$$

   This steps result is equal to 5.19.

3. The consistency index (CI) is calculated using equation 6.4.

$$CI = \frac{(Step\ 2\ result) - n}{n-1} \qquad \textit{(Eq 6.4)}$$

   The consistency index is equal to 0.047.

4. The CI is then compared to the random index (RI) for the appropriate n value, as shown in Table 7. This ratio is called the degree of consistency. For meaningful results, a ratio of smaller than 0.1 is desired.

n	RI
2	0
3	0.58
4	0.9
5	1.12
6	1.24

Table 7: Values of Random Index *(Source: Operations Research, W. Winston)*

The CI/RI ratio is thus equal to 0.042 for n equal to 5. This degree of consistency is satisfactory because it is smaller than 0.1.

6.3.4.3 Finding the Score for each Alternative Objective

For each objective a pair-wise comparison matrix is set up. These matrices show the relative degree to which each possible solution meets that objective compared to the other solutions. A vector w is then calculated to indicate the relative weights of each solution. This is calculated in the following way:

Matrix B shows the pair-wise comparison matrix for the low cost objective. The solutions that require one specialist without travel expenses carry equal weights. The asynchronous ultrasound without data transfer scores slightly less due to sonographer travelling time and expenses. The sonographers who require high salaries and the high cost of simulators cause these solutions to score poorly.

$$B_{LC} = \begin{array}{c} \\ AUS \\ SON \\ RTC \\ USS \\ VCR \\ AWT \end{array} \begin{array}{c} \begin{array}{cccccc} AUS & SON & RTC & USS & VCR & AWT \end{array} \\ \begin{bmatrix} 1 & 9 & 1 & 7 & 1 & 2 \\ 0.11 & 1 & 0.11 & 0.5 & 0.11 & 0.11 \\ 1 & 9 & 1 & 7 & 1 & 2 \\ 0.14 & 2 & 0.14 & 1 & 0.14 & 0.14 \\ 1 & 9 & 1 & 7 & 1 & 2 \\ 0.5 & 9 & 0.5 & 7 & 0.5 & 1 \end{bmatrix} \end{array}$$

By obtaining $B_{normalized}$ and finding the average value of each row, the relative weighting score of each solution in terms of the low cost objective can be calculated. This weight is represented by w_{LC}.

$$B_{normalized} = \begin{array}{c} \\ AUS \\ SON \\ RTC \\ USS \\ VCR \\ AWT \end{array} \begin{array}{c} \begin{array}{cccccc} AUS & SON & RTC & USS & VCR & AWT \end{array} \\ \begin{bmatrix} 0.27 & 0.23 & 0.27 & 0.24 & 0.27 & 0.28 \\ 0.03 & 0.03 & 0.03 & 0.02 & 0.03 & 0.02 \\ 0.27 & 0.23 & 0.27 & 0.24 & 0.27 & 0.28 \\ 0.04 & 0.05 & 0.04 & 0.03 & 0.04 & 0.02 \\ 0.27 & 0.23 & 0.27 & 0.24 & 0.27 & 0.28 \\ 0.13 & 0.23 & 0.13 & 0.24 & 0.13 & 0.14 \end{bmatrix} \end{array} \qquad w_{LC} = \begin{bmatrix} 0.26 \\ 0.02 \\ 0.26 \\ 0.04 \\ 0.26 \\ 0.17 \end{bmatrix}$$

In the same way the weighting for each solution in terms of the rest of the objectives can be calculated.

Matrix C shows the pair-wise comparison matrix for technological Infrastructure and w_{TI} the relative weights. It can be seen that those solutions that require bandwidth only achievable through wired internet connectivity carry equal weights. The asynchronous tele-ultrasound system can operate with mobile internet connectivity and thus scores better. The other solutions require no additional technological infrastructure and thus score equally.

$$C_{TI} = \begin{array}{c} \\ AUS \\ SON \\ RTC \\ USS \\ VCR \\ AWT \end{array} \begin{array}{c} \begin{array}{cccccc} AUS & SON & RTC & USS & VCR & AWT \end{array} \\ \begin{bmatrix} 1 & 0.33 & 4 & 0.33 & 4 & 0.33 \\ 3 & 1 & 6 & 1 & 6 & 1 \\ 0.25 & 0.25 & 1 & 0.17 & 1 & 0.17 \\ 3 & 1 & 6 & 1 & 6 & 1 \\ 0.25 & 0.25 & 1 & 0.17 & 1 & 0.17 \\ 3 & 1 & 6 & 1 & 6 & 1 \end{bmatrix} \end{array} \qquad w_{TI} = \begin{bmatrix} 0.12 \\ 0.27 \\ 0.04 \\ 0.04 \\ 0.27 \\ 0.27 \end{bmatrix}$$

Matrix D shows the pair-wise comparisons and w_{QT} show the relative weighting of each solution in terms of quality of training. The real-time consulting and asynchronous without transfer solutions score equally due to the one-on-one feedback given to the trainee. The simulator scores poorly due to the limited availability of patient profiles.

$$D_{QT} = \begin{array}{c} \\ AUS \\ SON \\ RTC \\ USS \\ VCR \\ AWT \end{array} \begin{array}{c} \begin{array}{cccccc} AUS & SON & RTC & USS & VCR & AWT \end{array} \\ \begin{bmatrix} 1 & 0.2 & 0.5 & 3 & 7 & 0.5 \\ 5 & 1 & 4 & 7 & 9 & 4 \\ 2 & 0.25 & 1 & 4 & 8 & 1 \\ 0.33 & 0.14 & 0.25 & 1 & 4 & 0.25 \\ 0.14 & 0.11 & 0.13 & 0.25 & 1 & 0.13 \\ 2 & 0.25 & 1 & 4 & 8 & 1 \end{bmatrix} \end{array} \qquad w_{QT} = \begin{bmatrix} 0.12 \\ 0.46 \\ 0.17 \\ 0.06 \\ 0.2 \\ 0.17 \end{bmatrix}$$

Matrix E shows the pair-wise comparisons and w_{EI} show the relative weighting of each solution in terms of ease of implementation. The simulator scores the best due to the trainee's independent learning from a specialist. The virtual classroom scores poorly due its requirement for synchronised meetings with many health care workers.

$$
E_{EI} = \begin{array}{c} \\ AUS \\ SON \\ RTC \\ USS \\ VCR \\ AWT \end{array}
\begin{array}{c} \begin{array}{cccccc} AUS & SON & RTC & USS & VCR & AWT \end{array} \\
\begin{bmatrix} 1 & 2 & 2 & 0.5 & 3 & 1 \\ 0.5 & 1 & 1 & 0.33 & 2 & 0.5 \\ 0.5 & 1 & 1 & 0.33 & 2 & 0.5 \\ 2 & 3 & 3 & 1 & 3 & 2 \\ 0.33 & 0.5 & 0.5 & 0.33 & 1 & 0.33 \\ 1 & 2 & 2 & 0.5 & 3 & 1 \end{bmatrix} \end{array}
\qquad
w_{EI} = \begin{bmatrix} 0.2 \\ 0.11 \\ 0.11 \\ 0.32 \\ 0.07 \\ 0.2 \end{bmatrix}
$$

Matrix F shows the pair-wise comparisons and w_{PA} shows the relative weighting of each solution in terms of personnel availability. The simulator scores best due to the trainee's independent learning from a specialist. The asynchronous without transfer and the additional sonographer solution score equally poor due to the absolute and relative scarcity of skilled sonographers in South Africa. The real-time consulting solution scores poorly due its time consuming nature and thus the need for the availability of many specialists.

$$
E_{PA} = \begin{array}{c} \\ AUS \\ SON \\ RTC \\ USS \\ VCR \\ AWT \end{array}
\begin{array}{c} \begin{array}{cccccc} AUS & SON & RTC & USS & VCR & AWT \end{array} \\
\begin{bmatrix} 1 & 7 & 5 & 0.25 & 1 & 7 \\ 0.14 & 1 & 0.33 & 0.11 & 0.14 & 1 \\ 0.2 & 3 & 1 & 0.14 & 0.2 & 3 \\ 4 & 9 & 7 & 1 & 4 & 9 \\ 1 & 7 & 5 & 0.25 & 1 & 7 \\ 0.14 & 1 & 0.33 & 0.11 & 0.14 & 1 \end{bmatrix} \end{array}
\qquad
w_{PA} = \begin{bmatrix} 0.20 \\ 0.03 \\ 0.07 \\ 0.47 \\ 0.20 \\ 0.03 \end{bmatrix}
$$

6.4 Summary

In summary, the solutions and their relative weightings are summarised in Table 8.

	LC	TI	QT	EI	PA	SUM	Rank
weight:	0.47	0.16	0.20	0.04	0.13		
AUS	0.26	0.12	0.02	0.20	0.20	**0.178**	1
SON	0.02	0.27	0.04	0.11	0.03	**0.071**	6
RTC	0.26	0.04	0.01	0.11	0.07	**0.142**	4
USS	0.04	0.27	0.04	0.32	0.46	**0.144**	3
VCR	0.26	0.04	0.01	0.07	0.20	**0.158**	2
AWT	0.17	0.27	0.04	0.20	0.03	**0.142**	4

Table 8: Analytic Hierarchy Process Summary

From this evaluation, it can be seen that the asynchronous tele-ultrasound system is the most feasible. This system will be evaluated for its legal, operation and scheduling feasibility requirements in the following chapters.

7 Legal Feasibility

7.1 Introduction

Patient consent and confidentiality are possible areas of concern when implementing telemedicine systems. This is referred to in Figure 10 as legal feasibility and is discussed in the following sections.

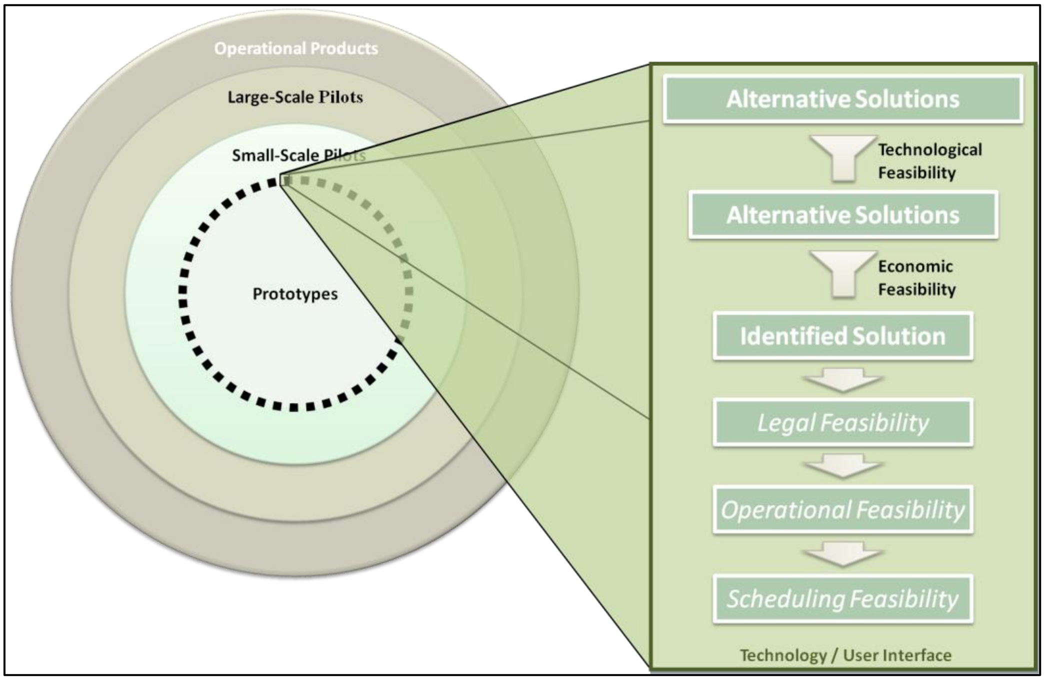

Figure 10: System Evaluation Roadmap

7.2 Legal Requirements

7.2.1 Quality Level of Service

In 1997 the Minister for Public Service and Administration, Zola Skweyiya, published the White Paper on Transforming Public Service Delivery. The purpose of this white paper, known as the *Batho Pele* White Paper, is to provide a policy framework and a practical implementation strategy for the transformation of Public Service Delivery. This is outlined in the eight *Batho Pele* (Sotho: People First) principles. These principles specify how public services, and not what services (i.e. volume, level and quality), should be provided. One of these principles however, specifies that users of public services should be informed on what quality and level of services they are to expect. [39]

In health care services, this is particularly relevant where patient consent is concerned. The National Health Act stipulates that care for experimental or research purposes may not be provided to a user without the user's informed consent. Patients should thus give consent, preferably written consent, if they are being treated through a system in its testing phases. Written consent should enable a patient to fully understand, appreciate and consent to the harm or risk involved in using the system, especially the risk of misdiagnosis. [25]

7.2.2 Data Security

The Bill of Rights in South Africa's constitution [50] states that all citizens have a right to privacy. Under these obligations, the National Health Act [51] specifies patients' rights to confidentiality. All information concerning a patient's health status, treatment or stay in a health facility is confidential. A health care worker may only disclose this information if the patient gives written consent.

When sending data electronically, there is risk regarding security breach. In South Africa, no explicit regulations yet exist to govern security standards [25]. One way of ensuring data security is to encode the data through a security protocol. Another method is to de-personalize data by removing any identifying information such as names and identification numbers from the records. Finally, user access can be restricted through the use of passwords. [52]

7.3 Legal Feasibility Summary

During the pilot project, all of the above mentioned legal requirements were met. These commitments to the ethical and legal requirements of health care were outlined in the researchers' proposal that was submitted to the Research Ethics committee of Stellenbosch University. Ethical clearance was granted to the researchers. [53]

8 Operational Feasibility

8.1 Introduction

One problem facing telemedicine implementation is the decrease of user enthusiasm for a project after the initial implementation stage [54]. Whitten *et al*. [55] claim that common barriers resulting in the underutilization of telemedicine include user liability, technical challenges, complex licensure and a lack of reimbursement. However, in their studies, they found that even in cases where these common barriers were accounted for, long-term user acceptance and widespread user adoption were still absent [55]. In Figure 11, this is referred to as the operational feasibility of the system. The process and human factor operational requirements and feasibility are discussed in the following sections.

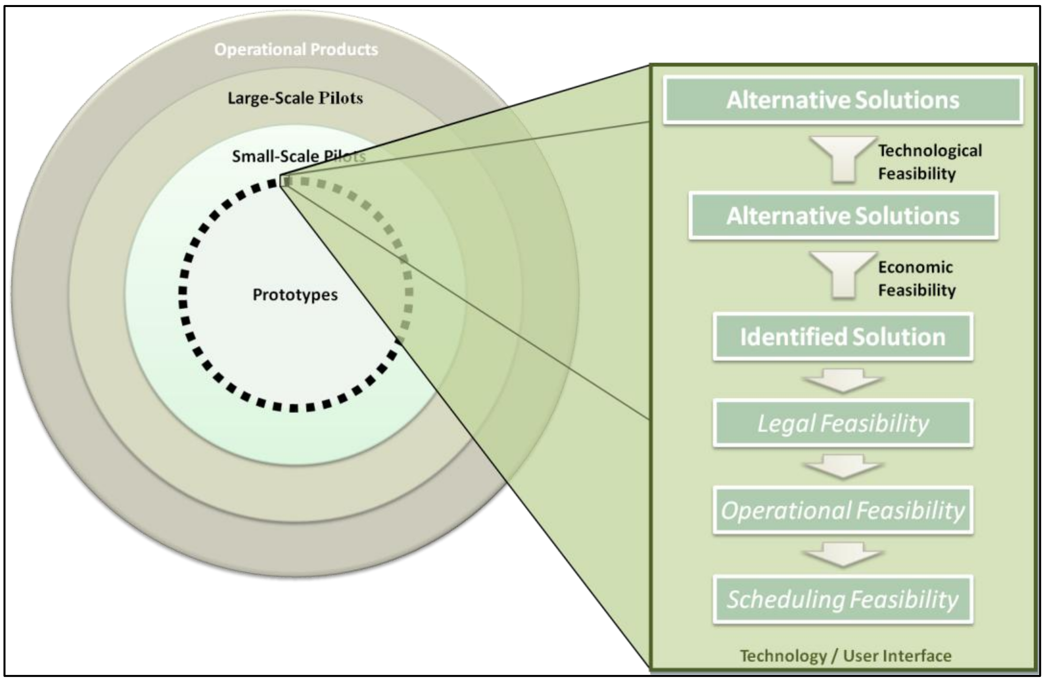

Figure 11: System Evaluation Roadmap

8.2 Process Feasibility Requirements

8.2.1 Radical versus Incremental Change

New technology or innovation in an organization requires change. The degree to which this change takes place can range from incremental to radical. When an innovation or new technology requires little change in current processes, it is considered incremental. When a system and its support structures need to be revolutionised in order to incorporate the new technology or innovation, it is considered radical. For this reason, the risk involved in radical change is greater than for incremental change. Also, radical change often represents a technology push onto users. Users can thus easily not accept the change due to the technology not meeting their needs. [15]

Because of the high risk of failure associated with telemedicine projects in South Africa, it is recommended that the process changes be incremental.

8.2.2 Process Reengineering Cycle

Telemedicine is a tool used for ensuring better and more effective health care. However, if people are not trained to use a tool effectively and the processes to complete the work are not changed to fit the tool, user acceptance cannot be expected. When people work less efficiently because of telemedicine, it is often rejected. The utility of a telemedicine technology can thus be constrained by old processes. [56]

One way to fit new tasks being introduced by technology into work practices, organization and procedures is process reengineering. Process reengineering is defined as the modification of an existing system to make the processes more efficient and effective and the system more responsive [57]. The process engineering cycle can be seen in Figure 12. It includes identifying the processes that will be affected and reviewing these processes to establish the "as-is" structure. The new processes are then designed, implemented and monitored for evaluation purposes. These steps for process reengineering will be followed to introduce the asynchronous ultrasound system into the daily operations of the rural clinics.

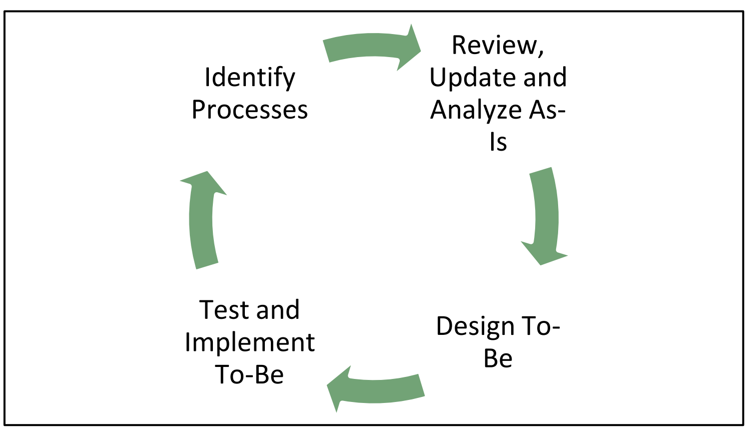

Figure 12: Process Reengineering Cycle
(Source: http://www.recruititassociates.com/financialservices/BPR.aspx)

8.3 Process Reengineering

8.3.1 Design of New System

The proposed processes to add to the current sonography patient care system are shown in Figure 13. These processes only affect the consultation process discussed in Chapter 3. Other daily operations in the clinics are unaffected.

During an "as-is" consultation, the nurse would proceed directly from determining the pregnancy maturity of a patient to making an appointment with the sonographer. It is proposed that in the "to-be" processes, the trainee nurse or midwife performs the extra tasks in between these two actions.

First, the nurse or midwife inquires if the patient is willing to participate in the educational system. If the patient does not agree, she can leave the consultation and return for her appointment with a qualified sonographer. If she does consent, the nurse or midwife will then capture the patient health information electronically. (This step is discussed in more detail in the following section.) After the information is captured, the nurse or midwife performs the sonogram and acquires the ultrasound images. These images are stored temporarily on the ultrasound machine. When the patient has left the consultation room, the nurse or midwife transfers the images to a personal computer, makes the necessary annotation on the images and uploads the images to the web.

These processes are in compliance with the processes followed in district hospitals where the sonographers and radiographers work with electronic health records. They complete the electronic reporting immediately after a consultation. This is due to the great number of patients they see per day, and to reduce the risk of human error, such as forgetting in their reporting patients or relevant patient health information. [58]

8.3.2 Patient Health Information Capturing

One of the technical complaints that the midwife had during the asynchronous ultrasound pilot project, was the complexity of the patient health information page on the website. The data fields on this page all had to be filled in before a consultation could be requested with a specialist. This process was time consuming and ineffective due to the frequent unavailability of patient health history as well as the irrelevance of some data fields. [9]

As mentioned before, most clinics still work on a paper based health record system [26]. Also, the long term user acceptance of telemedicine systems rely on the effectiveness of the system [55]. It would thus be beneficial if the collected paper-based patient health information could be digitised for use in the telemedicine system. This can be achieved through scanning the patient health record or taking a photo of it. In compliance with the legal

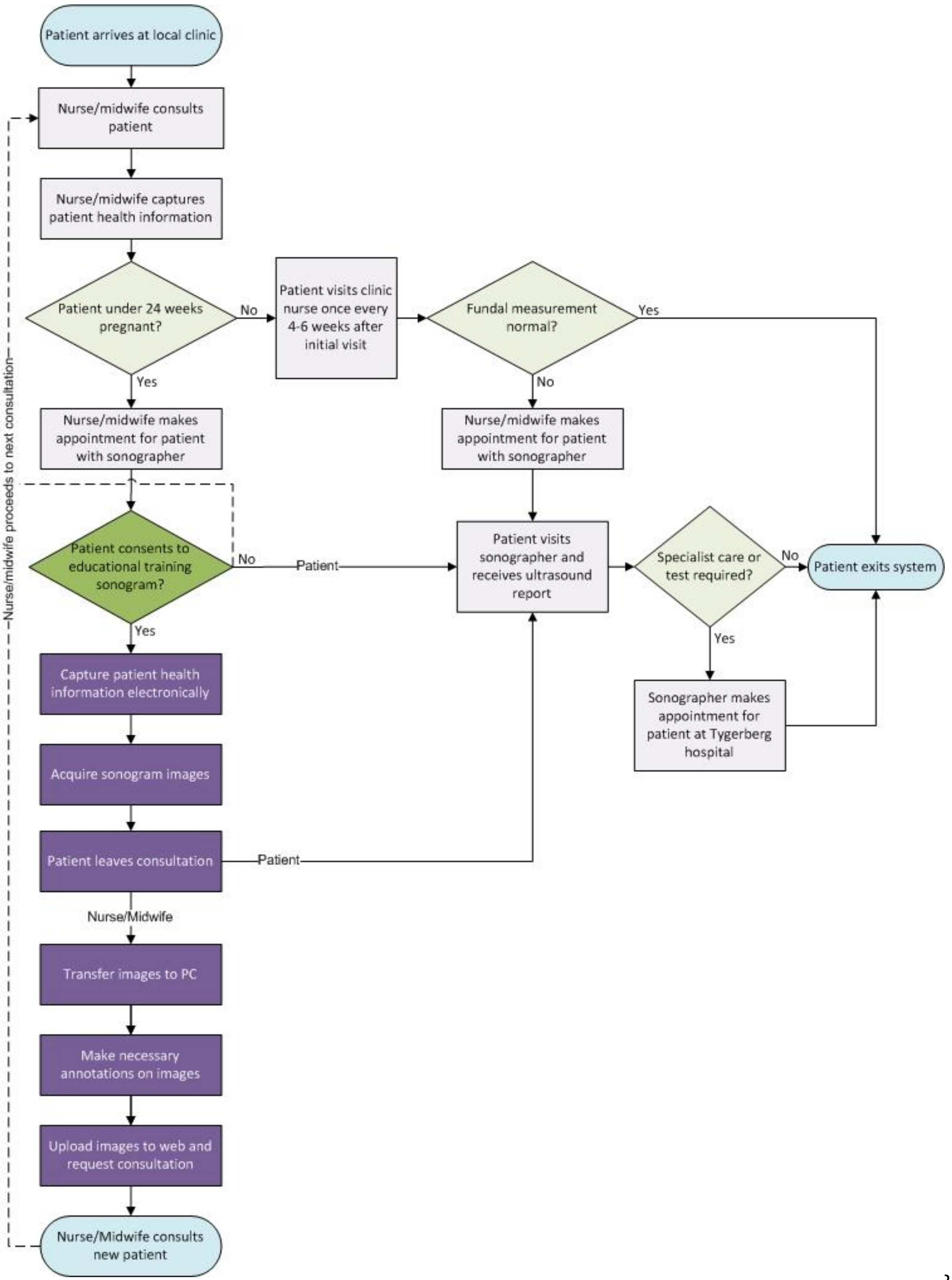

Figure 13: “As-Is” Patient Care System with Proposed “To-Be” Processes

requirements of patient confidentiality, the patient's identifying data fields can be censored. The digitised copy can be sent with the sonogram images when a specialist consultation is requested. This would eliminate the need for the nurse or midwife to duplicate on the website the already acquired (paper-based) patient health information.

8.4 Human Factors

8.4.1 Introduction

A human factor development approach can be taken to design user acceptance into a system. In her study, Dr Susanne Buck developed a number of principles that can contribute to long lasting user acceptance. Two of these factors are discussed in the following sections. [54]

8.4.2 Aim and Usefulness

Even though the advantage of having skilled sonographers is clear within the health system, the relative advantage for the users must also be clear [54]. This is due to the findings of Chau and Hu [59] in their study that confirmed that the "perceived usefulness appeared to be the most significant factor affecting doctors' acceptance of telemedicine technology".

This "perceived usefulness" can be achieved through feedback and evaluation. (The evaluation process is discussed in the next chapter.) If the nurse or midwife can gauge her improved skill levels, the incentive to continue will exist. Also, if the specialist sees through evaluation that the provided feedback is increasing the trainee's skill level, the advantage of the system will be clear.

8.4.3 User Profile

A user profile consists of three aspects. These, and their relevance to the system being evaluated, are discussed below [54]:

1. Expectations: Before a system is introduced, the user expectations must be determined. For example, some users may be concerned that their work routines will be negatively affected by this system. In this case, the additional processes of the system to a normal consultation must be made clear to the users. If it is made clear to the users that the system is not as time-consuming as feared, there may be fewer reservations in using the system.

2. Skills: To interact with a telemedicine system, certain skills need to be acquired. The asynchronous ultrasound system requires low-level computer literacy skills. It is important that the user web-interface be as intuitive as possible and that adequate training is provided to ensure user acceptance.
3. Restrictions: This is defined as the situations that impede effective interaction with a system. The most notable restriction in rural clinics is the busy schedule of nurses and midwives. The interaction time with the system must thus be minimised. For the asynchronous ultrasound system, this was attempted using the process reengineering cycle. Evaluation of these processes is discussed in the following chapter.

9 Scheduling Feasibility

9.1 Introduction

In order for the asynchronous ultrasound system to be successful, trainees using the system need to show improvement in their ultrasound image acquisitioning and interpretation skills. To determine if there is an advantage to using a telemedicine system, evaluation needs to be built into that system [13]. Thus, for the purpose of this project, the scheduling feasibility is not concerned with the implementation timeline, but rather the system evaluation. As is seen in Figure 14, this is the last step in the system evaluation process.

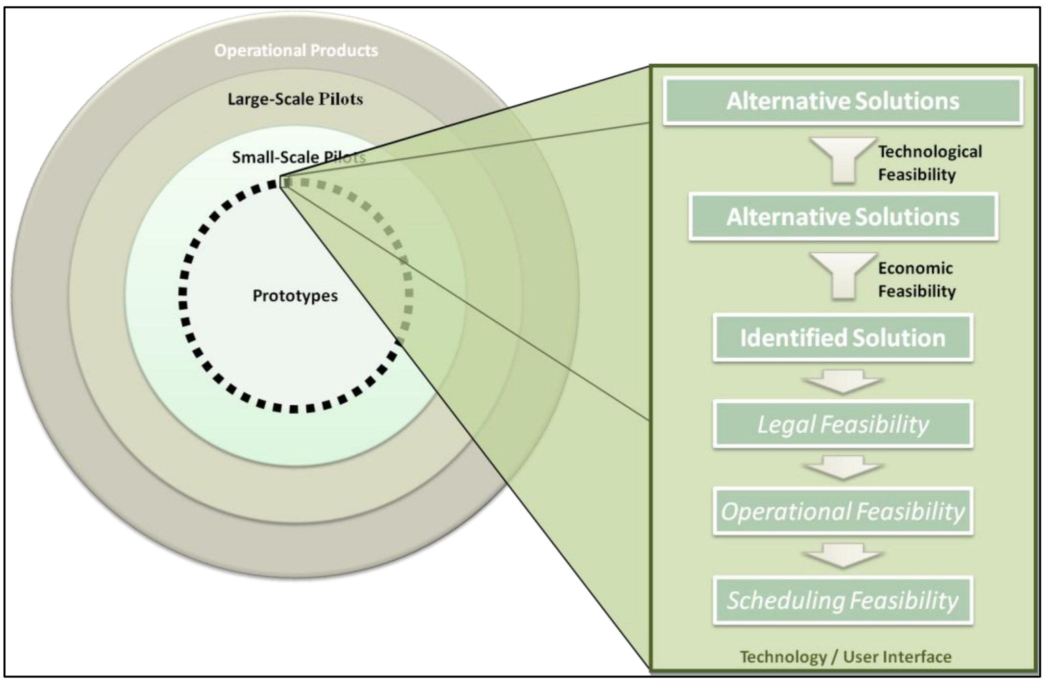

Figure 14: System Evaluation Roadmap

9.2 Evaluating Telemedicine Safety

9.2.1 Safety Requirements of the System

When evaluating a telemedicine system, two safety factors are studied. Firstly, a telemedicine system should not disadvantage the interpretation of information compared to conventional methods. Secondly, the management of a patient's treatment through a telemedicine system should not disadvantage the patient. [60]

9.2.1.1 *Establishing the Safety of the System*

9.2.1.1.1 Interpretation of Information

During the initial pilot project, the minimum image size for safe interpretation was determined. An image resolution of 640 * 480 pixels was deemed adequate. As was discussed in Chapter 4 in the technology feasibility study, the DICOM to JPEG compression standard is used in sonogram images. Using the compression ratio of 3.81 and a 16-bit depth the image size can be calculated with the following formula:

$$Image\ size = (640 * 480)\, pixels * \frac{16\, bits\ \ per\ \ pixel}{8\, bits\ \ per\ byte} / 3.81 / \frac{1\, kilobyte}{1000\, bytes} = 161.26\ kilobytes \qquad \text{(Eq.9.1)}$$

The uploading of images of this size is feasible within the technical specification discussed in Chapter 4. Thus, the system does not disadvantage the interpretation of patient information.

9.2.1.1.2 Patient Management

In the B/O region, qualified sonographers are available. As was shown in the patient care process of Figure 13, patients who consent to the telemedicine system receive two sonograms: one from the nurse or midwife, and one from the qualified sonographer. The improvement and the accuracy of the trainees' acquisition and interpretation skills can thus be measured against the "gold standard" of the qualified sonographers images and reports [26]. Thus, the safety of the system can be accurately evaluated before it is rolled-out to the rest of the country where this comparative "gold standard" is unavailable.

9.3 Evaluating Telemedicine Effectiveness

9.3.1 Requirements of the System

The asynchronous ultrasound system has two objectives, namely improving the acquisitioning and the interpretation skills of ultrasound images of a nurse or midwife. During the pilot project, these two skill improvements were addressed in parallel. The midwife who evaluated the system wrote a test before and after the testing period to test these skills. However, the test was a written one that addressed the identification of medical concerns on ultrasound images [54]. The image acquisitioning skills were thus not adequately tested [49]. Thus, when implementing the system in the B/O region, it is suggested that these two skill sets be tested independently.

During the pilot project, American specialists evaluated the images. Due to their inexperience with the typical South African profile, some diagnostic mistakes were made. It is thus recommended that in the future South African specialists or specialists with experience in Africa be consulted. [49]

9.3.2 Establishing the Effectiveness of the System

9.3.2.1 Image Acquisition Skills – Self Evaluation and Test Proposal

When the nurse or midwife uploads images to the web, the specialist responds with guidelines for better image acquisitioning. These guidelines refer to the depth of the image, the angle at which it was taken and the position on the torso from which it was taken [27]. The acquisitioning skills are perfected when the correct foetal measurements can be taken from the acquired images. These measurements include the foetal skull diameter, abdomen diameter and upper leg length [27].

This skill improvement can be self-evaluated by the nurse or midwife. Using the sonographer report of the patient, she can see if there is an increasing correlation between the measurements she acquires and those in the report. When there is a good correlation, she can indicate to a specialist that she wants to be formally evaluated. These formal evaluation requirements need be determined by a specialist.

9.3.2.2 Image Interpretation Skills – Self Evaluation and Test Proposal

When the nurse or midwife has adequately improved her image acquisitioning skills, she can proceed to image interpretation. This includes the identification of areas of clinical concern (for example the number of fingers and toes, the foetus positioning and the heart beat) [27]. These skills can only be evaluated to a certain extent by the nurse or midwife herself. Some diagnostic skills require specialist training. It is thus recommended that a specialist define the requirements for adequate interpretation skills and test the trainee when she indicates that she is ready.

Even if the nurse or midwife is deemed fit for acquiring and interpreting sonogram images, an open communication channel between rural clinics and specialist sites can be advantageous. It is recommended that further studies be done to establish the feasibility of a permanent telemedicine referral system (and not just an educative system) between qualified sonographers in rural areas and specialist sites. This can further improve the ultrasound services in South Africa in order to meet the Millennium Development Goals.

9.4 Remarks

The "gold standard" for the sonogram images acquired by the trainees in the B/O district will not be available in the rest of South Africa. This evaluation is thus only to determine if the system can be a success before national implementation. Further studies are recommended to determine how the continuous safety of the system will be evaluated in other parts of the country.

10 Conclusion and Recommendations

The purpose of this project was to find an optimal combination of technology and business processes to meet the sonography skills shortage in South Africa in a sustainable way. To achieve this, the following objectives were reached:

- Alternative solutions to address the sonography skills shortage in South Africa were investigated.
- Interviews were conducted with practicing sonographers, OB/GYN specialists and health district officials.
- The current obstetric sonography service system of the Boland/Overberg health district was documented.
- The technical and economical requirements for possible solutions to increase the number of available skilled sonographers in South Africa were determined.
- All of the possible solutions were evaluated in terms of their technological feasibility.
- All of the possible solutions were evaluated in terms of their economic feasibility.
- The most feasible solution was selected.
- The legal implications of the selected solution were considered.
- The business processes and change management strategies to facilitate sustained implementation of the system was developed.
- An implementation framework to ensure the constant evaluation and sustainability of the proposed system was suggested.

The current system was evaluated by conducting interviews with sonographers working in the Boland/Overberg public health district. Also, the need for the services was determined through data analysis from the health district's recent reports and interviews with a health district official and a specialist from Tygerberg Hospital.

From the literature, alternative educative solutions to the asynchronous pilot project were identified for meeting the demand for sonography services in the Boland/Overberg public health district. These included real-time ultrasound, virtual classrooms, ultrasound simulators, asynchronous ultrasound without data transfer and appointing additional sonographers.

These systems were evaluated for technological feasibility through an ICT audit. All of the systems were deemed technologically feasible, even if their technological infrastructure requirements are not currently present in the Boland/Overberg region. This added infrastructure costs, as well as implementation costs, specialist availability requirements, ease of implementation and roll-out objectives were used to determine each system's economic feasibility through an analytic hierarchy process. The asynchronous ultrasound system was found to be the most feasible.

The legal requirements for system use were then considered. This included patient privacy and consent, both of which the system can adhere to if implemented and used correctly.

The additional processes to incorporate the system in normal consultations were developed through process reengineering. It was found that these processes will not affect the daily operations of a clinic in a negative way. As part of this operational feasibility study, the human requirements for implementation were discussed. These included perceived aim and usefulness of the system, as well as user profiling.

Finally, the scheduling feasibility to determine if the system is safe and effective was discussed. This included the safety and evaluation processes that can be used by health officials to determine if the system is successful.

Thus, the purpose of the project was fulfilled. The most ideal technological solution was identified and its business processes and implementation plan developed.

It is recommended that future research include project management of the system as well as the development of an intuitive and user-friendly web-based interface for the asynchronous ultrasound system. Adequate training modules for using the technology must also be developed.

In conclusion, this project, due to its interdisciplinary nature, was an insightful and rewarding experience. It included working with professionals from various faculties and backgrounds. The various backgrounds caused several communication hurdles, but overcoming these through effective management resulted in a much more integrated solution. An opportunity to present the main goals of this project at the first South African Telemedicine Conference provided a valuable experience in presenting academic research. (The poster presentation is shown in Appendix B.)

Finally the conference, as well as this project, provided access to a group of professionals, whose diverse backgrounds has provided a holistic perspective of the problems and challenges, but also of the possibilities of telemedicine in South Africa.

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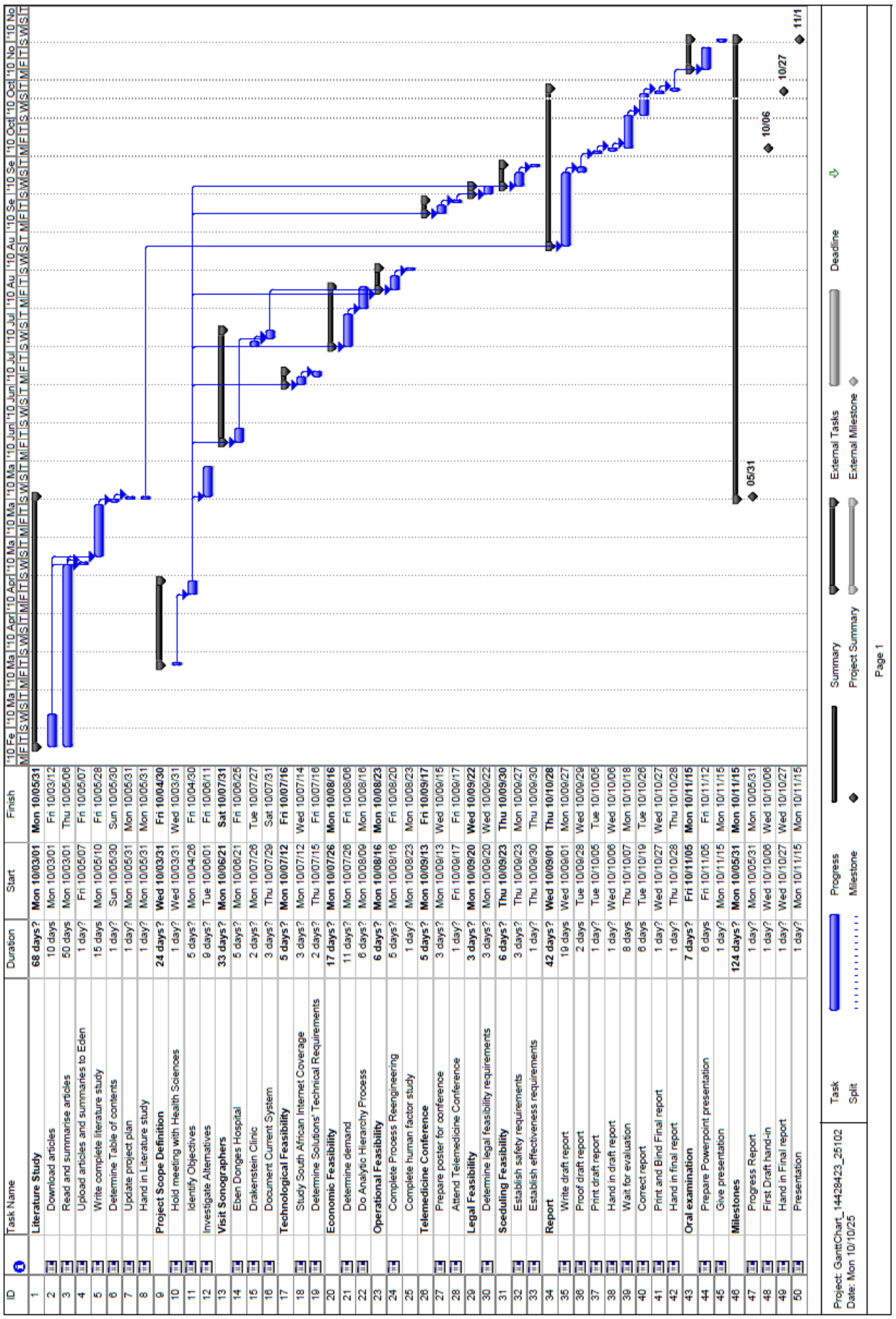
Appendix A: Project Planning



ID	Task Name	Duration	Start	Finish
1	**Literature Study**	**68 days?**	**Mon 10/03/01**	**Mon 10/05/31**
2	Download articles	10 days	Mon 10/03/01	Fri 10/03/12
3	Read and summarise articles	50 days	Mon 10/03/01	Thu 10/05/06
4	Upload articles and summaries to Eden	1 day?	Fri 10/05/07	Fri 10/05/07
5	Write complete literature study	15 days	Mon 10/05/10	Fri 10/05/28
6	Determine Table of contents	1 day?	Sun 10/05/30	Sun 10/05/30
7	Update project plan	1 day?	Mon 10/05/31	Mon 10/05/31
8	Hand in Literature study	1 day?	Mon 10/05/31	Mon 10/05/31
9	**Project Scope Definition**	**24 days?**	**Wed 10/03/31**	**Fri 10/04/30**
10	Hold meeting with Health Sciences	1 day?	Wed 10/03/31	Wed 10/03/31
11	Identify Objectives	5 days?	Mon 10/04/26	Fri 10/04/30
12	Investigate Alternatives	9 days?	Tue 10/06/01	Fri 10/06/11
13	**Visit Sonographers**	**33 days?**	**Mon 10/06/21**	**Sat 10/07/31**
14	Eben Donges Hospital	5 days?	Mon 10/06/21	Fri 10/06/25
15	Drakenstein Clinic	2 days?	Mon 10/07/26	Tue 10/07/27
16	Document Current System	3 days?	Thu 10/07/29	Sat 10/07/31
17	**Technological Feasibility**	**5 days?**	**Mon 10/07/12**	**Fri 10/07/16**
18	Study South African Internet Coverage	3 days?	Mon 10/07/12	Wed 10/07/14
19	Determine Solutions' Technical Requirements	2 days?	Thu 10/07/15	Fri 10/07/16
20	**Economic Feasibility**	**17 days?**	**Mon 10/07/26**	**Mon 10/08/16**
21	Determine demand	11 days?	Mon 10/07/26	Fri 10/08/06
22	Do Analytic Hierarchy Process	6 days?	Mon 10/08/09	Mon 10/08/16
23	**Operational Feasibility**	**6 days?**	**Mon 10/08/16**	**Mon 10/08/23**
24	Complete Process Reengineering	5 days?	Mon 10/08/16	Fri 10/08/20
25	Complete human factor study	1 day?	Mon 10/08/23	Mon 10/08/23
26	**Telemedicine Conference**	**5 days?**	**Mon 10/09/13**	**Fri 10/09/17**
27	Prepare poster for conference	3 days?	Mon 10/09/13	Wed 10/09/15
28	Attend Telemedicine Conference	1 day?	Fri 10/09/17	Fri 10/09/17
29	**Legal Feasibility**	**3 days?**	**Mon 10/09/20**	**Wed 10/09/22**
30	Determine legal feasibility requirements	3 days?	Mon 10/09/20	Wed 10/09/22
31	**Sceduling Feasibility**	**6 days?**	**Thu 10/09/23**	**Thu 10/09/30**
32	Establish safety requirements	3 days?	Thu 10/09/23	Mon 10/09/27
33	Establish effectiveness requirements	1 day?	Thu 10/09/30	Thu 10/09/30
34	**Report**	**42 days?**	**Wed 10/09/01**	**Thu 10/10/28**
35	Write draft report	19 days	Wed 10/09/01	Mon 10/09/27
36	Proof draft report	2 days	Tue 10/09/28	Wed 10/09/29
37	Print draft report	1 day?	Tue 10/10/05	Tue 10/10/05
38	Hand in draft report	1 day?	Wed 10/10/06	Wed 10/10/06
39	Wait for evaluation	8 days	Thu 10/10/07	Mon 10/10/18
40	Correct report	6 days	Tue 10/10/19	Tue 10/10/26
41	Print and Bind Final report	1 day?	Wed 10/10/27	Wed 10/10/27
42	Hand in final report	1 day?	Thu 10/10/28	Thu 10/10/28
43	**Oral examination**	**7 days?**	**Fri 10/11/05**	**Mon 10/11/15**
44	Prepare Powerpoint presentation	6 days	Fri 10/11/05	Fri 10/11/12
45	Give presentation	1 day?	Mon 10/11/15	Mon 10/11/15
46	**Milestones**	**124 days?**	**Mon 10/05/31**	**Mon 10/11/15**
47	Progress Report	1 day?	Mon 10/05/31	Mon 10/05/31
48	First Draft hand-in	1 day?	Wed 10/10/06	Wed 10/10/06
49	Hand in Final report	1 day?	Wed 10/10/27	Wed 10/10/27
50	Presentation	1 day?	Mon 10/11/15	Mon 10/11/15

Appendix B: SA Telemedicine Conference Poster