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Final Year Project

2010

The telemedicine system to increase patient's access to specialised cardiac care for assisting remote diagnosis.

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Declaration

I, the undersigned, hereby declare that the work contained in this final year project 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.

Sign on the dotted line:

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Date

ECSA Exit level outcomes references

Exit level outcome	Section(s)	Relevant Tool(s)
1. Problem solving	3- 7, p. 15-55	Problem formulation and project completion 
5. Engineering methods, skills & tools, including Information Technology	3, p. 16 2, p. 9-11 5, p. 34 -47 4, p. 19-31 6, p. 50-53	Case-and-effect analysis (Quality Management) Process flow charts (Work Study and Information Systems) Basic principles of electronic equipment (Electronics) The Analytical Hierarchy Process (AHP) (Operations Research) Cost implications of all alternatives are considered as part of the process of selecting the best alternatives.
6. Professional & Technical communication	Whole document	The technical content of this project is communicated professionally by means of this document as well as a poster presentation delivered at the first Southern African Conference in Telemedicine.
9. Independent learning ability	2, p. 4-15	Since the study of telemedicine is a new field that has not been touched during the industrial engineering study program. Independent learning through well developed learning skills was practised for a great part of the project by interviewing users of the system and completing literature study, to formulate concept of current situation in cardiac departments of Tygerberg hospital and Eben Dönges hospital
10. Engineering professionalism	1.2.3 p. 3	Execution of entire project in multidisciplinary context. Legal and ethical implications of all alternatives are considered as part of the process of selecting the best alternatives

Synopsis

Cardiology refers to the specialised study of heart disorders and is a focused field of knowledge practiced by cardiologists. Due to the specialised nature of cardiology, treatment is not given as widely and effectively in populated and under-resourced areas, like South Africa. In the public medical sector there are too many cardiac patients and not enough doctors with the necessary expertise to attend to their needs. Cardiac specialists that are situated only in urban areas in South Africa, cannot attend to the needs of all the rural cardiac patients Therefore, cardiac specialists assist rural doctors in diagnosing patients remotely. The assistance currently offered is not optimal and patients do not get the needed tertiary specialist care that is available in urban areas. For specialists to provide assistance they have to fully understand they patient's medical condition and therefore all the necessary patient data has to be transferred to the specialist. The various factors limiting the transfer of patient data and therefore also the patient's access to tertiary care cardiac is the patient's location relative to the specialist, the methods used to communicate patient data, human error in the diagnostic process, the complex nature of the diagnostic data , limited data transfer capabilities, the cost and the limitations of technology used. For the purpose of this study Tygerberg hospital will be used as the tertiary hospital and Eben Dönges hospital in Worcester as the rural hospital.

The current situation at both hospitals was assessed and the structure used for communication between the two institutions was documented. It was found that the technology is being used to share patient data, such as faxes and telephone calls, results in an unnecessarily protracted process. The restrictions which limit the current system were identified. It was found that outdated technology is used to share patient data because there is no faster communication network and because patient data is complex and files are large. The existing and potential technology was explored to formulate alternatives namely: electronic transfer of files in DICOM format; compressing the DICOM files with MPEG and JPEG before electronic transfer; implementing a PACS intranet between hospitals; and lastly to use DICOM viewers on workstations to view the DICOM patient data. Ultimately, the possible solutions and their feasibility were explored using the Analytical Hierarchy Process (AHP) to illustrate that a DICOM viewer in conjunction with a PACS intranet is the best solution to increase a remote patient's access to a specialist's knowledge.

If a PACS in conjunction with a DICOM viewer is implemented the effectiveness of data transfer procedure is increased, since data is always accessible via the PACS intranet and the DICOM viewer software allows post processing of DICOM files. The duration of the procedure is decreased for the doctor at Eben Dönges hospital, since files are automatically transferred to the central PACS server after study is completed; and for the specialist at Tygerberg Hospital time is saved since he can view the diagnostic images on a mobile device. The biggest cost for the solutions will be to implement a network between the hospitals and to acquire the PACS software license. The DICOM viewer software is free to download. The alternative is user-friendly since minimal effort has to be made to transfer data and the DICOM viewer user interface is simple to operate. This option enhances secondary and tertiary education most since DICOM files can be viewed on any standard of the self hardware with a DICOM viewer installed. Ethical or legal issues can develop with exchange of confidential patient information, but due to patient data only being connected to the patient MRN in the PACS system of Tygerberg, no patient's confidentiality will be breached.

Opsomming

Kardiologie verwys na die gespesialiseerde studie van hart-kwale en is 'n gefokusde veld van kennis beoefen deur kardioloë. As gevolg van die gespesialiseerde aard van kardiologie, word behandleing nie gegee so effektief soos moontlik in areas soos Suid-Afrika, waar daar hoë bevolkingsgetalle min hulpbronne, is nie. Inopenbare gesondheidsorg sektor is daar is te veel kardiale pasiënte, en nie genoeg dokters met die nodige kundigheid om aan hul behoeftes te voorsien nie. Kardiale spesialiste wat in Souid Afrika slegs in stedelike gebiede geleë is, kan nie aandag gee aan die behoeftes van al die landelike kardiale pasiënte nie. Daarom ondersteun kardioloë landelike dokters om kardiale pasiënte te diagnoseer en te behandel oor ‘n afstand. Die hulp wat tans aangebied word vir plattelandse dokters is nie optimaal nie en pasiënte kry nie die nodige tersiêre spesialis sorg wat beskikbaar is in stedelike gebiede nie. Vir spesialiste om ondersteuning en hulp te offer moet dit moontlik wees om die pasiënt se kondisie ten volle te verstaan en daarvoor moet al die nodige pasiënt data oorgedra word na die spesialis. Die verskillende faktore wat die oordrag van pasiënt data n dus die toeganklikheid vir pasiënt na tertiêre kardiale sorg beperk is die patient se plasing relatief tot die van die spesialis die beperking tot toegang van inligting; beperkte inligtingskommunikasie moontlikhede; die komplekse aard inligting; kostes; en die beperking tot tegnologie gebruik. Vir die doel van hierdie studie sal Tygerberg-Hospitaal gebruik word as die stedelike hospitaal en Eben Dönges-hospitaal in Worcester as die landelike hospitaal.

Die huidige kommunikasie tussen die twee hospitale was geassesseer en gedokumenteer. Dit was bevind dat die tegnologie wat tans gebruik word om pasiënt data te kommunikeer, soos faks en telefoonoproep, die proses onnodig verleng. Die beperkings op die huidige sisteem was geïdentifiseer en dit was bevind dat die huidige tegnologie gebruik nie op datum is nie. Dit is as gevolg van ’n tekort aan ’n vinniger kommunikasie netwerk, die kompleksiteit van patient data, asook die grootte van die data dokumente. Die tegnologie beskikbaar was ondersoek om alternatiewe kommunikasiemetodes te ondersoek. Die kommunikasiemetodes ondersoek sluit in, elektronies dokumentoorplasing in DICOM formaat. Die dokumente word verklein na MPEG en JPEG formaat voordat elektroniese oorgrad plaasvind. So word ‘n PACS intranet tussen hospitale geïmplimenteer. Laastens, word DICOM viewers gebruik op werkstasies om DICOM pasiënt data te bestudeer. Uiteindelik is die moontlike oplossings en hul geloofwaardigheid ondersoek deur gebruik te maak van Analytical Hierarchy Process (AHP), om te dui dat ‘n DICOM viewer saam met ‘n PACS intranet die beste uitweg gaan bied om pasiënte in landelike gebeide se toegang tot spesialis sorg te verbeter.

Die kombinasie van ‘n PACS intranet en ‘n DICOM viewer verbeter die effektiwiteit van die data oordragproses. Dit word moontlik gemaak, want die PACS intranet sorg dat data altyd bekombaar is, terwyl die DICOM viewer sagteware toelaat dat die DICOM dokumente na die tyd opgelaai word. So, word die tydsduur van die proses in Eben Dönges Hospitaal verminder, want nadat die studie voltooi is, word die dokumente onmiddelik gestuur na die sentrale PACS ontvanger. Die duur van die proses word net so verminder vir die Tygerberg dokter wat toegang het tot fotos wat diagnosering kan vermaklik. Die meeste van die kostes verbonde sal gaan om die netwerk tussen die twee hospitale te implimenteer, en om ‘n PACS sagteware lisensie te bekom. Daar is geen kostes verbonde om DICOM viewer sagteware om af te laai nie. Die uitweg is maklik gebruikbaar, want dit is eenvoudig om data oor te plaas en DICOM viewer interaksie is eenvoudig om te gebruik. Dit verbeter sekondêre en tertiêre opvoeding die meeste, want die DICOM dokumente kan bekom word deur enige standaard van eie hardeware en gekonnekteer word deur Wi-Fi. Etiese en wetlike probleme kan ondervind word met die mededeling van pasiënt data, maar omdat pasiënt data slegs op die Tygerberg pasiënt MRN in die PACS sisteem gelaai is, voorkom dit dat pasiëntevertroue verbreek word.

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Glossary

Angiogram	Angiography is a technique for examining the blood vessels and the heart chamber of a human body
Cardiology	Cardiology refers to the specialised study of heart disorders and is a focused field of knowledge in medicine practiced by cardiologists.
CliniCom	CliniCom is a centralised hospital information service (HIS) used by the Provincial Government of the Western Cape (PGWC). It has been rolled to 38 hospitals and specialised care centres throughout the region in line with efforts to advance healthcare delivery to the province. The CliniCom application is designed to provide electronic patient record across the entire province referenced with a universal medical reference number (MRN)
DICOM	See Digital Imaging and Communications in Medicine
DICOM (C-Store)	When storing the data in DICOM C-Store it gives an option of a list of DICOM servers to which the data can be sent.
DICOM (Query & Retrieve (Q&R))	The purpose of the DICOM Query/Retrieve is retrieving images from remote DICOM servers in order to store them locally. After the images have been received, they can be loaded and processed independent of the remote server.
Digital Imaging and Communications in Medicine (DICOM)	DICOM is an industry standard format for storing, handling and transmission of digital medical images. See the Chapter 4.1
ECG	See Electrocardiogram
ECHO	See Echocardiogram

Echocardiogram	An echocardiogram (ECHO) is a sonogram of the heart. It uses ultrasound techniques to recreate two-dimensional layers of the heart.
Electrocardiogram	Electrocardiography (ECG) is a technique used to analyse of the electrical activity of the heart over a period of time.
Exercise ECG	See Exercise Electrocardiogram
Exercise Electrocardiogram	An exercise Electrocardiogram (ECG) is a test which examines the heart for suspicious changes while under physical strain, like exercising.
Interface	An interface is a program that controls a display for the user (usually on a computer monitor) and that allows the user to interact with the system
Interoperability	Interoperability refers to the ability of application functions, distributed over two or more systems, to work successfully together.
Intranet	An intranet is a private computer network that uses Internet Protocol technologies to securely share any information.
Lossless data compression	Lossless compression permits an exact reconstruction of an image pixel by pixel. The compressed file has all of the data necessary to reconstitute the original file.
Lossy data compression	Lossless compression provides the highest image quality and is most compatible with off-line post processing and quantitative analysis but only results in a compression ratio of approximately 3:l
Medical reference number	Medical reference number (MRN) is the universal number used to access a patient's electronic records on CliniCom, used throughout the Western Cape.
MI	See Myocardial infarction
MRN	See Medical reference number

Myocardial infarction	Myocardial infarction (MI) commonly known as a heart attack, is the interruption of blood supply to part of the heart, causing some heart tissue to die.
PACS	See Picture Achieving and Communication System
Picture Achieving and Communication System	Picture Achieving and Communication System (PACS) is an intranet, in and between hospitals, that has been developed in an attempt to provide economical storage and rapid retrieval of digital medical images
Protocol	A protocol is rules determining the format and transmission of data
Telemedicine	Is a technology of telecommunication that is superimposed on the need for optimised data exchange between medical professionals, doctors and their patients
Ventricular tachycardia	A series of rapid heartbeats that originate in the lower chamber of the heart (the ventricles) which may cause the heart to beat inefficiently

1 Introduction

1.1 Background

Heart disease, also known as cardiac disease, is a collective term used for a variety of different diseases affecting the heart. Heart disease, together with HIV/AIDS, acute diarrhoea and malnutrition, is one of the leading causes of death in South Africa (Kahn et al, 2007: 8). Cardiology refers to the specialised study of heart disorders and is a focused field of knowledge practiced by cardiologists. Due to the specialised nature of cardiology, treatment is not given as widely and effectively in widespread, populated and under-resourced areas, like South Africa. In the public health care sector, the previously stated phenomenon, that treatment is not given as effectively as possible, is even worse due to the large numbers of patients and limited amount of specialised doctors with the necessary expertise to attend to their needs.

Tygerberg Hospital and Groote Schuur Hospital are the only hospitals in the Western Cape that provides tertiary, highly specialised cardiac facilities for adult patients. This explains why the majority of cardiologists in the Western Cape are located in one area. Patients from surrounding rural areas requiring specialised cardiac care are accommodated by these tertiary hospitals. For the purpose of this study Tygerberg hospital will be used as the tertiary hospital and Eben Dönges hospital in Worcester as the rural hospital.

Telemedicine is a rapidly developing application where the technology of telecommunication is superimposed on the need for optimised data exchange between medical professionals, doctors and their patients (Wallace, 1998: 55). To improve consulting in rural areas and assist remote medical procedures, telemedicine is an excellent option. Cardiologists are increasingly scarce, given that cardiac patients' imaging procedures are increasing by approximately 15% annually against an increase of only 2% in the cardiologist population (DCA Imaging Research Centre, 2010:). Telemedicine improves patient care by allowing cardiologists to provide services without actually having to be at the same location as the patient. This is particularly important when a specialist such as a cardiologist is needed as these professionals are generally only located at large city hospitals. Telemedicine allows for trained cardiac specialists to always be available. Trained specialists can thus support the diagnostic procedure, and any other decisions of referral can be a combined effort between the communicating professionals.

The vision of the National Department of Health of South Africa is to develop and uphold a caring and humane society in which all South Africans have access to affordable, good quality health care. The South African Chief Directorate of Information Evaluation and Research, Department of Health (2001) stated that "the challenge for us lies in reaching all our people, especially in the rural areas and being mindful of not increasing the development gap between the *haves and have-nots*" (Abrahams, Molefi 2006: 69-71.). Telemedicine can help transform this vision into a reality.

1.2 Problem statement, purpose, objectives and scope

1.2.1 Problem statement

There are too many cardiac patients and not enough doctors with the necessary expertise to attend to their needs. All rural cardiac patients cannot be treated by cardiac specialists situated only in urban areas like Tygerberg hospital, so cardiac specialist can, therefore, assist rural doctors to diagnose patients remotely. This assistance is not optimal and patients do not get the needed specialist knowledge available when diagnosed remotely. The different factors that limit a patient's access to specialised cardiac care is the patients location relative to the specialist, the methods used to communicate, human error, limited access to information, the cost and the limitations of technology used. These factors are illustrated in the cause-and-effect diagram in *Figure 1*

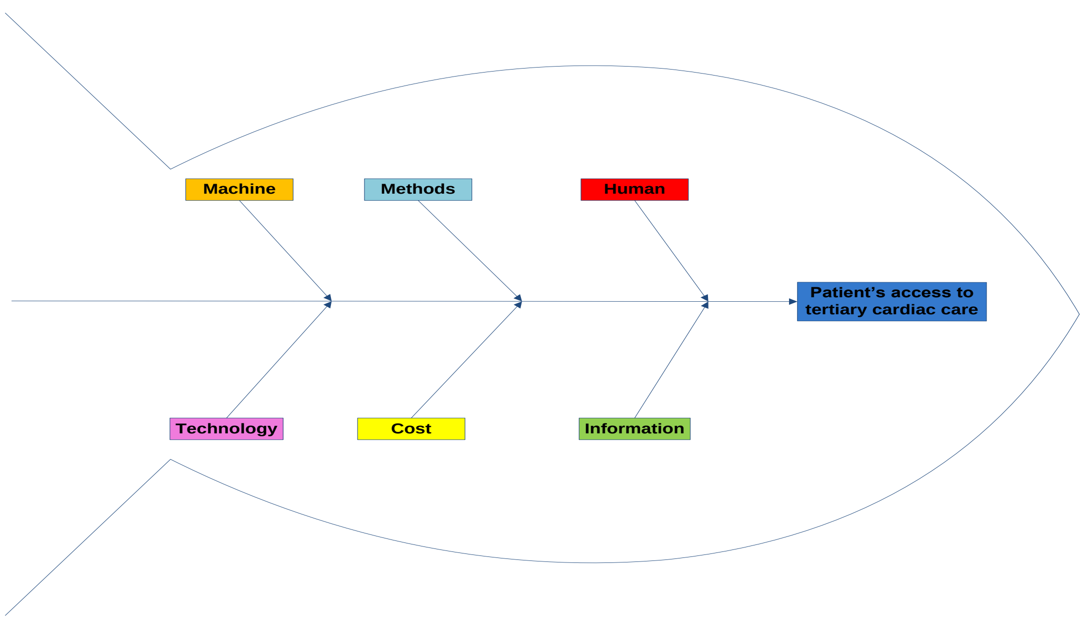


Figure 1: Cause- and- effect diagram of limits to patient's access to tertiary cardiac care

1.2.2 Purpose

The purpose of this project is to design a system that will optimise the assistance that can be offered by cardiac specialists to diagnose cardiac patients remotely at Eben Dönges Hospital. This system must achieve effective and efficient communication between medical personnel of different facilities in an attempt to maximise the amount of cardiac patients diagnosed remotely at Eben Dönges Hospital.

1.2.3 Objectives and scope

This project has a series of objectives which successively lead to the outcome of an optimised communication system. The objectives include the following: to document the current structure used for communication between the two institutions; identify the restrictions which limit the current system; evaluate existing and potential technology and to ultimately explore possible solutions and their feasibility. More specifically, the goal is to design a system to support decision making for referrals, diagnosis and treatment in the cardiac context. The implementation of this designed system is not included in the scope of the project. The design is based on existing possibilities and communication processes, so no new devices or technology is proposed. The system supports communication in aid of patient care, but the physical treatment of patients is beyond the scope of this project. The designed system is intended for the public sector, hence the importance of cost-effectiveness. The actual implementation of the system is considered to ensure a user-friendly configuration for easy data transfer.

1.3 Methodology

To reach the goal of this study the following procedure was followed:

The logical steps of the methodology can be seen in *Figure 2.* The project starts with broad assessment of the current situation. This assessment is narrowed down by documenting the current situation and then defining the problems identified. Following this, diverse and comprehensive research was done to identify the available opportunities. The opportunities led to the development of a set of alternative solutions. After the solutions were formulated they were evaluated and compared using the Analytical Hierarchy Process (AHP). The AHP presented the conclusion that best reached the goal: to increase communication and interoperability goals between the Eben Dönges and Tygerberg Hospital for assisting remote cardiac patient diagnosis. After the alternatives were evaluated a recommendation was made to highlight the possibilities suggested for implementation.

Figure 2: Flow diagram illustrating the methodology of project

2 Assess Current Situation

After the problem statement, purpose, objectives and scope of the project was determined, the current situation was assessed to identify the problems thereof. To gain understanding of the current situation visits were made to Tygerberg Hospital and the Eben Dönges Hospital. Interviews with Professor Anton Doubell, head of the department of cardiology, Stellenbosch University, and Doctor Philip Herbst, cardiac specialist at Tygerberg Hospital and Dr. K. Klusman, the physician at Eben Donges Hospital (who sees the cardiac patients) gave insight to the problems they encounter during their day-to-day activities. This chapter documents the current situation as explained by them.

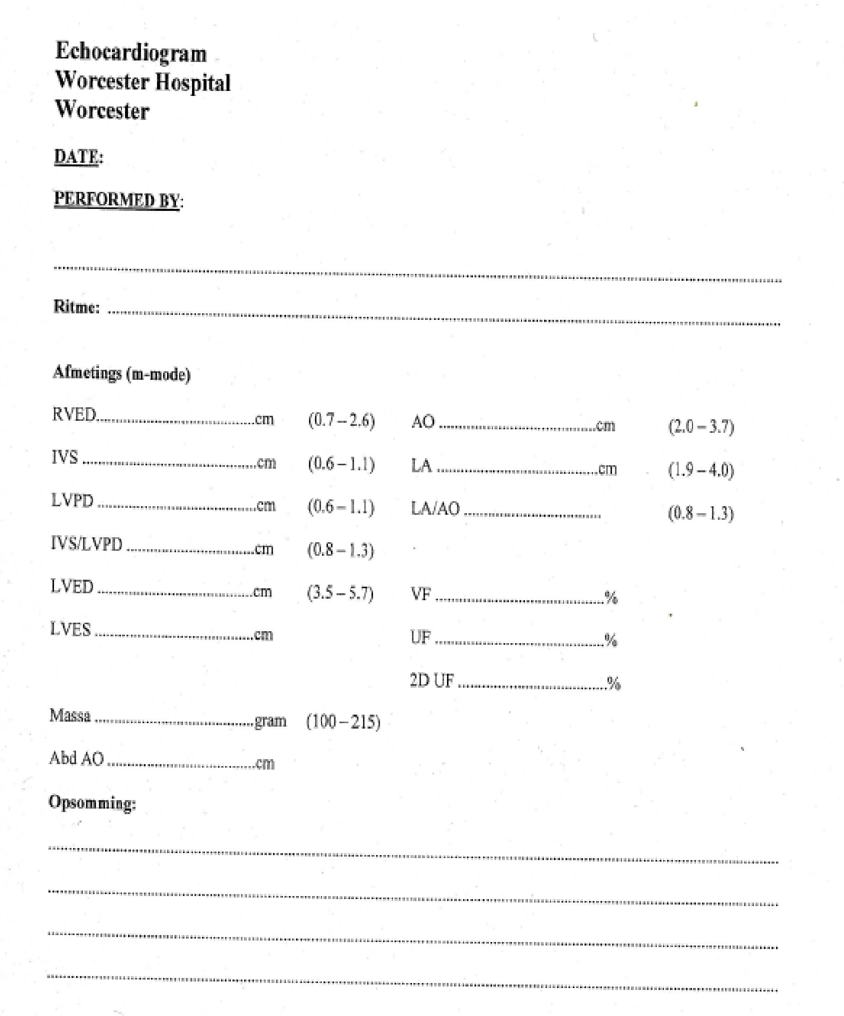
When a cardiac patient arrives at Eben Dönges Hospital they are taken into care, examined and diagnosed as soon as possible. The assessment of a patient involves firstly, gathering the necessary personal and physical information about the patient and secondly, doing a medical examination of the patient. This examination is done by means of taking an electrocardiogram (ECG) and, if necessary, an echocardiogram (ECHO) or exercise ECG. The terms *electrocardiogram* and *echocardiogram* are explained in detail in the paragraph 2.3.

After assessment, they are classified into one of four states: a state of false alarm, where the patient does not have a cardiac problem and leaves the cardiac diagnostic system to be treated or diagnosed elsewhere; a diagnosed state which can be treated locally; a diagnosed state that needs specialised treatment at Tygerberg Hospital or an undiagnosed state that exceeds local diagnostic capabilities and needs to be transferred to Tygerberg Hospital to be further diagnosed. The last two states are then considered as *referrals* as they are referred to Tygerberg Hospital.

If a local doctor has diagnosed a patient and it is possible to treat the patient locally (for example in the case of myocardial infarction), treatment follows on site. If a patient has been diagnosed but treatment needs exceed the local capabilities (for example in the case of ventricular tachycardia, which requires an angiogram) the patient is referred to Tygerberg Hospital for tertiary treatment. Patients are sent with a commonly recognised medical reference number (MRN) according to CliniCom, so the patient's personal data can be accessed. CliniCom is the inter-hospital database that is used in the Western Cape to store all personal data of a patient electronically. The patient's diagnostic data is, however, still in the form of a written report stored in a hard copy patient file. The hard-copy patient file is sent with the patient from Worcester. However, these patient files cause complications with patient diagnostic procedure as they are easily misplaced and can eventually lead to postponement of treatment. In some cases, all previous data is lost and the diagnostic processes have to be repeated.

In the case when Worcester's doctors are unable to diagnose a patient, they turn to Tygerberg Hospital for specialised cardiac assistance by phoning the cardiac specialist on duty. Due to the high demand of these specialists their shifts are usually fully booked and they are interrupted by this phone call to assist the doctors at Eben Dönges Hospital in the diagnostic process. The specialist listens to a verbal report of the patient's state and, if necessary, requests a fax to be sent containing patient data. This fax typically consists of an ECG and/or measurements taken from an ECHO. An example of the sheet used to document ECHO measurements at Eben Dönges Hospital is shown in *Figure 3*. As soon as a specialist receives the faxed data he analyses it and, if possible, gives diagnostic feedback from the information provided. This feedback is normally in the form of a phone call. If the cardiologist cannot address the problem telephonically with the available data, the patient is referred to Tygerberg Hospital for further examination.

The possibilities are very limited as to which data can be sent, since some of the most vital exams cannot be sent via fax, for example an ECHO which is three dimensional and in a time series format. There are several obstacles that with this means of data exchange: when data arrives it is unordered, incomplete and distorted; the data loses all possibility of processing as it is printed on paper; this data exchange is slow and postpones patient treatment, eventually prolonging the process that further congests the already crowded system.


Echocardiogram
Worcester Hospital
Worcester

DATE:

PERFORMED BY:

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Ritme: ....

Afmetings (m-mode)

RVED..............................cm	(0.7 – 2.6)	AO ....cm	(2.0 – 3.7)
IVS ....cm	(0.6 – 1.1)	LA ....cm	(1.9 – 4.0)
LVPD ....cm	(0.6 – 1.1)	LA/AO	(0.8 – 1.3)
IVS/LVPD ....cm	(0.8 – 1.3)		
LVED ....cm	(3.5 – 5.7)	VF ....%	
LVES ....cm		UF ....%	
		2D UF ....%	
Massa ....gram	(100 – 215)		
Abd AO ....cm			

Opsomming:

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Figure 3: Eben Dönges Hospital patient diagnostic data sheet for ECHO measurements

2.1 Eben Dönges Hospital current patient life cycle

The typical flow of processes that occur when a patient arrives at Eben Dönges Hospital in an non-emergency or emergency state, are illustrated in *Figure 4* and *Figure 5*. The processes that are followed to diagnose patient result in patients leaving the diagnosis system in one of four states illustrated in the flow diagrams in figures 4 and 5 and represented by four colours, showing the degree of desirability. The red state, which is most undesirable, is a false alarm patient; the orange state, which is the second most undesirable, is a patient that is transferred to Tygerberg for diagnostic purposes; the yellow state, which is the third most undesirable state, is a patient that is transferred to Tygerberg for treatment purposes; lastly, the green state, which is the desirable state, is when a patient is diagnosed and treated locally. The procedure involved to finally achieving the treatment of each type of patient and the complications involved, will be discussed below.

2.1.1 Current patient life cycle of non-emergency patients

When a new patient arrives at the hospital, a patient-file is created in the CliniCom database, which generates a MRN specific to the patient, as well as a hard copy file. When an existing patient arrives, their patient file can be obtained directly from the CliniCom database once they identify themselves either by their MRN, identity document (ID) or patient card obtained from the day clinic or previous hospital visit. When a patient is referred from a day clinic and does not have an appointment yet, an appointment is scheduled by the clerk at reception according to the day clinic specifications or referral note which the patient brings along. The hard copy patient file of each patient is readily available to the doctor at the ECG/ ECHO machine. These steps can be seen in phase A of *Figure 4*.

The patient is called forward by the doctor to begin the ECG/ ECHO assessment. The doctor takes care to ensure smooth testing conditions for accurate measurements of the problem areas, whilst the system automatically records the measurements. When the study is complete, the machine produces a physical print-out of the measurements observed. A photo of the images on machine is taken during the test in the case of an abnormal occurrence or suspicious behaviour. The doctor then compiles a report on the patient's condition and adds the physical dimensions of the problem areas on a sheet shown in *Figure 3*. The first attempt to diagnose patient locally is illustrated in phase B of *Figure 4*.

If a proper diagnosis cannot be made by the local doctor he/she contacts a specialist at Tygerberg Hospital and explains the conditions observed during the investigation, illustrated in phase C of *Figure 4*. If necessary, the doctor at Eben Dönges Hospital would then fax the written report with dimensions and images taken (if any). This is illustrated in phase D of *Figure 4*. The specialist then provides feedback and assistance with the diagnosis, if possible. If a diagnosis still cannot be made, the patient is referred to Tygerberg Hospital and an appointment is scheduled.

2.1.2 Current patient life cycle of emergency patients

Alternatively, when an emergency patient arrives at the emergency room of Eben Dönges Hospital by means of ambulance or personal transport, they are immediately taken to the intensive care unit (ICU) and treated. If there is no familiar related person to give patient information, treatment proceeds. The initial steps followed when a patient arrives are shown in phase A of *Figure 5*.

The physician performs the necessary examination to determine patient condition, by performing an ECHO or ECG. Again, the doctor takes care to ensure smooth testing conditions for accurate measurements of the problem areas, whilst the system automatically records the measurements. When the study is complete the machine produces a physical print-out of the measurements observed. A photo is taken during the test in the case of an abnormality. The doctor makes a diagnosis and treatment follows. The first attempt to diagnose the critical patient is illustrated in phase B of *Figure 5*.

If a proper diagnosis cannot be made by the local physician, he contacts a cardiac specialist at the Tygerberg Hospital and explains the conditions observed during the patient examination, illustrated in phase C of *Figure 5*. If necessary, the doctor at Eben Dönges Hospital in Worcester would fax a written report with dimensions and sometimes the images taken. The specialist then provides feedback and assistance with the diagnosis if possible. This is illustrated in phase D of *Figure 5*. If the diagnosis still cannot be made, the patient is referred to Tygerberg Hospital's emergency room immediately by means of hospital transport. The life cycle of information at Tygerberg Hospital is shown below in *Figure 6*.

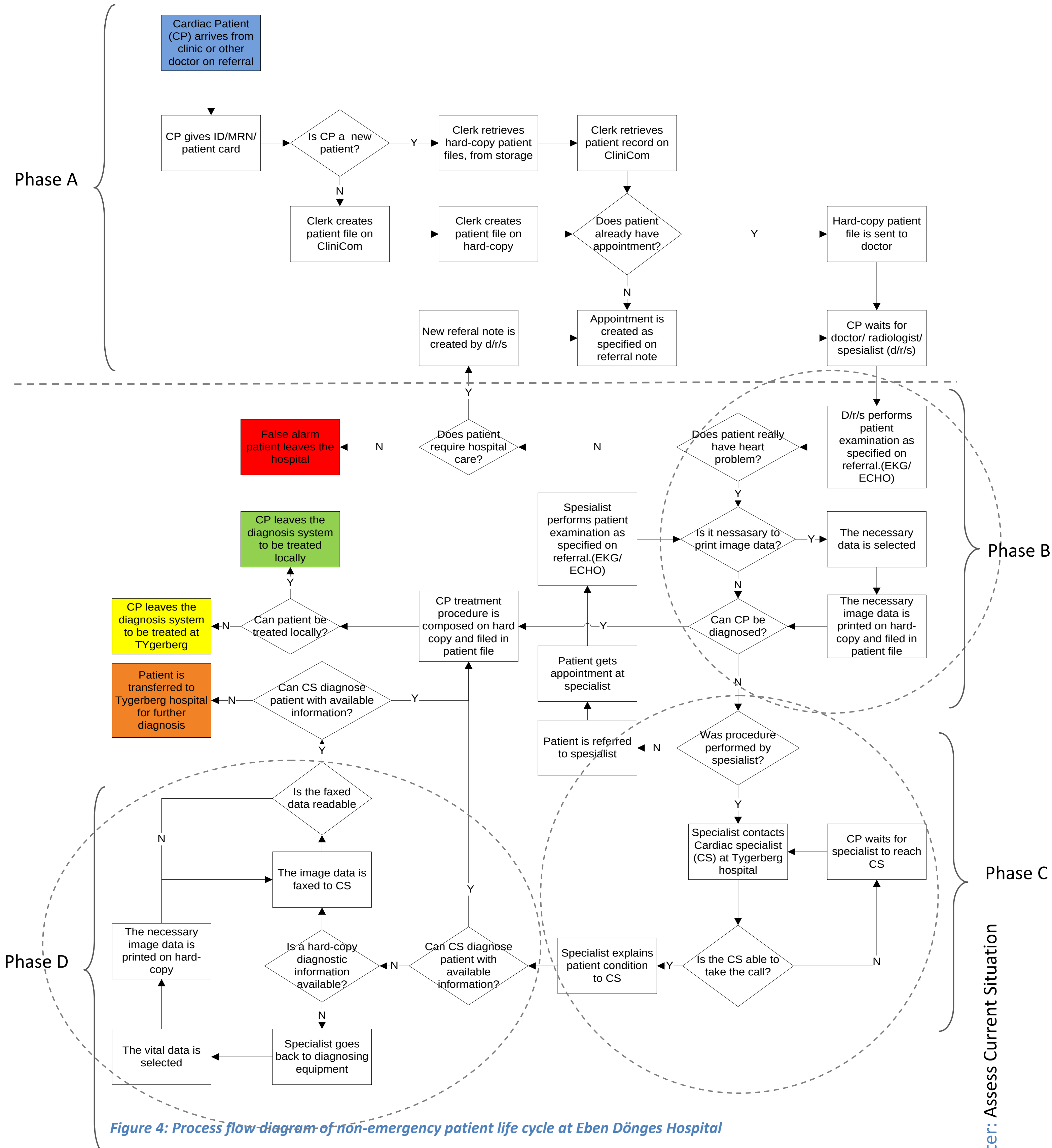

Figure 4: Process flow diagram of non-emergency patient life cycle at Eben Dönges Hospital

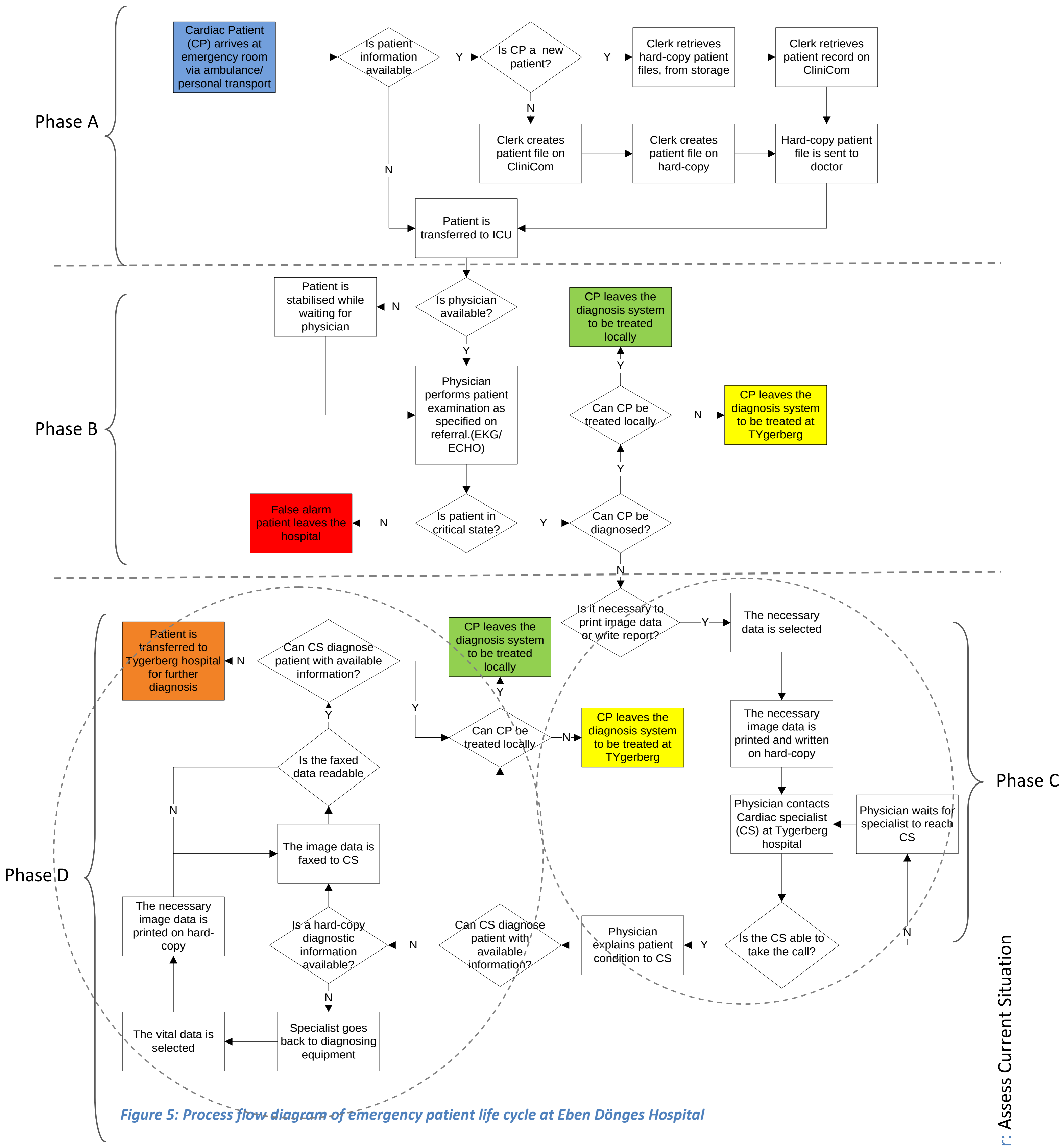

Figure 5: Process flow diagram of emergency patient life cycle at Eben Dönges Hospital

2.2 Tygerberg Hospital current patient data life cycle

Following is an explanation of the procedure followed at Tygerberg Hospital when the physician from Eben Dönges Hospital phones a cardiac specialist to assist with the cardiac patient diagnosis.

At Tygerberg Hospital the cardiac specialist on duty is called via an announcement over the intercom in the hospital, calling for an external patient assistance call. Depending on the state of the specialist's patient at hand, he will either leave the patient to attend to the call, or he will phone back as soon as possible after his patient is stabilised. The initial steps to reach the specialist are illustrated in *Figure 6*.

When the cardiac specialist reaches the phone he listens to a description of the remote patient's conditions. He makes a diagnosis if possible or otherwise the specialist asks for more information to be sent as seen in phase B of *Figure 6*. The physician at Eben Dönges Hospital sends all requested information, where possible. If needed, the physician goes back to the medical imaging modality and retrieves more detail. Meanwhile, the cardiac specialist waits for information and/or images to arrive. Frequently the first fax sent is too distorted or muddled with other documents, hence the specialist has to ask for another copy to be sent. The data transfer steps are seen in phase C of *Figure 6.* After the cardiac specialist receives all the data he makes a diagnosis, if possible, and returns the call to the physician at Eben Dönges Hospital to give diagnostic information or refers the patient to Tygerberg. Proffesor Doubell at Tygerberg explained that in an emergency situation, this process takes between three to four hours to complete, which is too long for the patient's life-threatening situation and can be the factor that determines whether the patient survives or not.

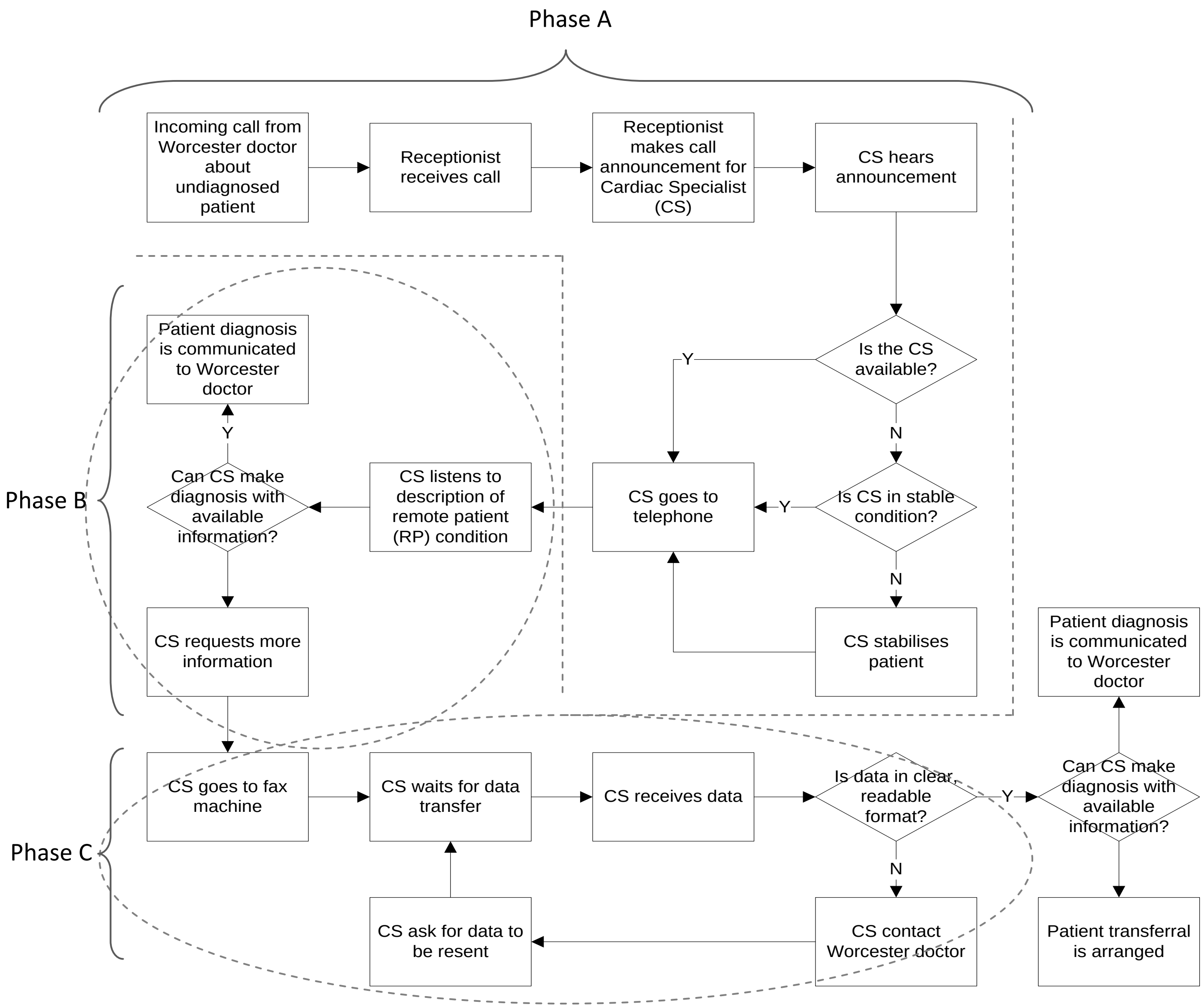

Figure 6: Process flow diagram of remote patient data for diagnostic purpose at Tygerberg Hospital

2.3 Current diagnostic equipment

After visiting both hospitals and discussing the current situation with medical staff, the staff involved with information technology (IT) were also consulted on the current situation and issues. Mr. P. Roode the PACS administrator from Eben Dönges Hospital and Ms D Purdy PACS administrator at Tygerberg Hospital as well as Mr R Tompson, Tygerberg's medical superintendent, which handles data management. The current diagnostic equipment will be discussed in the following paragraph.

2.3.1 Electrocardiography

Electrocardiography (ECG) is an technique used to analyse of the electrical activity of the heart over a period of time. With ECG technology it is possible to pick up electrical signals inside your body without having to penetrate the skin. Electrical signals are captured and recorded by skin electrodes which can be applied to the surface of the skin (Conover, 2004). An ECG is primarily used to measure the rhythms of the heart, and can easily reveal abnormalities. In case of a MI the ECG can identify if the heart muscle has been damaged in specific areas, although it does not cover all areas of the heart (Braunwald, Zipes & Libby, 2001: 108). The one limitation of ECG is that it cannot accurately measure the heart's pumping ability. For this reason echocardiography (ECHO) is employed (Sable, 2002: 358-369). This different technology is explained shortly.

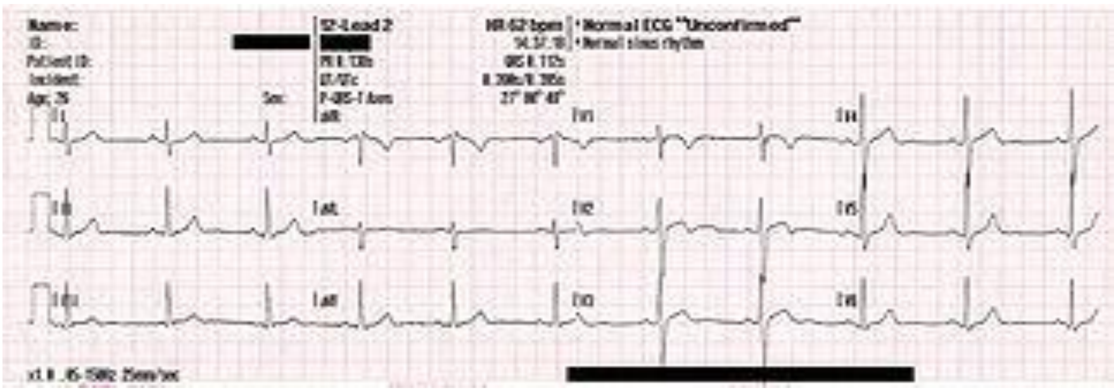

Figure 7: Electrocardiograph (ECG) file

When an ECG is taken of a patient, it is in digital format, but then printed out for doctor's use, like in *Figure 7.* ECG data is stored and processed in different formats, depending on the machine vendor. Professor Doubell stated that, even though ECGs are created in different formats, all ECG data can be converted to digital imaging and communications in medicine (DICOM) format on the imaging machine itself. The concept, DICOM, is expanded on in the chapter

Each imaging modality has its own complications but they all concern the complexity of the data produced and that it cannot be transferred with the current means. Therefore, cardiac specialists cannot be provided with the necessary information to fully comprehend a patient's condition in order to assist the remote diagnosis. In the next chapter alternatives are discussed that will enhance data transfer capabilities.

Develop

2.3.2 Exercise electrocardiography

An exercise ECG is a test which examines the heart for suspicious changes while under physical strain, like exercising. The application of the physical strain allows for some heart rate abnormalities to become apparent which, under normal circumstances, would not show on an ECG. These exercise ECGs are extended tests, usually between twenty to fifty pages of heart voltage data in time-series format.

2.3.3 Echocardiography

An echocardiogram (ECHO) is a sonogram of the heart. It uses ultrasound techniques to recreate two-dimensional layers of the heart, giving rise to the other common term used: *cardiac ultrasound*. *Figure 8: Echocardiography (ECHO)* below shows what a modelled layer looks like. The latest ultrasound technology now uses three dimensional real-time imaging (Conover, 2004: 86-96).

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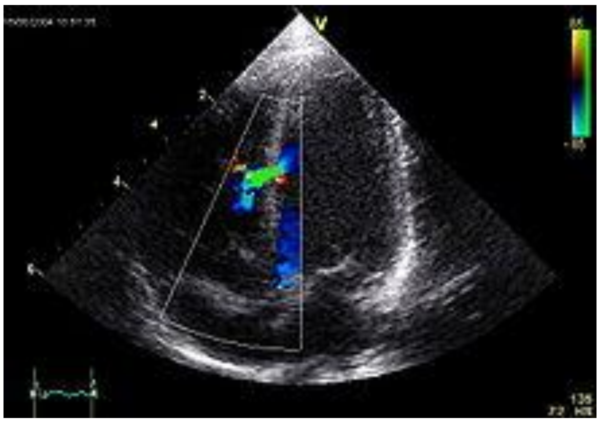


Figure 8: Echocardiography (ECHO)

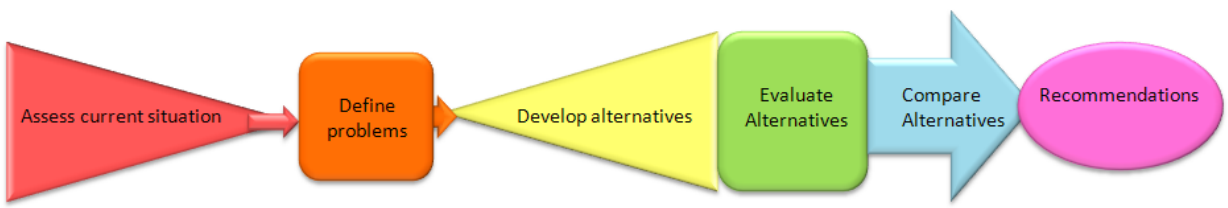
In addition to creating a three-dimensional image of the cardiovascular system, an ECHO can also produce accurate assessment of the velocity of blood and cardiac tissue at any arbitrary point. This is done by using pulsed or continuous wave Doppler ultrasound, improving flow-related measurements. The velocity of blood and cardiac tissue is continuously recorded by the ECHO machine and stored as metadata. The Doppler measurements can be viewed at any arbitrary point during the study (or after the study is done) by requesting the suited metadata. This allows assessment of cardiac valve areas and their function, any abnormal communications between the left and right side of the heart or any leaking of blood through the valves. Therefore, this is very important information for diagnostic the patient condition (Otto, 2003).

2.3.4 Angiography

Angiography is a technique for examining the blood vessels and the heart chamber of a human body. This is traditionally done by injecting radio opaque iodine or barium compounds into the blood vessel and imaging using X-ray based techniques such as fluoroscopy. These compounds are known as radio agents and are suitable to improve the visibility of the internal mechanism and the network of blood vessels of a projection screen (Prokop, 2000: 86-96)

At Tygerberg Hospital, IT is more advanced and all medical imaging machines are connected to a central PACS computer that automatically receives image data in their raw format once they are completed (PACS is discussed in more detail in paragraph 4.3. In comparison to Tygerberg, the hospital in Eben Dönges Hospita lhas no medical imaging machines connected to a computer, thus data is not transferred to a computer or viewed electronically. The machines are all capable of being connected to computers with USB ports or immediate internet connection via a network port, as there is network access in all cardiology rooms.

3 Identify problems



After visiting and analysing the current situation at both hospitals, a multitude of problems that exist within the field of diagnostic remote patients came forward. The factors that limit the ability of specialists to diagnose patients remotely are illustrated in *Figure 1* and are discussed in the following paragraph in more depth. The elaborated cause-and-effect diagram can be seen in *Figure 9*. There are too many cardiac patients and not enough doctors with the necessary expertise to attend to their needs. All rural cardiac patients cannot be treated by cardiac specialists, because they are situated only in urban areas like Tygerberg Hospital. Cardiac specialists, therefore, assist rural doctors to diagnose patients remotely. To assist the rural doctors with diagnosis, cardiac specialists need to view diagnostic information, but the information is complex and cannot be shared easily. Therefore, the assistance currently offered is not optimal and patients do not get the needed specialist opinion.

The biggest problem faced, which is that cardiac specialist cannot be provided with the necessary information to fully comprehend the patient’s condition to assist the remote diagnosis, leads to unnecessary patient referrals to Tygerberg Hospital just to be diagnosed. This is most frequently due to restrictions concerning complex data transfer, which limits the amount of advice the local doctor can receive from a cardiac specialist. The ECGs, exercise ECGs as well as ECHOs cannot be successfully sent via fax (Doubell, 2010). If the data can be sent electronically, current data format options allow for read-only files, thus data cannot be communicated in a format that allows for all processing (Processing is needed to view mathematical metadata that determines the amount of blood passing through a certain area in the heart and with what amount of pressure at a certain time). This is because different machines from various vendors each have a diverse raw format. Data can be converted to DICOM format, which is a common format that all machines can convert to and read. Three-dimensional time series data has complications to be processed by DICOM, since metadata is not accessible by different vendors. Again results in read-only files when viewed on the current software. Data transfer is also limited since the current wide area network (WAN) connecting the hospitals has limited capacity and big data files cannot be shared

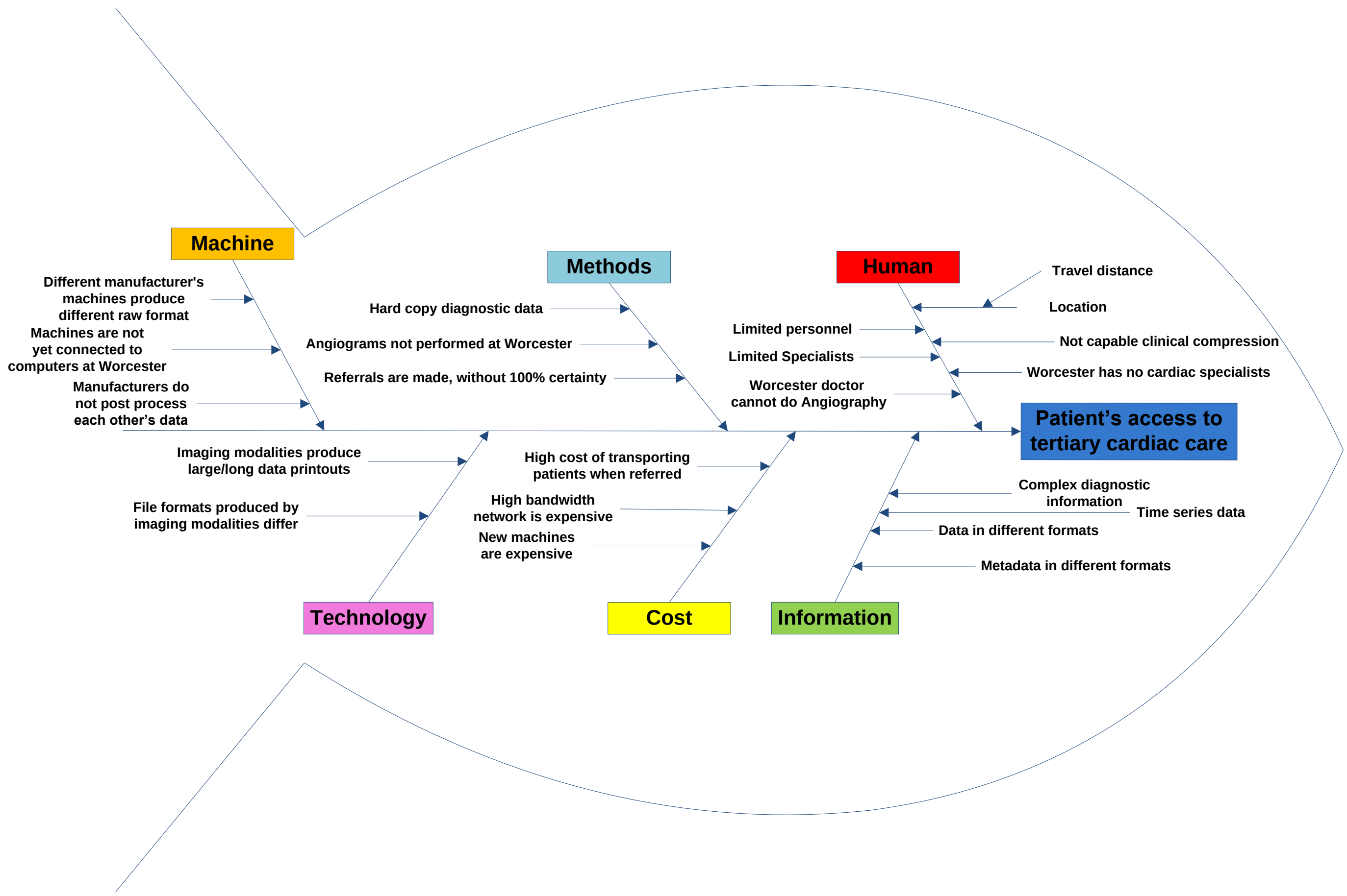


Figure 9: Elaborated cause-and-effect diagram of limits to patient's access to tertiary cardiac care

Another factor restricting remote diagnosis is that at Eben Dönges Hospital, doctors are not capable of performing an angiogram. Therefore, when a patient is in need of an angiogram they are always sent to Tygerberg Hospital. Very often, after the angiogram and diagnosis at Tygerberg Hospital, the patients are sent back to Eben Dönges Hospital for treatment (Doubell, 2010). The unnecessary referral of a patient not only wastes resources, but when a patient is transferred, the process is complicated by having only hard-copy patient data. The data is sent with the patient and numerous times gets misplaced or replaced by the wrong patient data.

Thus, if data is transferred electronically a problem is faced because these data files cannot be viewed in a format that enables processing (with all metadata viewable). After assessment and professional opinion from Mr. Vincent le Roux, Philips PACS developer and Mr. Deon Promel, Toshiba modalities distributer, it was made clear that the data formats are the same and should be readable. The data storage formats are attached in Appendix A. More assistance was given by the PACS administrators of both hospitals, Ms. Debbie Purdy from Tygerberg Hospital and Mr. Partic Roode from Eben Dönges Hospital to come to the conclusion that the problem with interoperability of the DICOM files is firstly, that the software used to view the files are vendor specific. That is to say that at Tygerberg Hospital they are using Philips software to view Toshiba's DICOM files and currently, files are only sent via written CD's for experimental purpose, since the band-width to transfer files are too low, the software used to write these files to CD is not up to date.

3.1 Problems with current diagnostic equipment

3.1.1 Electrocardiography

The interpretation of the electrical activity of the heart over time is a very fragile image, printed on a long strip of paper. This long image is distorted when faxed, and the image is also segmented on separate sheets of paper and is no longer one continuous picture. Thus, the receiver's image is unclear, and all of the loose sheets easily become disorganised and lost from the patient-file. Because of the nature of an ECG, a blurred study that is not ordered chronologically is difficult to interpret for the specialist at Tygerberg. This proves how inefficient the existing data transfer means are for transferring remote patient ECG's .

3.1.2 Exercise electrocardiography

The data of an exercise ECG is a series of information pages which is too much to send via fax. If the information is indeed faxed, the data will be segmented onto separate sheets, resulting in disordered and usually distorted pages of data which cause it to be meaningless since the main function of an exercise ECG is to illustrate the chronologic activity of the heart. The current means of transferring an exercise ECG is by land mail. This mailing process is inadequate, since the specialist usually does not receive the data in time, if he receives it at all.

3.1.3 Echocardiography

There are two methods of storing and transferring visual information, one is analogue media, usually in the form of videotapes for three dimensional images or images converted to two dimensional "slices", the other method is digital information stored in multiple formats that are specific to the particular brand of machines used.

The current method of only sending measurements retrieved from the study by fax is not nearly adequate. This is because local doctors are not necessarily capable of identifying all problem areas that are vital to the patient examination. This problem is currently addressed by converting the three dimensional image of the heart, gained by using ultrasound techniques, to a series of two dimensional "slices". A five minute echocardiograph study results in at least 200 images. Again, the local doctor has to decide which of these images are relevant for diagnosis, resulting in about 15-20 images that needs to be faxed. To receive images gives the specialist a better understanding of the problem, but the value of these "slices" are corrupted since these selected ECHO "slices" are not clear and detailed information is lost and can be distorted when arriving on the other side.

The three dimensional nature of the ECHO makes it difficult to share digitally with the existing means of data transfer. All manufacturers have specific data formats that cannot communicate with one another. All medical machinery used in South Africa must be able to convert digital data to DICOM format (Doubell, 2010) DICOM files are large with the average study requiring about 400 MB of storage space (Frommelt, Whitstone & Frommelt, 2002). The space limit of the Provincial Government of the Western Cape e-mails used are 10 MB per e-mail (Herbst, 2010), thus a study will again have to be separated into approximately forty parts, resulting in forty e-mails for a single study. Even though DICOM is a common data format, the format is not allowing successful processing (to view metadata) between different vendor's modalities. That is, the file can be viewed by all users on different manufacturers' systems, but cannot be processed afterwards. Processing is necessary for an ECHO since it allows doctors to view the metadata necessary to make an informed choice about the patient condition. If this is possible an inexperienced sonographer can perform a study and have a specialist analyse it over a distance as if he (in his expertise) was busy performing the study himself. The specialist can view the heart from any angle necessary and take measurements of that specific area.

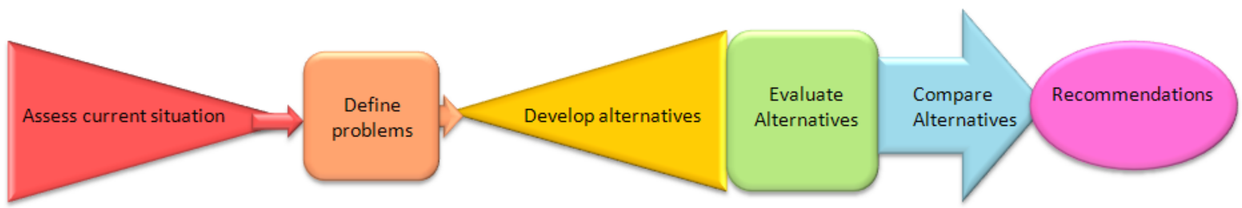
Tygerberg Hospital currently uses Philips medical imaging machines, while Eben Dönges Hospital uses Toshiba machines. Even though both machines save their data in DICOM format, the format is not completely processable when transferred to different vendor's machine. The reason that data is not processable is due to certain metadata of time related three dimensional images are not viewable by users of different manufacture's modalities. This is because they will open an image produced by a different manufacturer's machine than the one they are operating on. This is a problem area which will be investigated in the study.

3.1.4 Angiography

As mentioned before, doctors at Eben Dönges Hospital are not capable of doing angiograms locally. When a patient needs an angiogram, they are always sent to Tygerberg Hospital. After a proper assessment, including an angiogram at Tygerberg Hospital, patients are very often sent back to Eben Dönges Hospital in Worcester for treatment (Doubell, 2010).

Each imaging modality has its own complications but they all concern the complexity of the data produced and that it cannot be transferred with the current means. Therefore, cardiac specialists cannot be provided with the necessary information to fully comprehend a patient's condition in order to assist the remote diagnosis. In the next chapter alternatives are discussed that will enhance data transfer capabilities.

4 Develop Alternatives



In the previous chapter, aspects were identified that restrict data transfer by visiting hospitals and interviewing staff. It was pointed out that that all data is currently on hard-copy and transferred via telephone calls and fax. In this chapter, alternative methods for enhancing the amount of diagnostic patient data that can be transferred are selected for further exploration in an effort to increase the efficiency of the data transfer, to assist in remote diagnosis and to allow patients access to specialist care. These methods found, will be discussed in general as well as their relevance to cardiology and their advantages and disadvantages.

4.1 Digital imaging and communication in medicine

4.1.1 Description

Digital imaging and communications in medicine (DICOM) is a standard format in the industry, used for storing, handling and transmission of digital images. It includes a network communications protocol and definition as well as a file format definition. The National Electrical Manufacturers Association (NEMA, 2010) holds the copyright for the DICOM standard, which comprises of 18 parts, and is freely available at the NEMA website.

The DICOM standard was designed to ensure the interoperability of systems for exchanging medical images and information to create an effective network of electronic health record systems. DICOM maintains advanced technology by having more than 750 technical and medical experts actively participating in DICOM working groups, to update the DICOM standard four to five times each year and then re-published it at least once every two years (NEMA, 2010). DICOM 3.0 is currently the most widely used standard by hospitals worldwide and nationally the initiative is taken to only use medical machinery that is able to convert digital data to DICOM format (Doubell, 2010). Thus, all digital medical machinery in South African hospitals is capable of converting data to DICOM format and handling data in DICOM format. Attached in appendix B is the DICOM 3.0 standard.

4.1.2 Relevance to cardiology

DICOM files are unique and the preferred choice for transferring medical diagnostic data, since DICOM groups the information into data sets, also known as DICOM objects. This means that an ECG file, for example, actually contains the patient information and MRN within the file. Therefore, the image can never be separated from the patient information by mistake. A DICOM data object consists of a number of attributes, including items such as patient name, MRN, and more. One special attribute is the image pixel data which it contains. A single DICOM object can only contain one attribute of pixel data. The pixel data can correspond to a single image, but also to "frames", allowing storage of cine loops or other multi-frame data. An example is ECHO that is, by definition, is a multi-dimensional multi-frame image that can be stored in a single DICOM object (NEMA, 2010). To protect a patient's privacy the *anonymous* option is selected to de-personalise the file by replacing all patient data with "*anonymous*". The screenshot in *Figure 10*: Screen shot of an image of the heart in DICOM format shows that it is possible to import different layers and view the file in different formats by choosing *import frames as layers* or *N-Up configuration,* which are both medical views for assisting diagnosis (Tang, 2010). *Import frames as layers* is an option when viewing a file in DICOM format that will import frames into layers. This option is useful for manipulating the image or creating an animation. *N-Up configuration* is an option when viewing a file in DICOM format that will tile the frames onto one layer. Select this option if you would like to print the frames onto transparencies. (Tang, 2010)

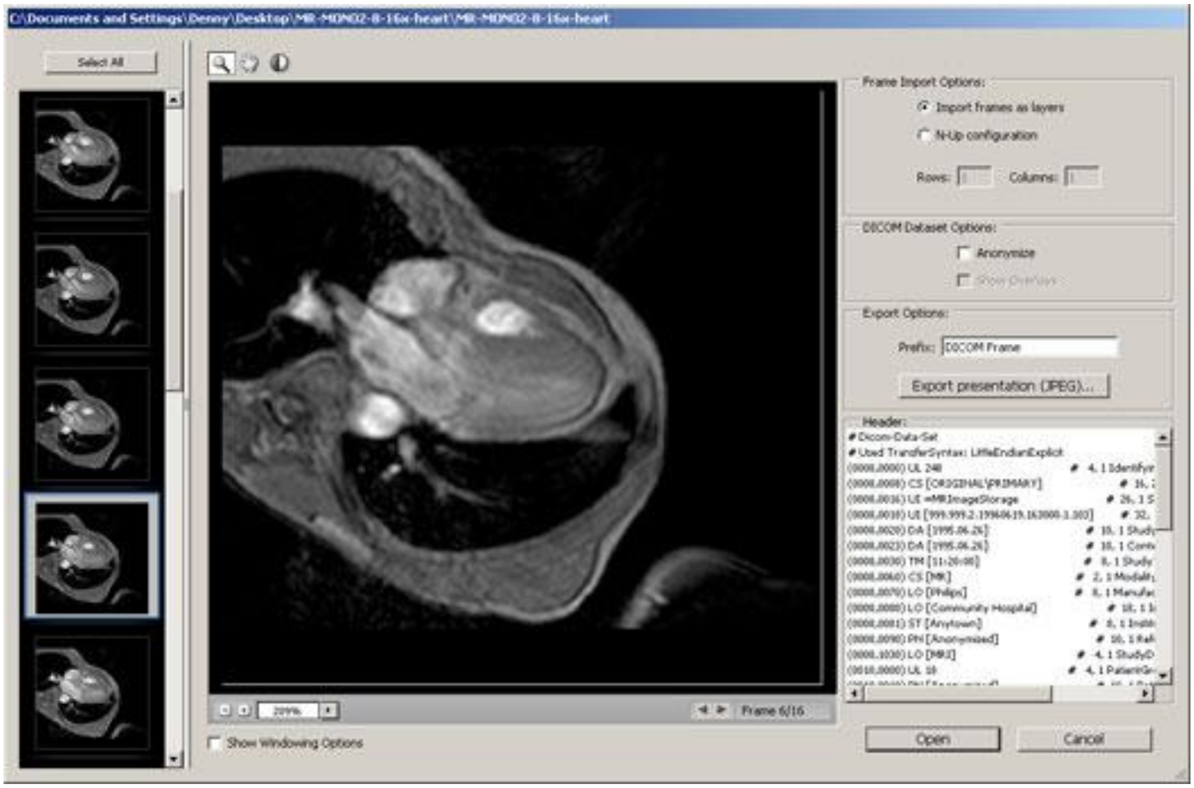


Figure 10: Screen shot of an image of the heart in DICOM format

To be able to e-mail the DICOM data files, it is necessary to have the files stored electronically on a computer, or the other option is to have the computer connect the medical imaging machines of Eben Dönges Hospital to the Internet. This can be achieved by either connecting the machine to a network cable, or connecting the machine to a computer, or to transfer the files with a flash drive to a computer. Since files are too big for network capabilities of immediate transfer to Tygerberg Hospital, and flash drives are a tedious unnecessary step when there is computer access in each room, with network access, connecting the modalities to a computer is the best option.

4.1.3 Advantages

Once data is in DICOM format, it can be sent via e-mail from one doctor to another in a common format that can be viewed by any doctor on any medical software. This will eliminate the probability of data being distorted when printed, and loose data sheets getting lost or disordered.

4.1.4 Disadvantages

The problem remains that studies are too large for a single e-mail. The average ECHO study in DICOM format requires about 400 – 500 MB of storage space for five minutes of data and the e-mailing capacity is 10 MB per e-mail. The local doctor will need to mail about fifty e-mails for five minutes of study data, resulting in the same problem which currently exists - the local doctors are not competent to perform successful clinical compression (compressing the diagnostic study by selecting only the areas that are vital to the patient examination.)

4.2 Data compression techniques

4.2.1 Description

Electronic compression reduces the amount of information contained in a digital frame or loop. The average size of medical data generated is around 250-300MB on average per patient per visit *(Ghrare et al*., 2008). The goal is to reduce files to a manageable size without sacrificing useful information. Electronic compression can be classified as lossless or lossy (Segar *et al*., 1999: 714-719). Lossless compression permits an exact reconstruction of an image pixel by pixel. The compressed file has all of the data necessary to recreate the original file. Lossless compression provides the highest image quality and is most compatible with offline post processing and quantitative analysis. The lossless compression however only results in a compression ratio of approximately 4:l (Santa-Cruz, D. 2000; Sable, C. 2002). Lossy compression eliminates redundant data and conserves space. Some of the data is lost in reconstruction of the file, but this information may not even be visible to the human eye. This will allow higher compression ratios. Lossy compression schemes have not been widely used for both clinical and legal reasons, because any information lost or error caused by the image compression process could affect clinical diagnostic decision. Therefore, due to the fear of loss in medical information raw or original data is usually stored in the best quality possible (Frankewitsch *et al*., 2005: 447-451). However, lossless compression algorithms can yield images with diagnostic data that are statistically identical (using methods such as least square error (LSE) and peak signal-to-noise ratio (PSNR) compared to the original images (Ghrare *et al*., 2008).

4.2.2 Relevance to cardiology

Tools for compression of DICOM data are discussed, since DICOM is the industry standard for exchange of medical data. DICOM objects contain various attributes - one special attribute contains the image pixel data. DICOM pixel data can be compressed using a variety of standards, including joint photographic experts group (JPEG), JPEG 2000, or LZW (zip) compression can be used for the whole data set, not just the pixel data. This is, however, very rarely implemented seeing that the other data is very small compared to the pixel data. MPEG is used for compression of motion pictures.

4.2.2.1 Joint photographic experts group

In 2000, joint photographic experts group upgraded JPEG, their original lossy tool for compression of still images, to a tool that can be used for lossy as well as lossless compression, JPEG2000. See the images comparing the JPEG to JPEG2000 in *Figure 11.* The JPEG2000 standard was compared in tests where images were compressed up to 200 times. When an image was compressed 200 times, although lossy, no visible difference was found by the specialists examining them. JPEG 2000 lossless compression on the other hand, was found to be a very effective technology for compression of still images from DICOM format without any loss of diagnostic data up to 4 times (Anastassopoulos, 2002, 783–788).

Figure 11: DICOM format x-ray compressed to 8bits/pixel by (a) compressed by JPEG2000 and (b) compressed by JPEG

4.2.2.2 Moving picture experts group

Moving picture experts group (MPEG) is the name of a family of standards used for coding audio-visual information (e.g., movies, video, and music) in a digital compressed format and is the most widely used standard for compressing video data (Ghrare *et al*., 2008; Spencer *et al*., 2000: 51-57). MPEG uses very sophisticated compression techniques, resulting in much smaller audiovisual files for the same quality than other video compression tools do (Ghrare *et al*., 2008).

A study done by the European federation of medical informatics in 2005 to assess the quality of MPEG4 compressed DICOM video data, states that MPEG4 compresses video data (such as ECHOs) to a third of the size while remaining statistically identical (that is lossless compression), but can compress data to a tenth of the original size without losing diagnostic information in the immediate view (that is to say that the video displayed is visually identical, but metadata for post processing is lost) (Frankewitsch *et al*., 2005: 447-451).

4.2.3 Advantages

Implementing data compression techniques will enable the doctor from Eben Dönges Hospital to electronically send data without the need for clinical compression or sending a variety of e-mails. An ECG study will be able to be sent with on email, since an original ECG is about 5MB and can be compressed lossless 5 times which results in 1MB that is less than the e-mail capacity of 10MB. An ECHO study , with an original size of 500MB can be compressed lossless 3 times 166MB which will result in 17 e-mails instead of 50) (Anastassopoulos, 2002, 783–788)

4.2.4 Disadvantages

After a study is electronically compressed and transferred to a different format it becomes a read only file and no post processing a possible and a great deal of diagnostic information is lost.

4.3 Picture archiving and communication system

4.3.1 Description

The picture archiving and communication system (PACS) is a medical image and information distribution system designed for integration into a medical institution's existing healthcare network and interconnects with other hospitals and users. The PACS software acts as a web server that, together with PACS hardware, forms an intranet. This intranet is developed in an attempt to provide economical storage and rapid retrieval of digital medical images with a central server and archive. The system utilises a medical industry standard protocol to exchange information with other connected devices that also comply with the standard. The universal standard format for PACS image storage and transfer used in South Africa is DICOM 3.0.

PACS consists of four major components: the imaging modalities such as ECHO, ECG and angiogram, where the diagnostic images are created; a secure network for the transmission of patient information;

workstations for interpreting, reviewing and enquiring of images, and lastly, a central PACS server. The PACS server consists of a quality assurance (QA) workstation as well as archives for the storage of medical information. The quality assurance (QA) workstation is the virtual machine that contains the computer program (web server software) which delivers the content of the stored data from the archives to the workstations for viewing. The archive stores all data and is central and accessible so clients can retrieve images and reports at anytime. The system is illustrated in *Figure 12: Four major components of PACS*.

The images are produced at the imaging modalities, where it is transformed to DICOM format and then sent to the QA workstation. The QA workstation serves as a checkpoint to make sure patient demographics as well as other important attributes of a study are correct. If all the information is correct, the images are passed to the archive for storage. The images can then be retrieved (using DICOM query and retrieve (Q&R) protocol) from the workstations connected.

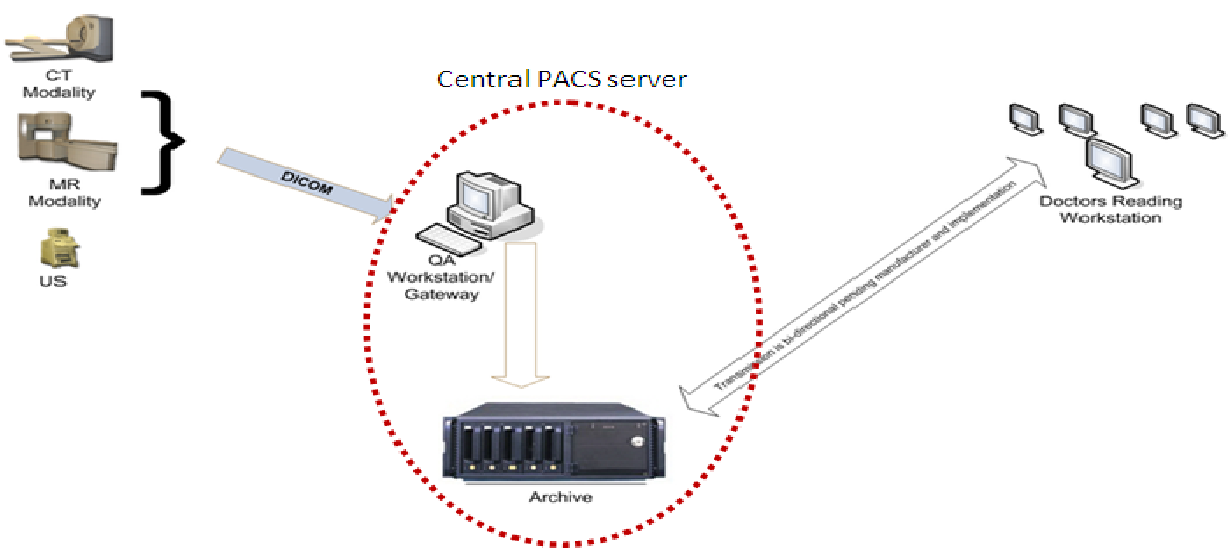


Figure 12: Four major components of PACS

4.3.2 Relevance to cardiology

PACS allows a cardiac specialist at Tygerberg Hospital to view DICOM format files that a health care practitioner at Eben Dönges Hospital. This accurate information sharing allows the specialist at Tygeberg Hospital to assist the health care practitioner performing the study to make diagnosis. **Error! Reference source not found.** illustrates how the PACS will be implemented to assist remote diagnosis.

If scanned documents and other nonmedical image data needs to be uploaded for the cardiac specialist to assist in diagnosis, these images need to be converted from their current format to DICOM 3.0 on the personal computer. This conversion is necessary for uploading images to the PACS. In this case, the files need to be converted to the universal format of DICOM3.0. Data can be converted to DICOM format using Print2PACS or PACSSCAN (Owens, 2010). Where the specialist sees the study done by remote doctor on his computer and can thereby assist the remote doctor telephonically to diagnose patient and formulate treatment procedure.

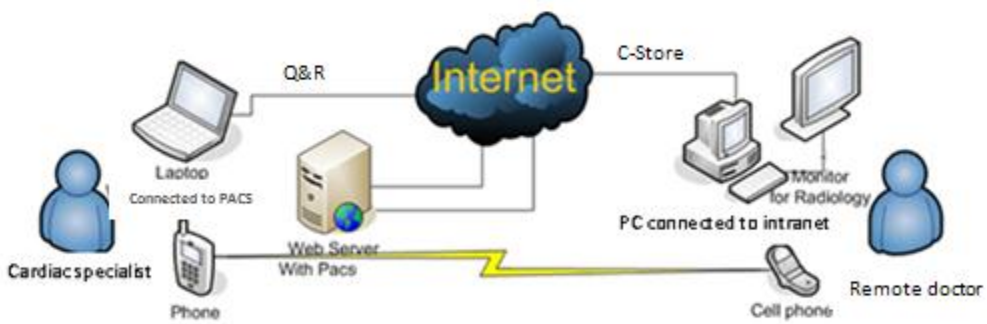


Figure 13: The PACS network that will assist remote diagnosis

Tygerberg Hospital currently uses the iSite PACS software, designed by Philips. The iSite Enterprise product is the software needed to deploy PACS. At Eben Dönges Hospital, however, they only have one computer with iSite software installed, which is connected to the central PACS server of Tygerberg Hospital. This permits a doctor at Eben Dönges Hospital to view all of the images available in the Tygerberg archive. The hospital in Worcester is in the process of creating a tender for acquiring a PACS for the Eben Dönges Hospital as well, to ensure interoperability between the two hospitals. Most PACSs can communicate with each other through DICOM, but in the case that technologies do not conform to a common language, a software package called XDS can be utilised (Roode, 2010). XDS is a basic interface and data processing program for analysing the data output.

4.3.3 Advantages

The major advantage of employing a PACS is that a there is constant connection between the user and images from multiple sites via the central PACS server. This means that the user can acquire medical information from various types of equipment connected to the PACS intranet at anytime. Therefore, the local doctor at Eben Dönges Hospital does not need to convert files to DICOM, transfer files to a computer and send the files to the cardiac specialist. By default all studies transfer to the central PACS server after the study is completed and can then be viewed by anyone connected to the system, by entering patient MRN.

4.3.4 Disadvantages

While PACS solutions have produced simple ways for wide distribution of images it often lacks the necessary tools for advanced image processing and 3D visualisation of video data (Faha, 2006). DICOM files are readable but not completely capable of being processed by the different manufacturers' modalities. According to Mr. Vincent le Roux, the problem is with the CD-writer currently used to write these files to CD. This problem will be solved when the PACS system is in place, because then the data will be transferred electronically and not via CD's. Electronic transfer of video files is still not possible, due to low band-width internet connection; therefore, this M. V le Roux's hypothesis cannot be tested until the files can be sent electronically.

4.4 DICOM viewers

4.4.1 Description

The increases in performance of personal computers allow implementing complex image processing and visualisation tools on the standard off-the-shelf hardware (Faha, 2006). DICOM viewers are software tools that offer a graphic user interface together with an image processing and analysis tool to view DICOM files. This software allows interchangeability of medical data which enables viewing, segmenting and measuring all in DICOM format as well as post processing. With this integrated interface it is possible to view DICOM files on any computer.

The three most common DICOM viewers, in order of complexity, are: ImageJ, MicroDicom and OsiriX respectively. These three viewers were compared, but OsiriX was found to be the most suitable for viewing three-dimensional time series data. ImageJ is very basic solution, only for still image viewing. This software can be used in an educational setup to open Dicom files, but where a PACS exists it is not of use since PACS has more viewing features than the normal ImageJ (Sheets, Vavylonis, 2010). On the other hand, MicroDicom and OsiriX have three dimensional video viewing capabilities, but only OsiriX allows for processing (to view Doppler measurements for example) (Stoykov, 2010). Therefore, OsiriX is the most advanced of the three DICOM viewers.

4.4.2 Relevance to cardiology

OsiriX is an advanced DICOM viewer for viewing and post processing three dimensional time series image data, such as ECHO studies. The software effectively manages copious amounts of image data transferred by any PACS or medical imaging modality that are in DICOM format. OsiriX was design to assist users to navigate through large sets of image data; to import data, export data, query the data database and process images that were obtained from the database to retrieve metadata stored (Teng, 2009: 1). *Figure 14* illustrates some of the different user views that can be accessed. *Figure 15: OsiriX screen shot showing some of the processing available*.

The OsiriX software is developed in Objective-C programming language on a Macintosh operating system. OsiriX is provided free of charge under the general public open-source licensing agreement at http://homepage.mac.com/rossetantoine/osirix.

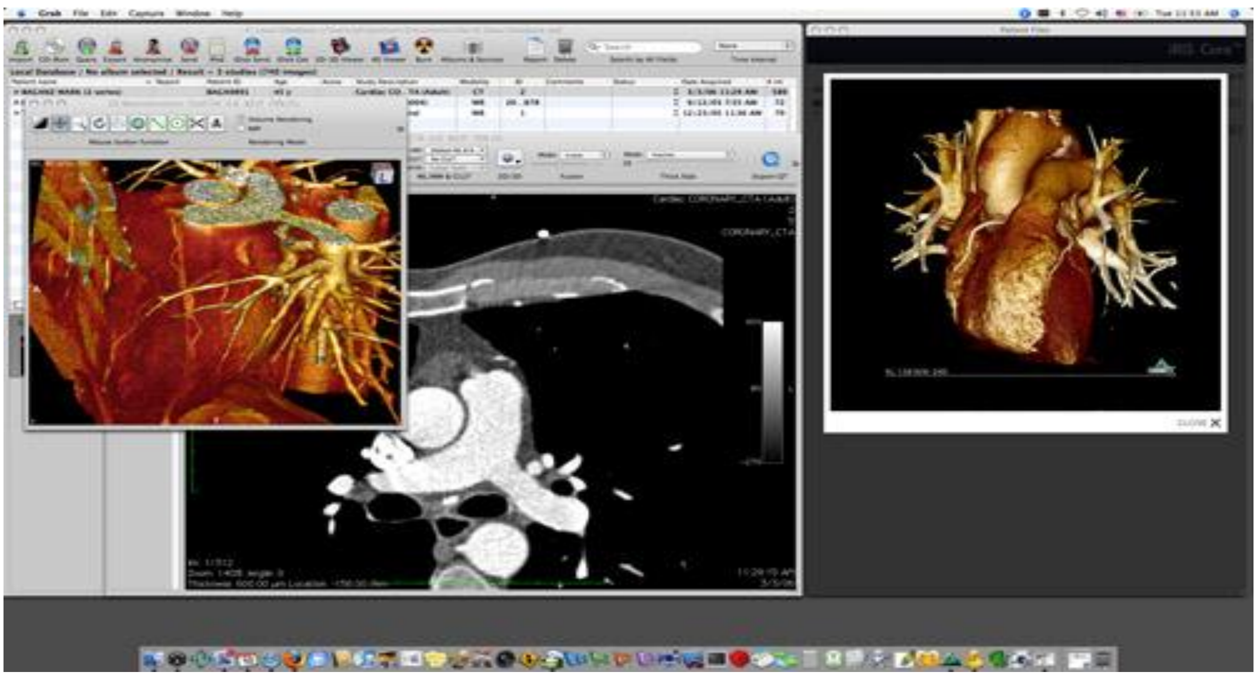


Figure 14: Osirix screen shot showing different user view formats

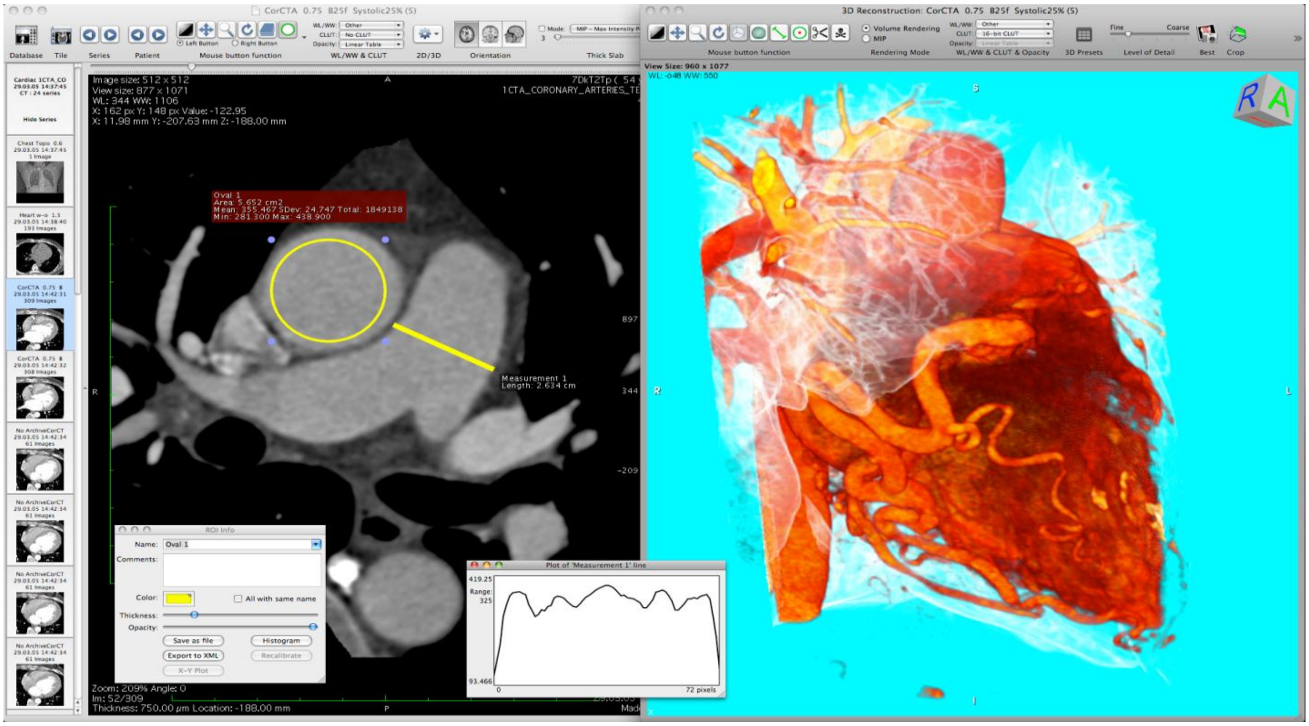


Figure 15: OsiriX screen shot showing some of the processing available

Osirix is also available as iPone, iPod touch or iPad application. This feature allows you to search for and retrieve images from a PACS server or a DICOM-compliant workstation from your mobile device and directly download the images (through WiFI) to OsiriX database on your mobile device. OsiriX displays the list of studies stored locally on the mobile device (Iphone OsiriX Group, 2010). The iPhone and iPod are not capable of all the post processing, but assists in diagnosis in visibly displaying two and three dimensional time series diagnostic data. A screen shot of a three dimensional DICOM image on the iPone is shown in *Figure 16*. Post processing can be done on the iPad.

Figure 16: OsiriX iPone screen shots

4.4.3 Advantages

When DICOM viewer software is used in addition to a PACS, this will allow the specialist to do all post processing necessary and to view the data from where he is currently working, since it is available on mobile devices. DICOM viewer will reduce the cost of software acquisition, maintenance, and user training because it is a tool that is cheap, versatile, easy to use and maintain (Faha, 2006).

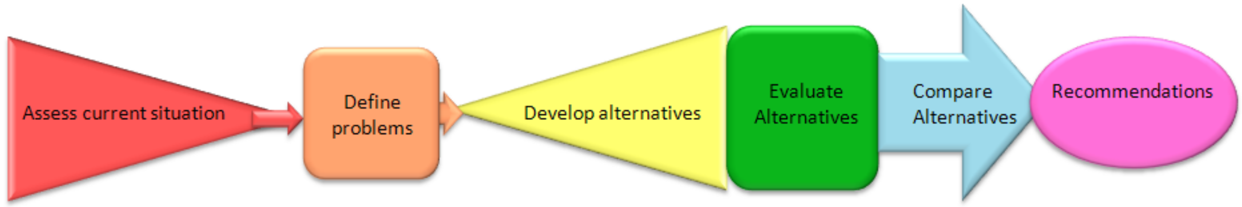
4.4.4 Disadvantages

OsiriX is only available on the Macintosh operating system.

OsiriX Mobile cannot display images greater than 1024x1024 pixels, it will prompt a message stating "*Image NOT at full resolution"* on an iPhone/iPod, but it is possible on the iPad. Other limitations of the iPhone/iPod include: WiFi transfers are not fast, since the device resources (CPU, memory and storage) are limited. It is not a workstation to do processing at. The iPad, however, is like a computer and all post processing is possible (Iphone OsiriX Group, 2010).

The alternative methods identified were: the common data format, DICOM, which allows interchange of different formats of data; data compression techniques, which compressed DICOM data to save storage space; a central database and intranet to share more diagnostic data effectively; as well as DICOM viewers, which are image management software for personal computers that allow post processing of DICOM image data.

5 Evaluate Alternatives



In the previous chapter alternative methods to enhance the amount of diagnostic patient data that can be transferred; to increase the efficiency of the data transfer; to allow patients access to specialist care and to assist in remote diagnosis were identified and discussed. The alternate methods are: Use of electronic data transfer in DICOM format, data compression techniques, PACS intranet between the hospitals and a variety of DICOM viewers. In the following paragraph these opportunities are compared as to how well they fulfill each objective. The objectives are: to effectively transfer patient data; to minimise the duration of the data transfer procedure; to find a cost-effective and user-friendly solution. Other objectives that will be considered are to eliminate the legal and ethical issues concerned and to find a solution that offers secondary or tertiary educational benefits. These objectives are illustrated in *Figure 17: The different objectives that alternatives are measured by*.

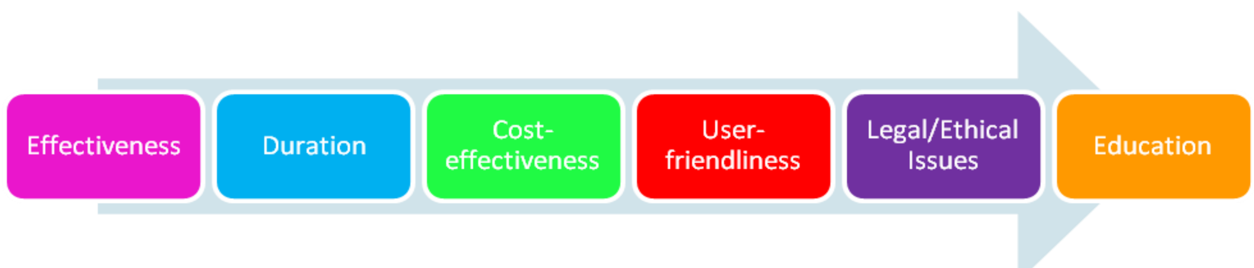


Figure 17: The different objectives that alternatives are measured by

5.1 Files sent electronically in DICOM format

In the next section the alternative to electronic data transfer of DICOM files via e-mail are discussed relevant to each of the objectives.

5.1.1 Effectiveness of data transfer procedure

5.1.1.1 Diagnostic data communication

This alternate solution of electronic data transfer increases the speed and quality of the data communicated. Video data does not need to be sliced and sent in still images as video clips can be sent in DICOM format. This solution does not allow for whole studies to be transferred, and therefore, does not solve the problem of ineffective clinical compression, due to the limiting e-mail capacity of 10MB.

5.1.1.2 Interoperability of diagnostic data

The process discussed does not increase the interoperability of the data, since the current software used to view DICOM files does not allow for post-processing of data from different medical imaging modalities. Viewing ECGs in DICOM format from different ECG modalities is fine, since no processing of data is needed. On the other hand to view angiograms or ECHOs, processing is needed to view metadata (e.g. the Doppler measurements of the heart at a certain stage in the cardiac cycle) to make an informed diagnostic decision. This is not possible with the current DICOM viewing software tools.

5.1.2 Duration of procedure used for transferring diagnostic data

All diagnostic patient data is stored in a hard-copy format, printed or hand-written documents and therefore, getting the files into a digital format on the machines to a computer and e-mailing it is an extra step in the process life cycle (seen in the flow diagram of *Figure 18: Process flow diagram of non-emergency patient at Eben Dönges if documents are e-mailed in DICOM format.* and *Figure 19*).

5.1.3 Cost effectiveness of implementation

The only implementation needed to employ electronic data transfer will be to connect the medical imaging machinery at Eben Dönges Hospital to computers, and connect the computers to the Internet. Seeing that all machinery is digital and has USB ports, connecting them will entail following a setup manual supplied by the manufacturer. There is an existing network cable in all rooms where radiology is performed; hence a network connection will easily be achieved.

5.1.4 User-friendliness of data transfer procedure

Users need to be trained on transforming files to DICOM format and to a computer or flash drive. Selecting the part of the study that is essential to diagnosis and cropping that part of the study in the DICOM file format, is another skill that will need training. Both the previously mentioned skills are easily mastered when hardware is connected properly, hence training will be minimal.

5.1.5 Secondary or tertiary educational benefit

This option will contribute to education in the industry, since files are electronic and can be used for teaching in lectures and seminars. It is possible that after the vital section of a study is selected by a doctor, a medical “trainee” can transform the study to DICOM format and crop it if necessary before sending the e-mail, which will also allow them to learn.

5.1.6 The ethical and legal issues regarding this option

There is an ethical and legal concern regarding all patient data being electronic, because electronic data is easily shared and distributed. In the defence of electronic data transfer, it is more manageable, therefore it does not get misplaced as easily causing it to land in the wrong hands. With the DICOM anonymous function, a patient’s identity can be withdrawn from files and completely removed, therefore eliminating the possibility of distributing confidential patient data.

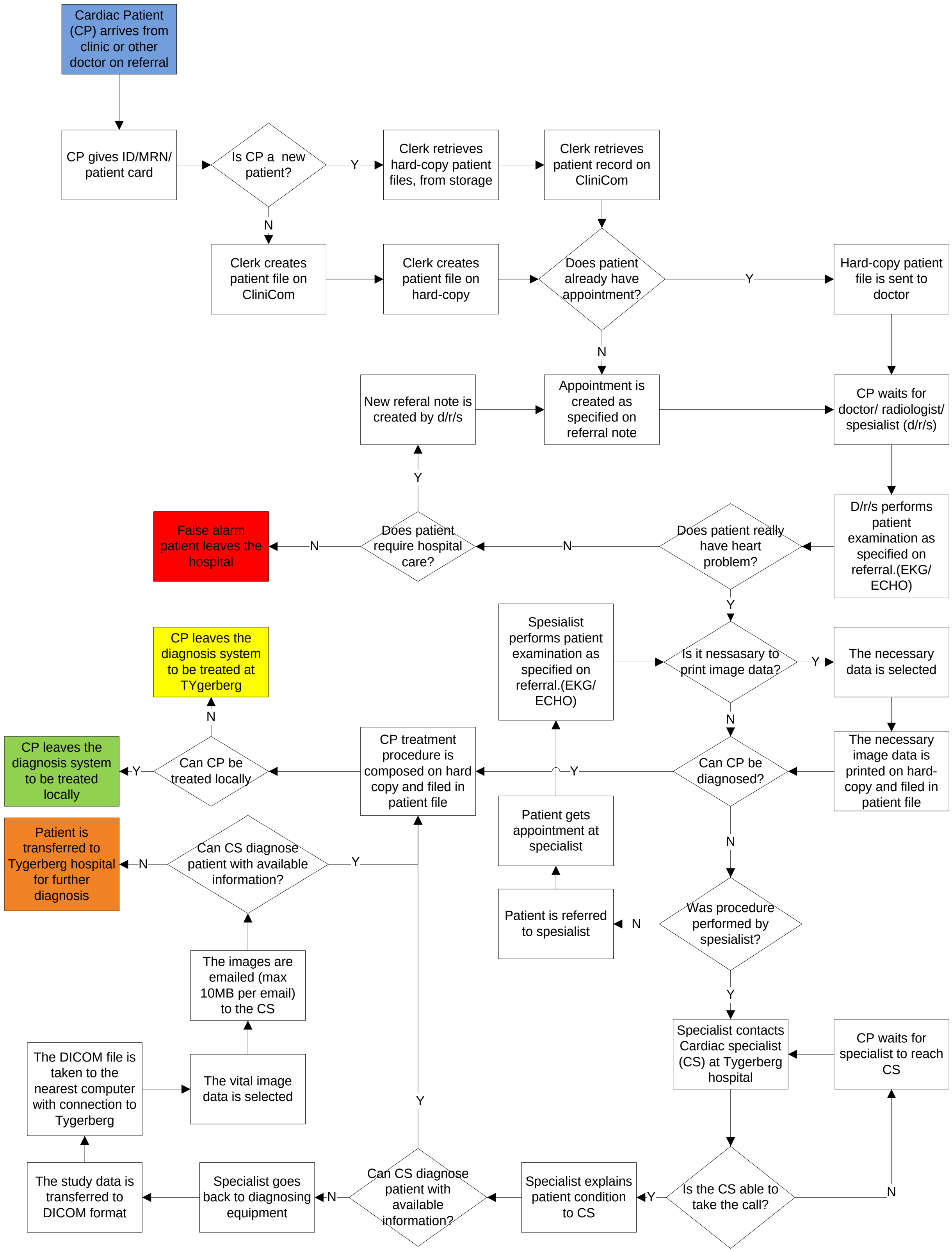


Figure 18: Process flow diagram of non-emergency patient at Eben Dönges if documents are e-mailed in DICOM format.

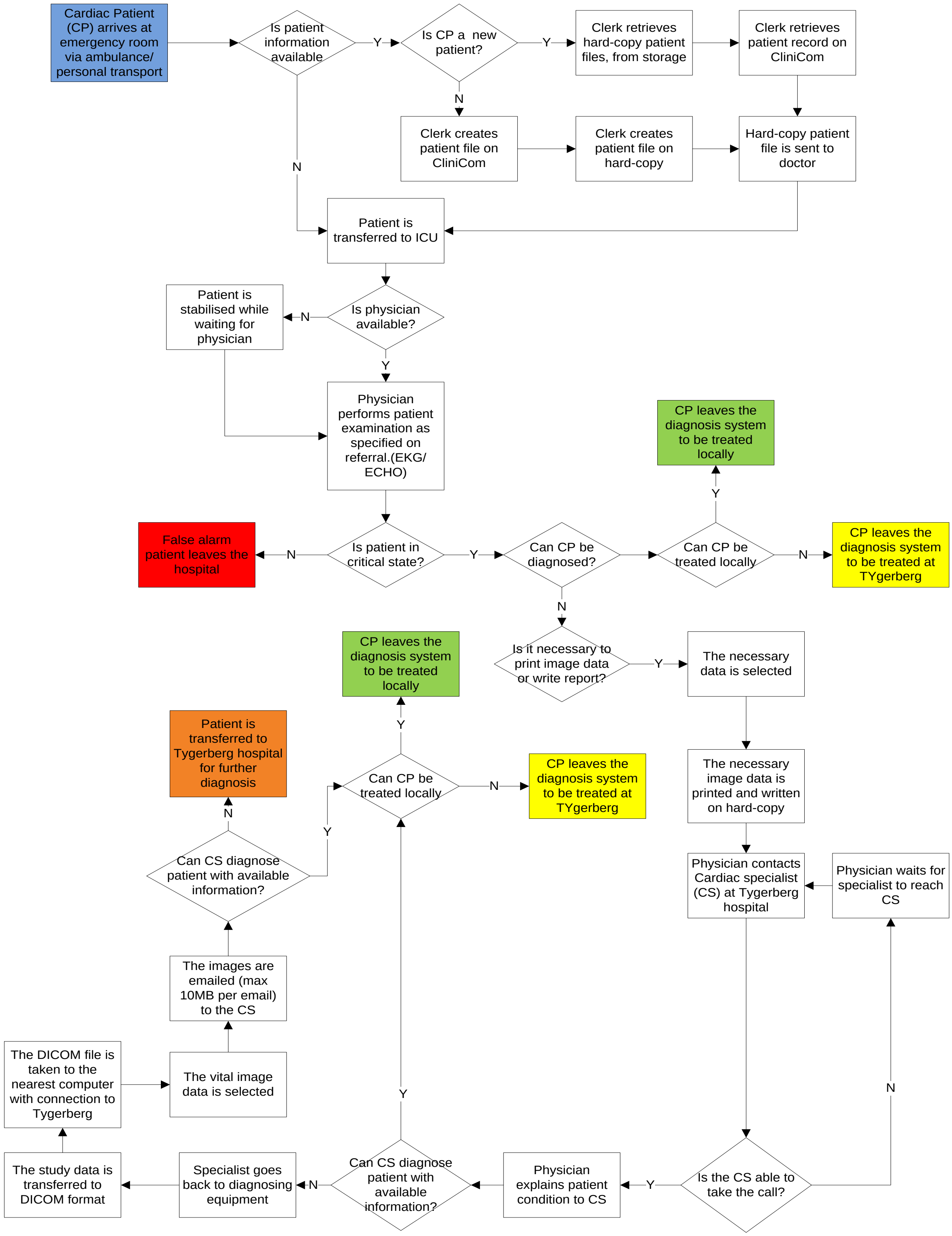


Figure 19: Process flow diagram of emergency patient at Eben Donges if documents are e-mailed in DICOM format

5.2 Data Compression techniques

In the next section the alternative to compress DICOM files before electronic data transfer is discussed relevant to each of the objectives.

5.2.1 Effectiveness of data transfer procedure

5.2.1.1 Diagnostic data communication

The process of data compression increases the speed and quality of the data communicated. Video data does not need to be sliced and sent in still images, and can be sent in DICOM format. This solution allows for whole ECG studies to be transferred, but not whole video studies such as ECHOs. However, with compression, a video study ten times longer than without compression can be sent, but it is still too large for a single e-mail. Therefore, this does not completely solve the problem of ineffective clinical compression.

5.2.1.2 Interoperability of diagnostic data

The process discussed does not increase the interoperability of the data, due to the fact that the compression process transforms the file into a read-only format. This cancels the opportunity for post-processing of medical data since the newly compressed file can only be viewed and not explored in-depth.

5.2.2 Duration of procedure used for transferring diagnostic data

All diagnostic patient data is stored in a hard-copy format, printed or hand-written and, therefore, getting the files into a digital format from the machines to a computer and then e-mailing it is an extra step in the process life cycle, seen in the flow diagram of *Figure 20: Process flow diagram of non-emergency patient at Eben Donges if documents are e-mailed in compressed JPEG2000 or MPEG format* and *Figure 21: Process flow diagram of emergency patient at Eben Dönges if documents are e-mailed in compressed JPEG2000 or MPEG format.*.

5.2.3 Cost effectiveness of Implementation

The implementation involved will be to connect the medical imaging machinery at Eben Dönges Hospital to computers and connect the computers to the Internet. The compression software, Image Converter Plus, can be downloaded for free, and is available on http://www.imageconverterplus.com/download/. Since all machinery is digital and has USB ports, connecting them will entail following a setup manual supplied by the manufacturer. There are existing network cables in all rooms where radiology is performed, therefore, a network connection will easily be established.

5.2.4 User-friendliness of data transfer procedure

Users need to be trained on transforming files to DICOM format and to a computer or flash drive. Another important skill needed is selecting the part of the study essential for diagnosis and cropping that part of the study in the DICOM file format, then compression the file. All these mentioned skills are simple and easily obtained with no prior knowledge of the software. There are demonstration videos available on the internet to assist the training of using the converter.

5.2.5 Secondary or tertiary educational benefit

This alternative of data compression will contribute to education, since files are electronic and can be used for teaching in lectures and seminars. It is possible that, after the vital section of a study is selected by a doctor, a medical “trainee” can transform the study to DICOM format and crop it if necessary before sending the e-mail, which will also allow them to learn.

5.2.6 The ethical and legal issues regarding this option

There is an ethical and legal concern regarding all patient data being electronic, because electronic data is easily shared and distributed. In the defence of electronic data transfer, it is more manageable, therefore, possibly less easily misplaced causing it to land in the wrong hands. With the DICOM anonymous function, a patient’s identity can be withdrawn from files and completely removed, therefore eliminating the possibility of distributing confidential patient data. Another ethical/legal issue is that diagnostic data can be lost when images are compressed (Frankewitsch *et al.*, 2005: 447-451). Diagnostic quality is higher than in the original situation, but the detailed legal issue is beyond the scope of this project.

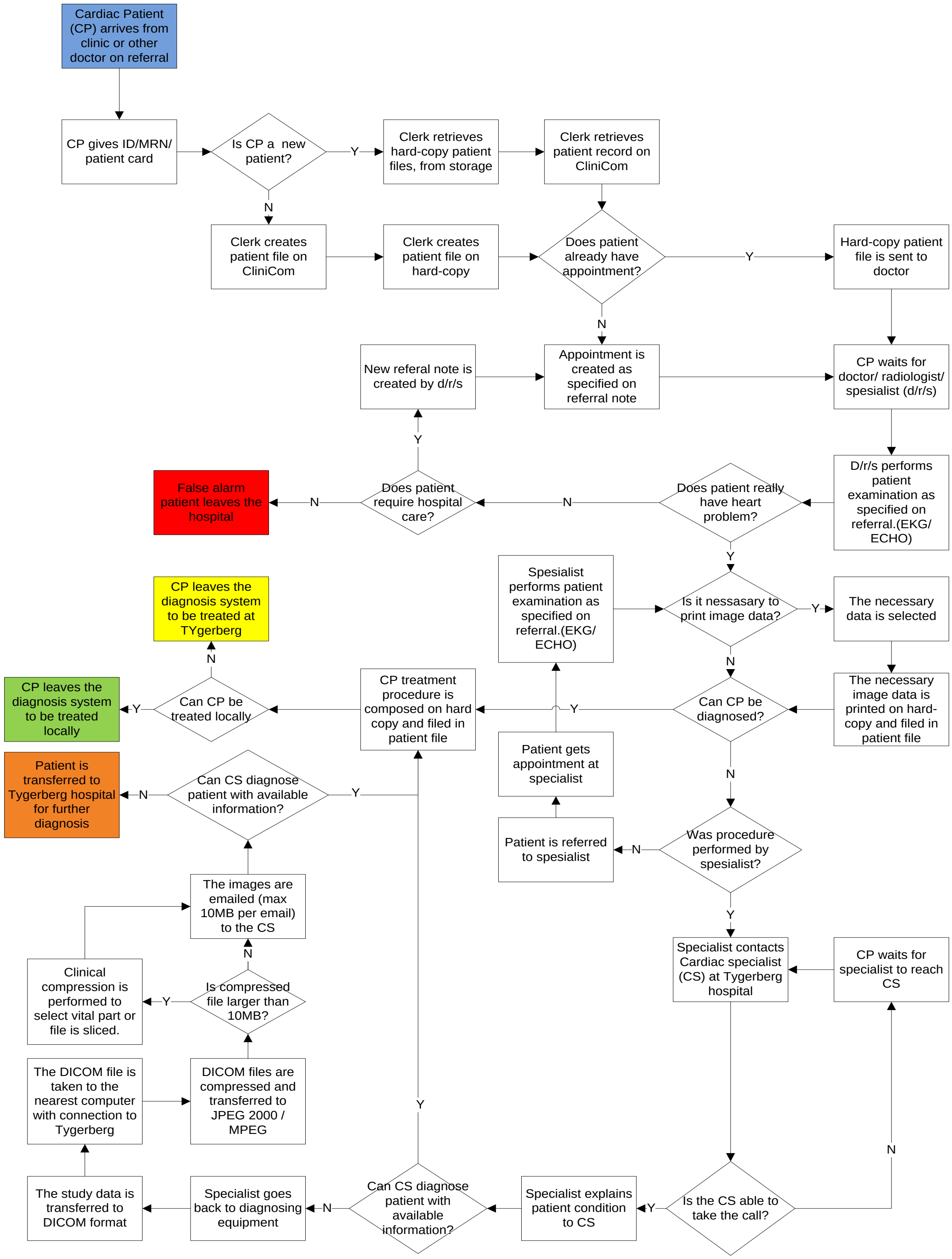


Figure 20: Process flow diagram of non-emergency patient at Eben Donges if documents are e-mailed in compressed JPEG2000 or MPEG format

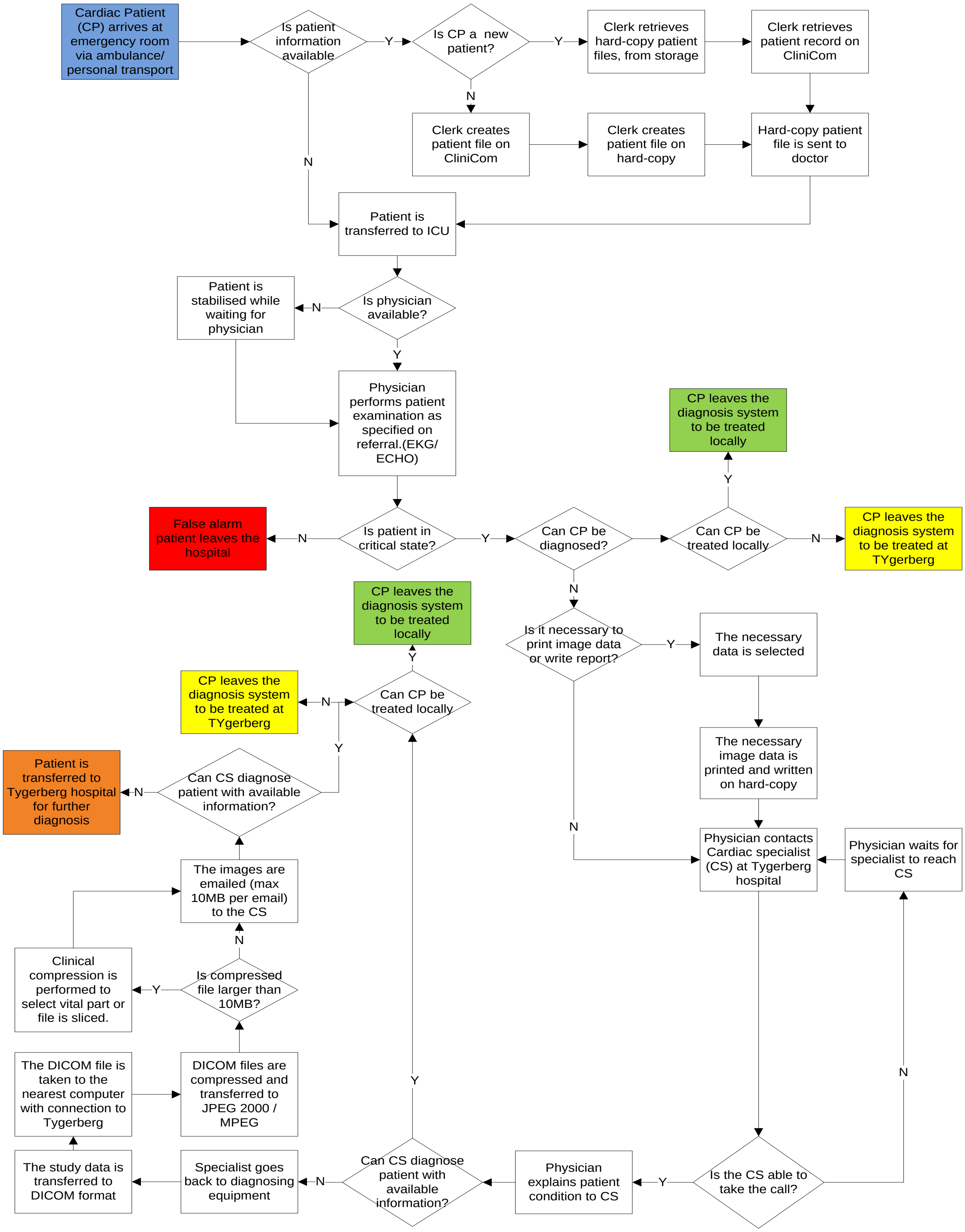


Figure 21: Process flow diagram of emergency patient at Eben Dönges if documents are e-mailed in compressed JPEG2000 or MPEG format.

5.3 PACS intranet between Eben Dönges Hospital and Tygerberg Hospital

In the next section the alternative to establish a PACS intranet between the two hospitals is discussed relevant to each of the objectives.

5.3.1 Effectiveness of data transfer procedure

The PACS intranet can greatly contribute to increasing the efficiency of communication and interoperability between the two hospitals. Data is automatically transferred to an electronic file on the central processor by the PACS system. Specific data can then be accessed from any computer connected to the intranet, using the patient MRN.

5.3.1.1 Diagnostic data communication

This process increases the speed and quality of the data transferred, since data is always available and can be accessed with little trouble. This method of contact streamlines information and prevents communication gaps or data being "lost in translation". Video and still image data can be shared completely without the need for clinical or electronic compression

5.3.1.2 Interoperability of diagnostic data

The process discussed enhances interoperability of the data, because when data is shared in the DICOM format, depending on the compatibility of the modalities, post-processing is possible. In this case the possible processing is limited.

5.3.2 Duration of procedure used for transferring diagnostic data

All diagnostic patient data is still stored in the form of hard-copy printed or written documents, but in this case, diagnostic image data is automatically transferred to the central PACS server, without the need to send the data. Therefore, the local doctor can call the cardiac specialist on duty from the room where he is performing the diagnosis, with the patient MRN. The specialist on duty will still be interrupted in his shift, but he can go the computer and view the full patient file by a simple "query and retrieve" and do all the processing independent of the remote server. With PACS in place there is no need for clinical compression or for transferring files to computers with internet connection. This saves the local doctor a lot of time. This improved process flow diagram can be seen in *Figure 22* and *Figure* 23: Process flow diagram *of emergency patient at Eben Donges if a PACS is implemented between the two hospitals.* Even though the specialist on duty still needs to discontinue his current activity and go to a computer to view the files, at least the files can be accessed immediately and are all in a good quality for processing. There is no need to make phone calls and request the same sets of data numerous times for improved legibility; automatically identifying this process as one with a high success rate of remote diagnosis.

5.3.3 Cost effectiveness of implementation

The implementation of this system entails connecting the medical imaging machinery at Eben Dönges Hospital to computers, and connecting the computers to the PACS central server of Tygerberg Hospital as seen in *Figure 12*. This has already been done at Tygerberg Hospital. The software involved also needs to be installed by the existing IT department. Seeing that all machinery at Eben Dönges Hospital is digital and has USB ports, connecting them will be easy and a simple setup manual supplied by the manufacturer is sufficient. There is a network cable in all rooms where radiology is performed, therefore network connection will easily be established. At the moment the connection between Tygerberg and Eben Dönges Hospital is achieved by a wide area network (WAN). A high band-width network cable, of which the size is still uncertain, needs to be installed connecting the two hospitals.

5.3.4 User-friendliness of data transfer procedure

Minimal training is needed since files are automatically sent to the server, but users need to be trained to open files at the remote workstations. This promises to be easy with a simple, user-friendly interface. The specialist will not need training to open the DICOM files, because there is already a PACS in place at Tygerberg Hospital and the specialists are already familiar with the program.

5.3.5 Secondary or tertiary educational benefit

Information technology, being integrated into secondary and tertiary education, training becomes integrated into medical curricula. The nature of education will change with PACS in place, due to the increased availability of online, real-time imaging data. Studies could be made available for students to view. With a PACS system in place all images will be available during lectures and seminars, for educational and discussion purposes. With a simple connection between the computer in the lecture or seminar room and the PACS central server, students can be exposed to medical information at hand. With PACS, not only physicians on ward will be able to view the files but also in other departments or the files of outpatient practices and this can all be shown to students for educational purposes.

5.3.6 The ethical and legal issues regarding this option

Ethical or legal issues can develop with exchange of confidential patient information, but due to patient data only being connected to the patient MRN in the PACS system of Tygerberg Hospital, no patient's confidentiality will be breached (Herbst, 2010). With the DICOM anonymous function, patient data can be removed, eliminating the possibility of distributing confidential data. An e-mail is more easily shared and distributed, but is also less likely to accidently transfer to wrong destinations.

Another legal issue is that diagnostic data is not allowed to be lost; therefore, legal rules force PACS-holding departments to store data in a manner that there is no loss in diagnostic expressiveness (Frankewitsch *et al*., 2005: 447-451).

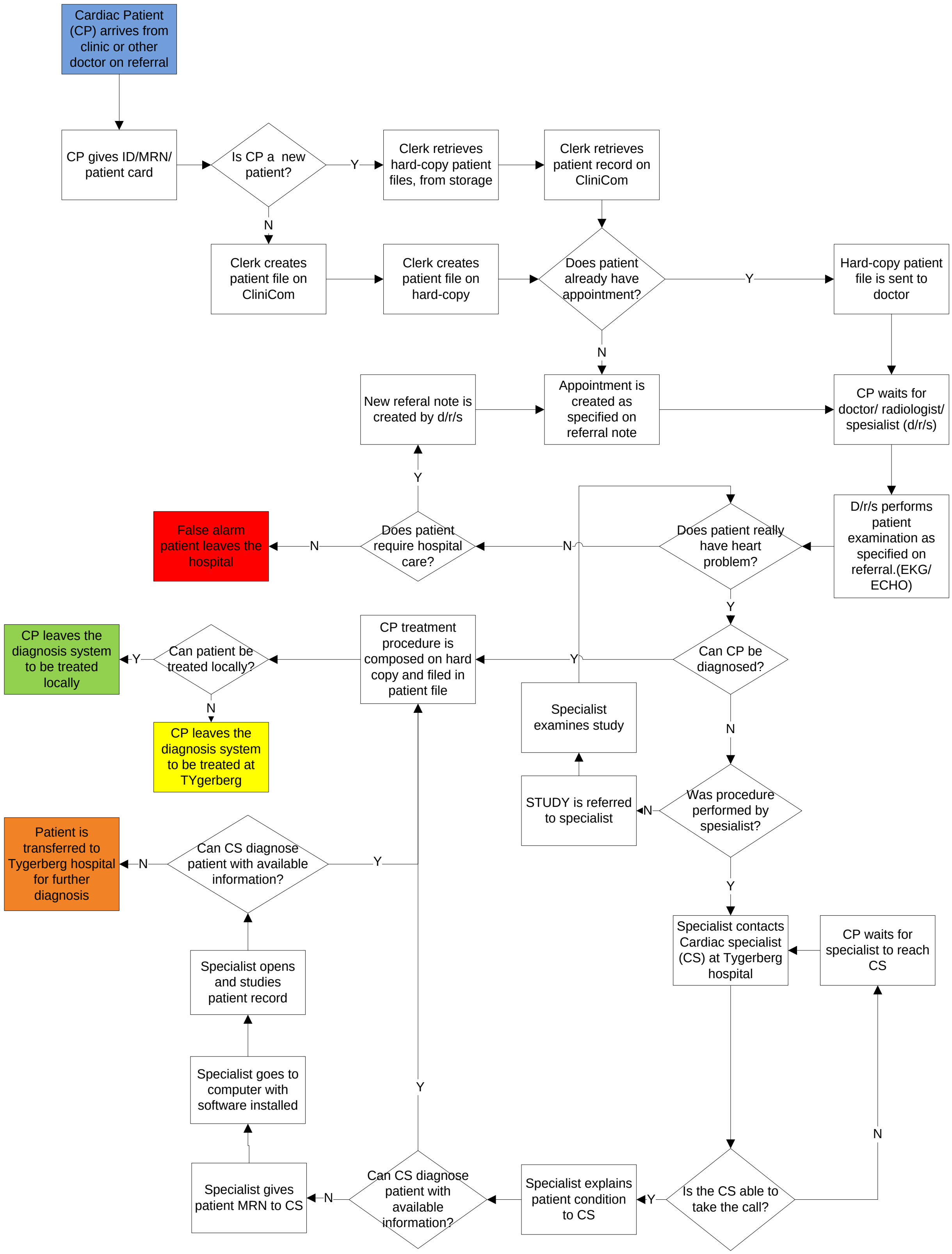


Figure 22: Process flow diagram of non-emergency patient at Eben Donges if a PACS is implemented between the two hospitals

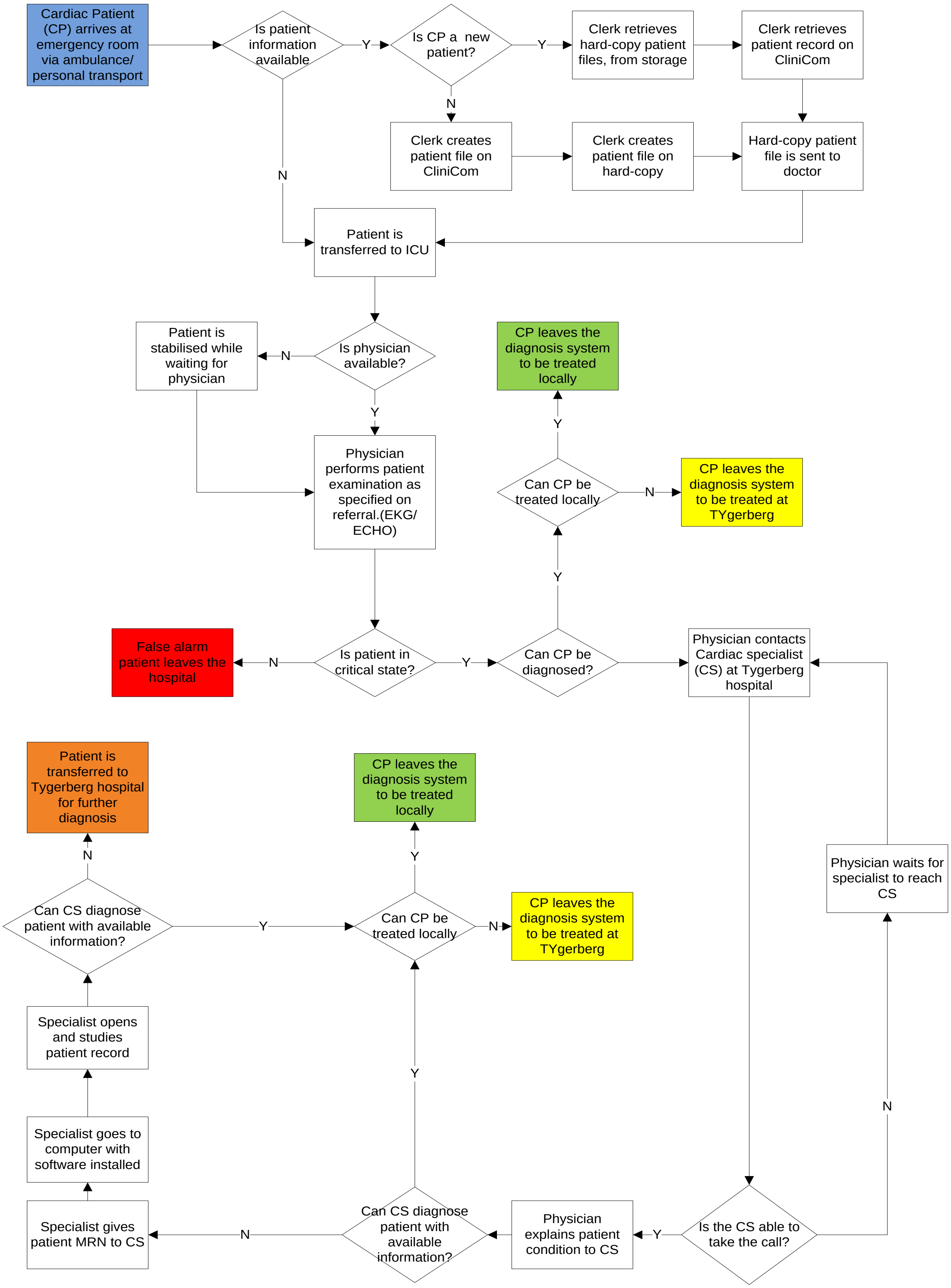


Figure 23: Process flow diagram of emergency patient at Eben Donges if a PACS is implemented between the two hospitals.

5.4 DICOM viewers

In the next section the alternative to use DICOM viewers to view DICOM files shared via PACS intranet is discussed relevant to each of the objectives.

5.4.1 Effectiveness of data transfer procedure

The process enables full communication and interoperability between the two hospitals. Data is automatically transferred to an electronic file on the central processor by the PACS system. The data can then be accessed from any computer connected to the intranet, by means of entering the patient MRN, and viewed on a user friendly interface that allows processing.

5.4.1.1 Diagnostic data communication

The process discussed increases the speed and quality of the data communicated, since data is always available and of high quality. Video and still images can be shared completely without the need for clinical or electronic compression, eliminating the factor of possibly losing metadata.

5.4.1.2 Interoperability of diagnostic data

The process discussed offers full interoperability of the data, because when the data is shared in the DICOM format, the viewer allows users to view and process data, no matter compatibility of the modalities.

5.4.2 Duration of procedure used for transferring diagnostic data

All diagnostic patient data is still stored in the form of hard-copy printed or written documents, but in this case diagnostic image data is automatically transferred to the central PACS server and without the need to send the data. Therefore, the local doctor can call the cardiac specialist on duty from the room where he is performing the diagnosis, with the patient MRN. The specialist on duty will still be interrupted in his shift, but he can view the full patient file by a simple “query and retrieve” and do all of the processing independent of the remote server. With PACS in place there is no need for clinical compression or for transferring files to computers with an Internet connection. This saves the local doctor a lot of time. In this case the data can be viewed on any computer, iPod, iPhone or iPad with the OsiriX software and processing of the data can be done. The time saved with optimising the data transfer and processing, can easily save a patient’s life. This process flow diagram can be seen in *Figure 24*.

5.4.3 Cost effectiveness of Implementation

The implementation needed will be to connect the medical imaging machinery at Eben Dönges Hospital to computers and connect the computers to the PACS central server of Tygerberg Hospital as seen in *Figure 12*. This has already been done at Tygerberg Hospital. The software needed can be installed by the IT department at the Eben Donges Hospital. Seeing that all machinery at Eben Dönges Hospital is digital and has USB ports, connecting them will entail following a setup manual supplied by the manufacturer. There are network cables readily available in all rooms where radiology is performed; hence network connection will be easily established. At the moment the connection between Tygerberg Hospital and Eben Dönges Hospital is achieved by a wide area network (WAN). A high band-width network cable, of which the size is still uncertain, needs to be installed between the two hospitals.

All DICOM viewer software is available for free to download, except the software needed for the mobile devices, which costs $19. 95, that is R136.442 as the exchange rate specified on 13 October 2010 by businessday.co.za (OsiriX team, 2010).

5.4.4 User-friendliness of data transfer procedure

Minimal training is needed, since files are automatically sent to the server, but users need to be trained to open files at the remote workstations. This is made easy due to the simple and user-friendly nature of the interface. The instruction manual is available at http://www.osirix-viewer.com/Learning.html.

5.4.5 Secondary or tertiary educational benefit

With information technology being integrated into secondary and tertiary education, training becomes integrated into medical curricula. The nature of education will change with the Dicom Viewer in place, since a medical DICOM image can be opened on any computer for viewing and processing. Increased availability of online, real-time imaging data will assist education by making studies available for students to view once they have downloaded the free DICOM viewer software. With a connection to PACS in place all images will be available during lectures and seminars, for educational and discussion purposes. With PACS not only physicians on ward will be able to view the files but also in other departments or the files of outpatient practices and this can all be shown to students for educational purposes.

5.4.6 The ethical and legal issues regarding this option

Ethical or legal issues can develop with exchange of confidential patient information, but due to patient data only being connected to the patient MRN in the PACS system of Tygerberg, no patient's confidentiality will be breached (Herbst, 2010) With the DICOM anonymous function, patient data can be removed, eliminating the possibility of distributing confidential data. An e-mail is more easily shared and distributed, but is also less likely to accidently transfer to wrong destinations.

Another legal issue is that diagnostic data is not allowed to be lost; therefore legal rules force PACS-holding departments to store data in a manner that there is no loss in diagnostic expressiveness (Frankewitsch *et al*., 2005: 447-451).

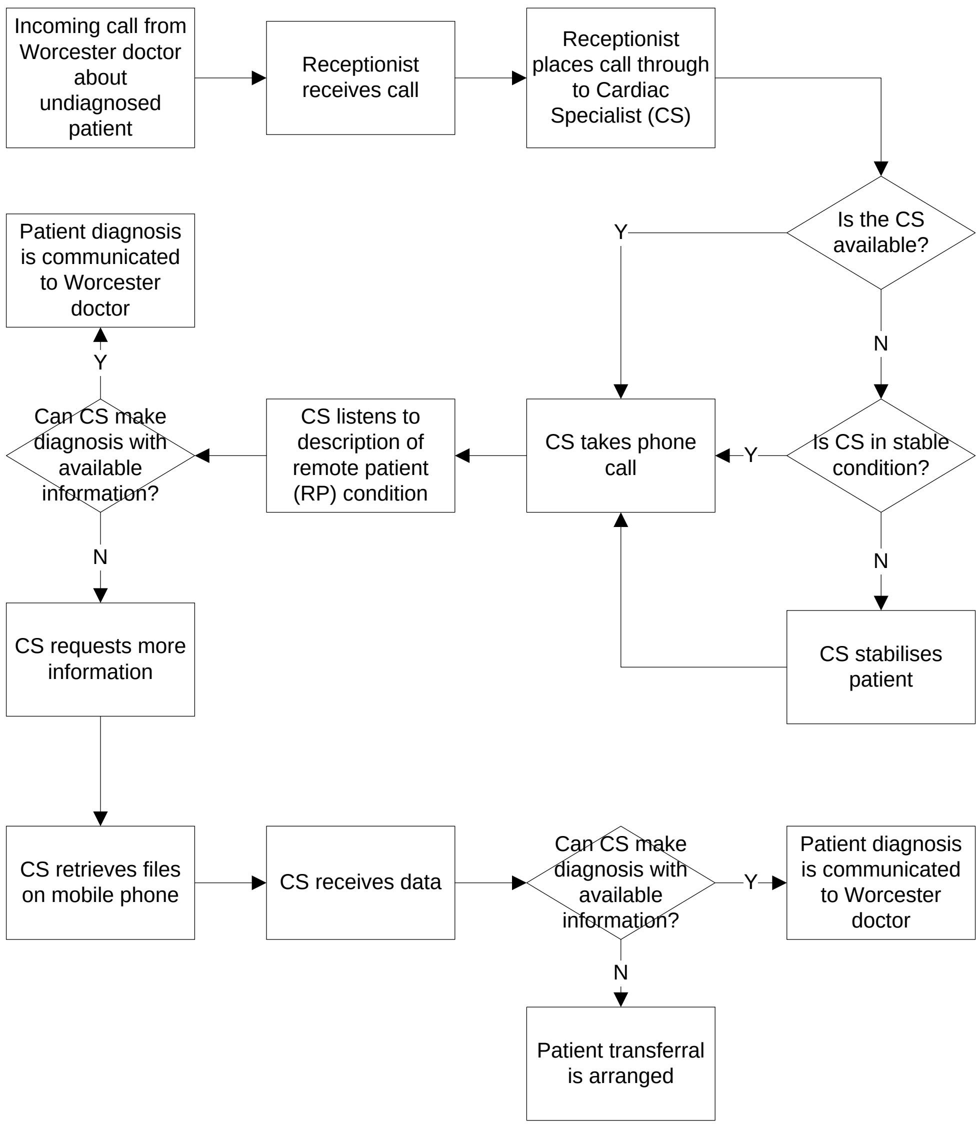
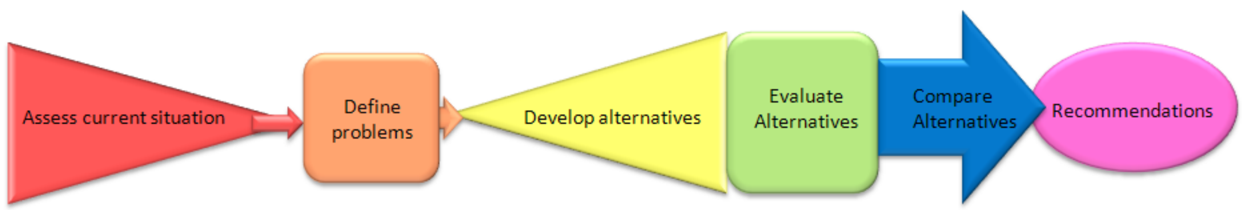


Figure 24: Flow Diagram of Remote Patient Data for diagnosing purpose at Tygerberg hospital in DICOM viewer is implemented

In the chapter each alternative was discussed relevant to how well they fulfil each objective. The objectives are: to effectively transfer patient data; to minimise the duration of the data transfer procedure, to find a cost-effective and user-friendly solution; to eliminate the legal and ethical issues concerned and to find a solution that offers secondary or tertiary educational benefits. It was found that implementing a PACS intranet will minimise the duration of the data transfer, while DICOM viewer will most effectively transfer patient data. E-mailing originals or compressed DICOM files are the most cost effective alternative. All alternatives enhance education, since files are, at least, electronic. All alternatives share the ethical issue of communicating confidential patient data, but this can be altered by making data anonymous with the DICOM function to remove patient data. In the next chapter the alternatives are compared by the Analytical Hierarchy Process (AHP) to find the alternative that increases the patient's access to a specialist's knowledge most.

6 Compare Alternatives



In the previous chapter alternative methods were compared as to how they satisfy each objective. In the following chapter the alternatives are evaluated with the Analytical Hierarchy Process (AHP) to determine the system which best solves the problem at hand. The success of the system depends on how effectively it achieves communication and interoperability between the Eben Dönges Hospital and Tygerberg Hospital to give patients access to specialist knowledge by assisting with remote cardiac patient diagnosis.

The AHP provides a logical method for structuring the problem to make an objective decision by quantifying the elements for comparison (Winston, 2004: 785). Firstly, the different objectives are examined as to how well they solve the current problem. They are thereby rated relative to each other for a pair-wise comparison and plotted on a matrix. The matrix is then determined and normalised to give each objective's weight relative to the other. Thirdly, the matrix is tested for consistency of the comparison by determining a consistency index (CI). Fourthly, the alternatives are compared to each other as to how well they reach each specific objective. This comparison allows the researched alternatives to be described in a numerical value. Fifthly, a pair-wise comparison matrix is formulated and normalised to see how the alternatives compare on a specific objective. The final step is to find the product of all of the objective-scores and the objective-weights - this will reveal the highest scoring objective.

To determine the weight of each objective, the different objectives are examined as to how important they are to solve the current problem. The objectives are then compared to each other and weighted thereby to quantify them. The objectives are:

- Firstly, to design an effective system to assist patient diagnosis. This implies the effectiveness of transferring patient data and to minimise the duration of the procedure to transfer data is most important. For effectiveness of communicating patient data, interoperability is more desired than only communication of data. It therefore ranks as a higher priority objective.
- Secondly, no matter how well the goal is reached, the solution needs to be feasible. A solution that is too costly or effortful to implement is not viable. Therefore, to find a cost-effective solution is ranked second most important.
- The factor that most frequently makes telemedicine applications fail after is has been obtained and implemented, is resistance to change by users. Therefore, the user-friendliness of the solutions is third most important.
- Another important objective is that the solution must not break any ethical or legal code in implementation. Since all of the developed alternatives do not breach either ethical or legal codes of health care, these factors are just rated at an average and are not the distinguishing factor between alternatives.
- Another very important factor is the inherent unity between tertiary education and specialised medical services which were considered, and the benefit telemedicine offers to enhance medical teaching abilities. Therefore, increasing educational opportunities are considered as the forth most important factor to use as a measure of success.

6.1 Objective weight

6.1.1 Determine the weights of each objective

After a discussion with Professor Doubell (2010) it was decided that the weights of each object relative to the other are as illustrated in the pair-wise comparison matrix below. For example, effectiveness of the data transfer process is 1.1 times (as illustrated in the pair-wise comparison matrix) times as important for as the duration of the process to increase patients access to specialised cardiac care.

Table 1: The pair-wise comparison matrix (A)

	E (Effectiveness)	D (Duration)	C (Cost)	UF (User-friendliness)	I (Issues)	Ed (Education)
E	1	1.1	1.5	2	8	5
D	1/1.1	1	1.1	1.7	7.5	5
C	1/1.5	1/1.1	1	1.5	7	4
UF	1/7	1/1.5	1/1.7	1	5	3
I	1/2	1/7.5	1/7	1/8	1	0.7
Ed	1/5	1/5	1/4	1/3	2	1

Normalizing the realize weights of the objectives results in the following matrix seen in Table 2.

Table 2: Pair wise matrix normalised

	E (Effectiveness)	D (Duration)	C (Cost)	UF (User-friendliness)	I (Issues)	Ed (Education)
E	0.29	0.27	0.33	0.30	0.26	0.27
D	0.27	0.25	0.24	0.26	0.25	0.27
C	0.20	0.23	0.22	0.23	0.23	0.21
UF	0.04	0.17	0.13	0.15	0.16	0.16
I	0.15	0.03	0.03	0.02	0.03	0.04
Ed	0.06	0.05	0.05	0.05	0.07	0.05

Using the normalised pair wise matrix a weight for each objective is determined; these weights are illustrated in Table 3.

Table 3: Weight of each objective (w)

Effectiveness of data transfer procedure	0.29
Duration of procedure used for transferring diagnostic data	0.25
Cost effectiveness of implementation	0.22

User-friendliness of data transfer procedure	0.14
The ethical and legal issues regarding this option	0.05
Secondary or tertiary educational benefit	0.06

6.1.2 Evaluate the weight of each objective for consistency

Using the steps in the AHP, the objective weights were tested for consistency, the results are illustrated below by multiplying the original pair wise comparison matrix with the weights for the objectives.

Table 4: Matrix multiplication to obtain the consistency index (CI)

$$\begin{pmatrix} 1 & 1.1 & 1.5 & 2 & 8 & 5 \\ 1/1.1 & 1 & 1.1 & 1.7 & 7.5 & 5 \\ 1/1.5 & 1/1.1 & 1 & 1.5 & 7 & 4 \\ 1/7 & 1/1.5 & 1/1.7 & 1 & 4 & 3 \\ 1/2 & 1/7.5 & 1/7 & 1/8 & 1 & 0.7 \\ 1/5 & 1/5 & 1/4 & 1/3 & 1.5 & 1 \end{pmatrix} \begin{pmatrix} 0.29 \\ 0.25 \\ 0.22 \\ 0.14 \\ 0.05 \\ 0.06 \end{pmatrix} = \begin{pmatrix} 20.28 \\ 17.97 \\ 15.48 \\ 9.73 \\ 3.41 \\ 3.93 \end{pmatrix}$$

The results obtained from the matrix multiplication were used to determine the consistency index (CI). In the equation below, A is the pair wise comparison matrix of the objectives, w is the weights of the objectives and n is the number of objectives that were being used.

$$CI = \frac{\frac{1}{n}\sum_{i=1}^{n} \frac{i'th\ entry\ in\ Aw}{i'th\ entry\ in\ w} - n}{n-1} = 0.08$$

Having 6 objectives and a CI below 1.24, concludes that the weights were appropriately calculated (Winston, 2004: 789).

6.2 Alternative scores

6.2.1 Alternative scores for each objective

The scores of the alternatives of each objective are calculated according to the discussion of how well that specified alternative meets each objective in chapter 5. See appendix B for more detail on how the scores for each alternatives for the specific objective was calculated.

The score of each alternative for effectively transferring data (obtained from Table 9 in Appendix B)

Emailing of DICOM format data	0.07
Compression used on DICOM format data	0.08
Data share, via a PACS intranet	0.35
Using a DICOM viewer in conjunction with PACS	0.50

The score of each alternative for minimizing duration of the data transfer procedure (obtained from Table 12 in Appendix B)

Emailing of DICOM format data	0.06
Compression used on DICOM format data	0.06
Data share, via a PACS intranet	0.31
Using a DICOM viewer in conjunction with PACS	0.57

The score of each alternative for being cost-efficiency (obtained from Table 15 in Appendix B)

Emailing of DICOM format data	0.34
Compression used on DICOM format data	0.39
Data share, via a PACS intranet	0.18
Using a DICOM viewer in conjunction with PACS	0.10

The score of each alternative for user-friendliness (obtained from Table 18 in Appendix B)

Emailing of DICOM format data	0.05
Compression used on DICOM format data	0.09
Data share, via a PACS intranet	0.36
Using a DICOM viewer in conjunction with PACS	0.50

The score of each alternative consequent to minimal legal issues (obtained from Table 21 in Appendix B)

Emailing of DICOM format data	0.27
Compression used on DICOM format data	0.54
Data share, via a PACS intranet	0.14
Using a DICOM viewer in conjunction with PACS	0.05

The score of each alternative for maximising the tertiary and secondary education possibilities (obtained from Table 24 in Appendix B)

Emailing of DICOM format data	0.06
Compression used on DICOM format data	0.11
Data share, via a PACS intranet	0.28
Using a DICOM viewer in conjunction with PACS	0.56

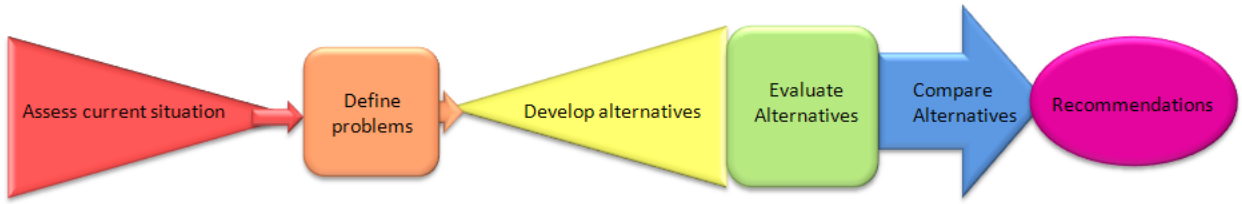
6.3 Determining the best suited alternative

Table 5: Table compared scores for best suited alternative

	Alternatives	**Email DICOM format**	**Email compressed format**	**PACS**	**Viewer**
Objectives					
Effectiveness of data transfer procedure	0.29	0.07	0.08	0.35	0.50
Duration of procedure used for transferring diagnostic data	0.25	0.06	0.06	0.31	0.57
Cost effectiveness of implementation	0.22	0.34	0.39	0.18	0.10
User-friendliness of data transfer procedure	0.14	0.05	0.09	0.36	0.50
The ethical and legal issues regarding this option	0.05	0.27	0.54	0.14	0.05
Secondary or tertiary educational benefit	0.06	0.06	0.11	0.28	0.56
TOTAL SCORE		0.13	0.17	0.29	0.42

In the chapter the AHP is used to compare the alternatives. The AHP determines that a DICOM viewer in conjunction with a PACS intranet is the best solution to increase the patient's access to a specialist's knowledge. This alternative is discussed below as to how it meets the alternatives.

7 Recommendation and conclusion



7.1 Recommendation

In the previous chapter the Analytical Hierarchy Process (AHP) illustrated that a DICOM viewer, in conjunction with a PACS intranet, is the best solution to increase a patient's access to a specialist's knowledge. Therefore, this is the best solution to implement given the objectives and their specific weights, as discussed in the next paragraph.

If a PACS, in conjunction with a DICOM viewer, is implemented the effectiveness of data transfer procedure is increased, since data is always accessible via the PACS intranet and the DICOM viewer software allows for post-processing of DICOM files. The duration of the procedure is decreased for the doctor at Eben Dönges Hospital, since files are automatically transferred to the central PACS server after study is completed; and for the specialist at Tygerberg Hospital, since he can view the diagnostic images on mobile device. The biggest cost of the solution will be to implement a network between the hospitals and acquiring the PACS software license. The DICOM viewer software is free to download. The alternative is user-friendly, since minimal effort has to be made to transfer data and DICOM viewer user interface is simple to operate. This option enhances secondary and tertiary education most since DICOM files can be viewed on any standard of the self hardware. Ethical or legal issues can develop with exchange of confidential patient information, but due to patient data only being connected to the patient MRN in the PACS system of Tygerberg, no patient's confidentiality will be breached.

To implement DICOM viewers, in conjunction with a PACS intranet between hospitals, it is necessary to firstly obtain high speed internet connection between the hospitals, since cardiology images are too big to send via the current WAN internet connection. Secondly, it will be necessary to obtain the PACS and DICOM viewer software and a mobile device to run the DICOM viewer software on, which will improve efficiency of the data sharing procedure even more.

7.2 Conclusion

To conclude, objectives to meet the goal of designing a system to increase patient's access to specialised cardiac care for assisting remote diagnosis were met as follows: The current situation was assessed and the structure used for communication between the two institutions were documented. It was found that the technology is being used to share patient data, such as faxes and telephone calls, results in an unnecessarily protracted process. The restrictions which limit the current system were identified and it was found the outdated technology to share patient data is used because there is no faster communication network because patient data being communicated is complex and files are large. The existing and potential technology was explored to formulate alternatives namely: electronic transfer of files in DICOM format; compressing the DICOM files with MPEG and JPEG before electronic transfer; implementing a PACS intranet between hospitals; and lastly, to use DICOM viewers on workstations to view the DICOM patient data. Ultimately the possible solutions and their feasibility was explored using the Analytical Hierarchy Process (AHP) to illustrate that a DICOM viewer, in conjunction with a PACS intranet is the best solution to increase a remote patient's access to a specialist's knowledge.

7.2.1 Future work

During the study it was found that, although DICOM files from different modalities are not able to be post processed, they are stored in the same format. The exact reason for DICOM files currently not transferring with all metadata able to be reached for post processing is still not certain. The three dimensional time series data cannot be shared via network (since network capacity is to low) and therefore DICOM data has to be written to CD to share for experimental purpose. It is uncertain to whether it is the DICOM format or the program that writes the files to CD that currently causes meta-data to be lost. This is an area for future study.

7.2.2 Verification

Since it does not fall in the scope of this project to implement the system, it was analysed by Professor Anton Doubell for verification. After examining the project he confirmed that the current situation was correctly assessed and the current problem was understood. He confirmed that deploying a DICOM viewer in combination with a PACS intranet is a relevant solution to the current problem and that high speed network connection is definitely needed between the hospitals to share data. He also explained that post-processing, although needed for educational purposes, is only needed for diagnostic purposes for about two percent of patients. Therefore, although this problem is still not fully understood it is not vital to the current problem to optimise remote patient diagnosis.

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Appendix A

Mr Vincent Le Roux confirmed compatibility of the Philips iSite PACS and Thoshiba Ultrasound modality. In the following table the service-object pair (SOP) class of DICOM storage is compared.

Table 6: Comparison of Thoshiba and Philips ISITE SOP class

	Toshiba SOP CLASSES	Philips ISITE SOP CLASSES
Secondary Capture Image Storage	1.2.840.10008.5.1.4.1.1.7	1.2.840.10008.5.1.4.1.1.7
Ultrasound Image Storage (retired)	1.2.840.10008.5.1.4.1.1.6	1.2.840.10008.5.1.4.1.1.6
Ultrasound Image Storage	1.2.840.10008.5.1.4.1.1.6.1	1.2.840.10008.5.1.4.1.1.6.1
Ultrasound Multi-frame Image Storage	1.2.840.10008.5.1.4.1.1.3.1	1.2.840.10008.5.1.4.1.1.3.1
Basic Text SR Storage	1.2.840.10008.5.1.4.1.1.88.11	1.2.840.10008.5.1.4.1.1.88.11
Enhanced SR Storage	1.2.840.10008.5.1.4.1.1.88.22	1.2.840.10008.5.1.4.1.1.88.22
Key Object Selection Document Storage	1.2.840.10008.5.1.4.1.1.88.59	1.2.840.10008.5.1.4.1.1.88.59
US Private Data Storage	1.2.392.200036.9116.7.8.1.1.1	N.A

Appendix B

<u>The score of each alternative for effectively transferring data</u>

After rating the objectives for each alternative in chapter 5, the weights of each alternative was determined to each other are as illustrated in the pair-wise comparison matrix below.

Table 7: The pair-wise comparison matrix for alternatives for effectively transferring data

	DICOM	Compression	PACS	Viewer
DICOM	1	0.9	0.2	0.15
Compression	1.1	1	0.22	0.15
PACS	5	4.5	1	0.7
Viewer	7	6.5	1.4	1

Table 8: The normalised pair-wise matrix for alternatives for effectively transferring data

	DICOM	Compression	PACS	Viewer
DICOM	0.07	0.07	0.07	0.08
Compression	0.08	0.08	0.08	0.08
PACS	0.35	0.35	0.35	0.35
Viewer	0.50	0.50	0.50	0.50

Table 9: The score of each alternative for effectively transferring data

Emailing of DICOM format data	0.07
Compression used on DICOM format data	0.08
Data share, via a PACS intranet	0.35
Using a DICOM viewer in conjunction with PACS	0.50

<u>The score of each alternative for minimizing duration of the data transfer procedure.</u>

Table 10: The pair-wise comparison matrix for alternatives for minimizing duration of the data transfer procedure

	DICOM	Compression	PACS	Viewer
DICOM	1	1.1	0.2	0.1
Compression	0.9	1	0.18	0.1
PACS	5	5.5	1	0.5
Viewer	9	10	1.8	1

Table 11: The normalised pair-wise matrix for alternatives for minimizing duration of the data transfer procedure

	DICOM	Compression	PACS	Viewer
DICOM	0.06	0.06	0.06	0.06
Compression	0.06	0.06	0.06	0.06
PACS	0.31	0.31	0.31	0.29
Viewer	0.57	0.57	0.57	0.59

Table 12: The score of each alternative for minimizing duration of the data transfer procedure

Emailing of DICOM format data	0.06
Compression used on DICOM format data	0.06
Data share, via a PACS intranet	0.31
Using a DICOM viewer in conjunction with PACS	0.57

The score of each alternative for being cost-efficiency

Table 13: The pair-wise comparison matrix for alternatives for being cost-efficiency

	DICOM	Compression	PACS	Viewer
DICOM	1	0.9	2	3
Compression	1.1	1	2.2	4

PACS	0.5	0.45	1	2
Viewer	0.3	0.2	0.6	1

Table 14: The normalised pair-wise matrix for alternatives for being cost-efficiency

	DICOM	Compression	PACS	Viewer
DICOM	0.34	0.35	0.34	0.30
Compression	0.38	0.39	0.38	0.40
PACS	0.17	0.18	0.17	0.20
Viewer	0.10	0.08	0.10	0.10

Table 15: The score of each alternative for being cost-efficiency

Emailing of DICOM format data	0.34
Compression used on DICOM format data	0.39
Data share, via a PACS intranet	0.18
Using a DICOM viewer in conjunction with PACS	0.10

<u>The score of each alternative for user-friendliness</u>

Table 16: The pair-wise comparison matrix for user-friendliness

	DICOM	Compression	PACS	Viewer
DICOM	1	0.5	0.1	0.1
Compression	1.5	1	0.3	0.2
PACS	7	4.5	1	0.7
Viewer	9	6	1.5	1

Table 17: The normalised pair-wise matrix for alternatives for user-friendliness

	DICOM	Compression	PACS	Viewer

DICOM	0.05	0.04	0.03	0.05
Compression	0.08	0.08	0.10	0.10
PACS	0.38	0.38	0.34	0.35
Viewer	0.49	0.50	0.52	0.50

Table 18: The score of each alternative for user-friendliness

Emailing of DICOM format data	0.05
Compression used on DICOM format data	0.09
Data share, via a PACS intranet	0.36
Using a DICOM viewer in conjunction with PACS	0.50

<u>The score of each alternative consequent to minimal legal issues</u>

Table 19: The pair-wise comparison matrix for minimal legal issues

	DICOM	Compression	PACS	Viewer
DICOM	1	0.5	2	5
Compression	2	1	4	10
PACS	0.5	0.25	1	2.5
Viewer	0.2	0.1	0.4	1

Table 20: The normalised pair-wise matrix for alternatives for minimal legal issues

	DICOM	Compression	PACS	Viewer
DICOM	0.27	0.27	0.27	0.27
Compression	0.54	0.54	0.54	0.54
PACS	0.14	0.14	0.14	0.14
Viewer	0.05	0.05	0.05	0.05

Table 21: The score of each alternative for minimal legal issues

Emailing of DICOM format data	0.27
Compression used on DICOM format data	0.54
Data share, via a PACS intranet	0.14
Using a DICOM viewer in conjunction with PACS	0.05

<u>The score of each alternative for maximising the tertiary and secondary education possibilities</u>

Table 22: The pair-wise comparison matrix for maximising the tertiary and secondary education possibilities

	DICOM	Compression	PACS	Viewer
DICOM	1	0.5	0.2	0.1
Compression	2	1	0.4	0.2
PACS	5	2.5	1	0.5
Viewer	10	5	2	1

Table 23: The normalised pair-wise matrix for alternatives for maximising the tertiary and secondary education possibilities

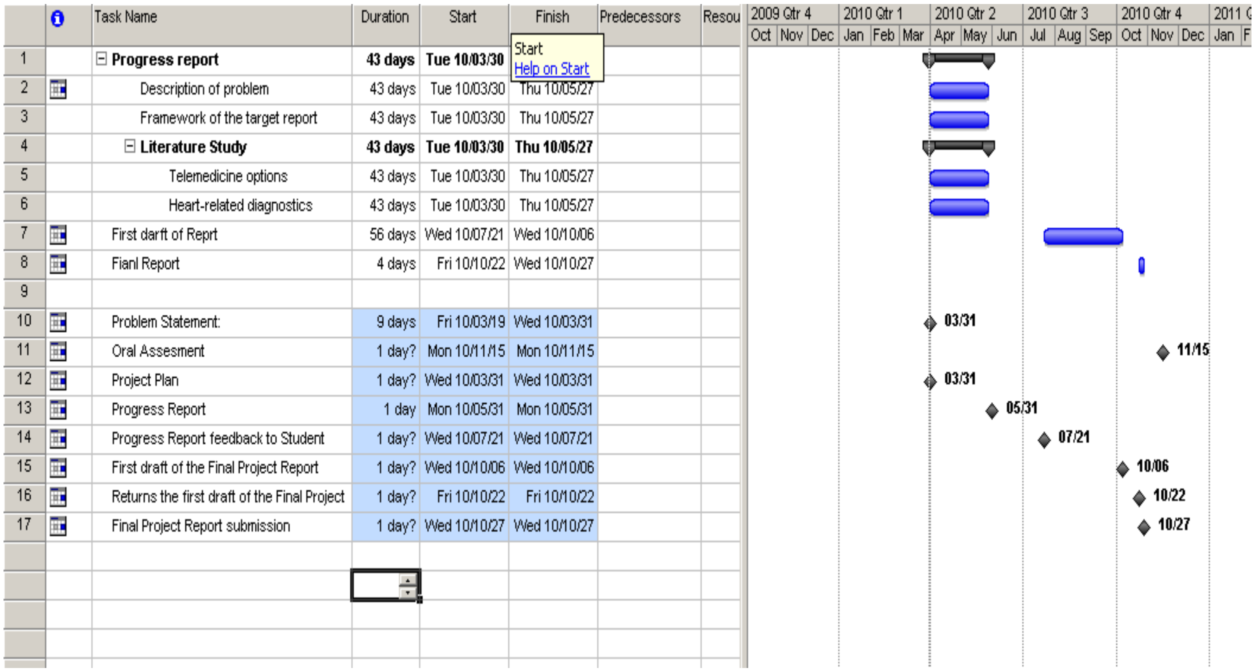
	DICOM	Compression	PACS	Viewer
DICOM	0.06	0.06	0.06	0.06
Compression	0.11	0.11	0.11	0.11
PACS	0.28	0.28	0.28	0.28
Viewer	0.56	0.56	0.56	0.56

Table 24: The score of each alternative for maximising the tertiary and secondary education possibilities

Emailing of DICOM format data	0.06
Compression used on DICOM format data	0.11
Data share, via a PACS intranet	0.28
Using a DICOM viewer in conjunction with PACS	0.56

Appendix C

Appendix D



	Task Name	Duration	Start	Finish	Predecessors	Resou
1	**Progress report**	**43 days**	**Tue 10/03/30**			
2	Description of problem	43 days	Tue 10/03/30	Thu 10/05/27		
3	Framework of the target report	43 days	Tue 10/03/30	Thu 10/05/27		
4	**Literature Study**	**43 days**	**Tue 10/03/30**	**Thu 10/05/27**		
5	Telemedicine options	43 days	Tue 10/03/30	Thu 10/05/27		
6	Heart-related diagnostics	43 days	Tue 10/03/30	Thu 10/05/27		
7	First darft of Repr	56 days	Wed 10/07/21	Wed 10/10/06		
8	Fianl Report	4 days	Fri 10/10/22	Wed 10/10/27		
9						
10	Problem Statement:	9 days	Fri 10/03/19	Wed 10/03/31		
11	Oral Assesment	1 day?	Mon 10/11/15	Mon 10/11/15		
12	Project Plan	1 day?	Wed 10/03/31	Wed 10/03/31		
13	Progress Report	1 day	Mon 10/05/31	Mon 10/05/31		
14	Progress Report feedback to Student	1 day?	Wed 10/07/21	Wed 10/07/21		
15	First draft of the Final Project Report	1 day?	Wed 10/10/06	Wed 10/10/06		
16	Returns the first draft of the Final Project	1 day?	Fri 10/10/22	Fri 10/10/22		
17	Final Project Report submission	1 day?	Wed 10/10/27	Wed 10/10/27		

Figure 25: Final year project Gantt chart