University of Southern Queensland

EVALUATING THE ACCEPTANCE OF MOBILE TECHNOLOGY IN HEALTHCARE: DEVELOPMENT OF A PROTOTYPE MOBILE ECG DECISION SUPPORT SYSTEM FOR MONITORING CARDIAC PATIENTS REMOTELY

A dissertation submitted by

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Abstract

This research focuses on managing cardiovascular disease (CVD) using mobile technologies and a decision support system (DSS). Evidence from this study indicates that this development can benefit health professionals in medical diagnoses of CVD, which is the most prevalent cause of death in Australia. Capturing cardiac data early when infarction is suspected has the potential to save lives and reduce health costs. This research is built upon a mobile ECG decision support system (M-ECG DSS), which allows remote monitoring of patients. It provides real-time data for specialists, GPs, hospitals and emergency service without the need for hospital admission or travel. The research combines web browser and native applications with DSS together for the first time to give health professionals a non-delay access and fast interpretation to support diagnosis on a mobile device (with synthetic ECG data being used). The mobile ECG decision support system (M-ECG DSS) is expected to improve overall referral processes and diagnoses of CVD patients remotely located from physicians by eliminating or minimising unpredictable elements such as delays in diagnosis time and speed.

The primary research aim is to identify ECG functional and DSS system characteristics to arrive at possible solutions for mobile ECG implementations. The research also evaluates the acceptance of the M-ECG DSS system that has been developed. The scientific merit of the research lies in the innovative development of a prototype system that displays the relevant information graphically and in real-time. This research adapts the Technology Acceptance Model (TAM) and Information System Success Model (ISSM) to increase actual use of the application; furthermore, it investigates attitudes toward intention to use the technology and explores the associations between medical system services and acceptance by individual healthcare staff.

This research focuses on the quality of distributing a patient’s detail to clinicians. Data collection methods employed in this research encompass interviews and surveys. Qualitative data was gathered from a group of users as an effective means

of soliciting views of acceptance of M-ECG DSS from cardiologists, doctors and nurses and to identify attitudes, opinions and acceptance of using this system. In this research, quantitative descriptive statistics are also used to triangulate the results. Eighteen participants from regional hospitals took part in the research - 12 in Taiwan and 6 in Australia. Participants consisted of cardiologists, doctors and nurses who have knowledge on remote medical treatment and pre-hospital (medical treatment before arriving at hospital) services.

The research findings clearly identify the need for this type of application for disease management and patient care. A M-ECG DSS should contain not only ECG functional characteristics but also DSS system characteristics in order to be able to monitor a CVD patient remotely. In addition, the platform developed can be articulated to other disease diagnoses and to pre-screen outpatients. Doctors can save time as all necessary vitals have been taken and available in a patient's record before they present for consultation. This is a challenge, given the variety of mobile devices available to health professionals. Studies have shown that unless such a system is reliable and intuitive to use, its uptake will be limited.

A combination of mobile web browser and native apps has created a new experience for health professionals for CVD diagnosis, and speeding up decision-making. Findings establish that a mobile device has the ability to present more comprehensive details than a paper-based ECG presentation. The research also shows that a DSS in a mobile device should not only provide decision-making information but also increase system resources availability. There is strongly agreement amongst health professionals that a digital measurement tool is a necessary inclusion in mobile DSSs. It can help clinicians to interpret patient data easily, with minimal errors. The research finds that health professionals will realise benefits from monitoring suspect and actual heart disease, and monitoring in real-time patients’ activity patterns. Future research may be conducted for constructing a more complete mobile health system as well as a DSS for decision-making. This current research will allow health professionals in hospitals and clinics to monitor patients with minimum human intervention.

Certification of Dissertation

I certify that the ideas, developments, experimental works, results, analyses, and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award.

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Meng Kuan (Adam) Lin
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List of Acronyms and Abbreviations

3G	3d generation mobile telecommunications
AUI	Adaptive user interface
API	Application programming interface
APP	Application on mobile
ASP.Net	Active server pages developed by Microsoft
CSS	Cascading style sheets
CVD	Cardiovascular disease
DICOM	Digital imaging and communications in medicine
DSS	Decision support system
DBMS	Database management system
DOA	Dead on arrival
ECG	Electrocardiography
EH	Event handler
EHR	Electronic health record
EMR	Electronic medical record
EMS	Emergency medical services
GPRS	General packet radio service
GSM	Global system for mobile communications
GPS	Global positioning system
HF	Heart failure
HIT	Health information technology
HSDPA	High-speed downlink packet access
HTML	HyperText markup language
IT	Information technology
IS	Information system
ICU	Intensive care unit
MTP	Multi-touch processing
M-ECG	Mobile ECG
MS-SQL	Microsoft structured query language
MVC	Model View Controller
OS	Operating system
PDA	Personal digital assistant
REST	Representational state transfer
TAM	Technology Acceptance Model
TSA	The signal algorithm
UMS	User menu system
URL	Uniform resource locator
UI	User interface
XHTML	eXtensible hypertext markup language

Publications Related to This Study

Meng-Kuan, L, Joseph, M, Gururajan, R & John, WL 2011, 'Development of a prototype multi-touch ECG diagnostic decision support system using mobile technology for monitoring cardiac patients at a distance', paper presented to 15th Pacific Asia Conference on Information Systems (PACIS2011), Brisbane, Australia, 11-13 July.

Meng-Kuan, L, Gururajan, R, Joseph, M, John, WL & Hafeez-Baig, A 2010, 'A web-based ECG decision support system using multi-touch function to support cardiac diagnosis', paper presented to 5th International Conference on Cooperation and Promotion of Information Resources in Science and Technology: Information Sharing in U-Era (COINFO'10), Beijing, China, 27-29 Nov.

Meng-Kuan, L, Joseph, M, Gururajan, R, John, WL & Hafeez-Baig, A 2010, 'Efficacy and feasibility of a mobile ECG decision support system - a preliminary conceptual model', paper presented to 14th Pacific Asia Conference on Information Systems (PACIS2010): Service Science in Information Systems Research, Taipei, Taiwan, 9-12 July.

Meng-Kuan, L, Joseph, M, Gururajan, R & John, WL 2012, 'A web-based decision support system for ECG data transfer using a mobile network to monitor cardiac patients remotely: applying multi-touch function to support cardiac diagnosis', *the International Journal on Networked Business* (Accepted).

Chapter 1 Introduction

1.1 Introduction

Electrocardiogram (ECG) is a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart. It is detected by electrodes attached to the skin's surface and recorded by a device external to the body (Dean & Stephen 2009). ECG instruments are currently used in general practice and hospitals. The interval between individual segments from an ECG can be analysed to confirm a suspect infarction case. The use of integrated data transfer and storage has made it possible to associate it with an individual patient's data, such as name, age, past history and medications.

Cardiovascular disease (CVD) is a disease that involves a heart or blood vessel. It refers to any disease that affects the cardiovascular system and is usually related to atherosclerosis. One of the rapidly growing areas of telemedicine is long-term and long-range CVD patient monitoring at a distance from a hospital or clinic. This is made possible with emerging electrogram instruments that are used to record arrhythmia (heart disorder) or record ECG readings allowing a cardiac expert to review trends. An ECG is the primary tool used for diagnosis and to understand the severity of a myocardial infarction or heart attack. To save an emergent cardiac patient's life, it is important for the clinician to receive accurate information on any detrimental change of conditions in a patient as quickly as possible. There is a growing demand for developing personalised, non-hospital based care systems to improve the management of CVD patients as heart disease is the highest cause of death around the world, including Australia. Transmitting ECG data using mobile phone technology to overcome the distance gap between patient and doctor when not in a face-to-face consultation and improving the ability for cardiac monitoring diagnosis and decision-making becomes the most on-demand service for CVD care.

1.2 Background to the Research

Telemedicine generally means the use of communications and information technologies in order to deliver healthcare. ECG telemonitoring systems have been rapidly increasing in number and acceptance in Australia over the last decade (Fahim et al. 2009), improving access to cardiac patients. According to DEEWR (2009), from the perspective of communities that are reliant on quality education and training for their growth and development in Australia, ECG instrument can potentially benefit changes to the system and resource allocation .

Recent advances in mobile technology, computing power and memory size have increased the application of technology to telemedicine in general and to ECG monitoring in particular (Qiang et al. 2008). In addition, recent releases of the iPhone iOS (Operating System) from Apple™ as well as powerful mobile programming platforms such as Windows Mobile from Microsoft™ and Android from Google™, have made possible a mobile phone handset-based telehealth service solution for telemonitoring readings from an ECG instrument. A wireless ECG instrument has the ability to work with mobile phone technology specifically by ameliorating patient monitoring and sharing details between general practitioners (GPs) and specialist physicians in private and public hospitals, enhancing the speed of assessment and efficient decision-making in the diagnosis required.

A study by Engin et al (2005) identified the fact that telemedicine applications are becoming very popular because of an increasing ageing population and insufficient personnel capacity in hospitals. The use of telemedicine capabilities to manage chronically ill patients is becoming more and more clinically relevant and economically cost-effective. Engin et al’s study presented a design of a prototype telemedicine system which provides human electrocardiogram (ECG) signals transferred via a telephone land-line network. The system they developed covered management of electronic records of patients and access to patients’ detail from hospitals.

Recent developments in wireless technology eliminate the traditional expensive and bulky ECG instrument and cables, which allows caregivers greater freedom of movement while acquiring electrocardiograms. The expansion of Go-wireless (Voice/Data Mobile Solutions) technology, the Wireless and Mobile (WAM) network offers a cost-effective improvement over traditional cables. Although the wireless network has a risk of losing data (Hamida 2008), it will still greatly ease ECG readings' acquisitions, improving workflow in a variety of clinical scenarios such as crowded bedsides, cramped care areas, and difficult-to-manoeuvre spaces. Elimination of cables will also reduce a significant source of artefact and improve the quality of the acquired ECG reading (Chung et al. 2007). Perhaps, the most important benefits of Go-wireless technology will be its ability to deliver significant clinical advantages without any significant costs to patients or hospitals and at a distance.

Mobile phones can also play an integral role in remote care for patients with chronic illnesses (Olga 2008). In order to adopt mobile technologies to assist physicians and other health professionals with decision-making tasks, such as determining diagnosis of patient data, a decision support system (DSS) has the potential to bridge the knowledge gap by 'organising and presenting the appropriate information sources to the user so that they are able to make clinical decision with reduced error and increased accuracy' (Karin & Michael 2007, p. 761). With the new generation of mobile technology, cardiovascular diseases and other existing heart diseases can be detected accurately and timely. In the case of a heart infarction, an ECG recording can be transmitted immediately through an advanced mobile ECG system. Mobile systems need to be able to transmit real-time recording details to doctors for evaluation and diagnosis. Moreover, a 12-lead ECG provides a more detailed look at the heart and speeds the turnaround of test results. Cardiologists, doctors and nurses can successfully use a portable wireless mobile phone to receive data from a 12-lead ECG instrument attached to an ECG device without a patient having to visit a hospital or community clinic.

1.3 Research Problem

Less than 10 years ago, researchers from Texas demonstrated the ability of transferring ECG data via wireless technology to hand-held computers where it could be reliably interpreted by cardiologists (Galbiati et al. 2004). The existing literature concerning the ubiquity of delivering ECG services by using mobile technology and the advantage of mobile adoption as a DSS to provide new functionality in CVD service is limited, especially for real-time monitoring and instant decision-making. Research connecting mobile adoption and acceptance of new healthcare technology remains limited to a certain extent, particularly for mobile ECG developments.

In this respect, the research question (RQ) identified is based on ECG functional characteristics required under a mobile device in order to develop the best DSS interface suited to meet health practitioners' needs. The question also evaluates factors that contribute to mobile health technology use in CVD care services. Thus, this research identifies the most appropriate information that can be captured and displayed in a DSS. A preliminary review of literature of these two fields of study and their interconnections resulted in identifying the main research gap formulated in the overarching research question.

RQ: Can a M-ECG DSS that encapsulates key functional and system characteristics improve user acceptance of health technology for monitoring of cardiac patients remotely?

Underpinning the study's conceptual model are two main theories – Technology Acceptance (TAM) and Information System Success (ISSM) models. The TAM was specifically developed to involve computer acceptance in general while the ISSM is primary targeted on interrelationships among the success factors of a specific IS. However, a combination of TAM (Davis et al. 1989) and ISSM (DeLone & McLean 2002) models for improving use of applications and attitudes towards using technology is yet to be explored in healthcare (Richard & Ben-Tzion 2010). This study works towards the validation of a conceptual model for adopting a M-ECG DSS application and evaluating its acceptance. The objective of this research is to provide greater acceptance of mobile health technology delivery by identifying those ECG functional and DSS system characteristics to arrive at possible solutions for mobile implementation. The concept of adopting mobile DSS for ECG diagnosis is graphically represented in Figure 1.1. Thus, the study can both identify ECG/DSS characteristics and enable mobile technologies for successful implementation.

Moreover, the research aims to understand configuration for a M-ECG DSS and its ability to successful deliver medical services as well as gaining acceptance by doctors and nurses. The level of acceptance by users (diffusion) is also evaluated in this research to determine the possibility of implementing mobile technology within a hospital's practices. The Lewin Group, Inc (2000) mentions that clinical acceptance of a telehealth application may depend on the degree of confidence clinicians have in their clinical findings from using a system as well as a clinician's satisfaction with the encounter in the absence of face-to-face interaction with patients. According to Hu et al. (1999), user acceptance is a critical success criterion for Information Technology (IT) adoption and can be sufficiently explained, accurately predicted and effectively managed by means of a host of relevant factors such as *'user behaviour'* and *'user satisfaction'*.

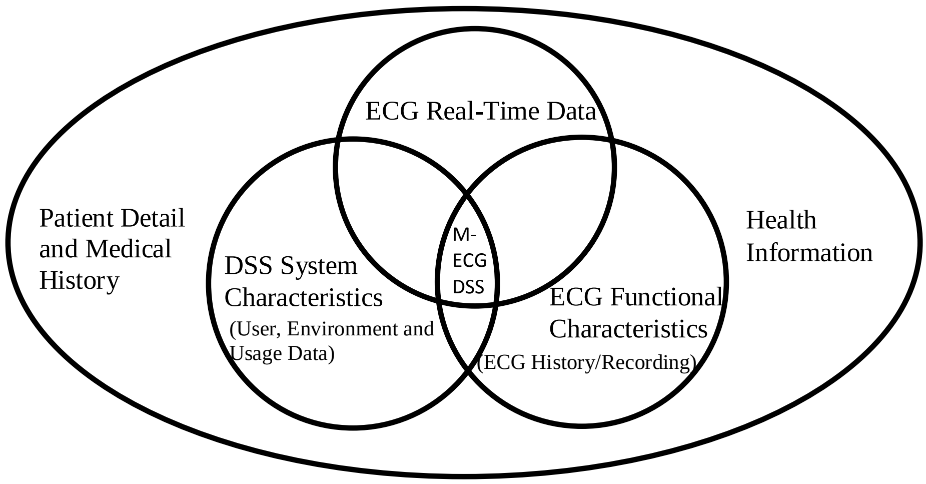


Figure 1.1: Concept of adopting mobile DSS for ECG diagnosis

1.4 Justification of the Research

A number of ECG telemonitoring evaluation studies have been reviewed to gain a better understanding of mobile ECG evaluation domains and factors that lead to successful implementations and use of mobile ECG systems. Jen-Hwa (2003) mentioned that evaluation of telehealth system success or effectiveness is a fundamental challenge to healthcare organisations. Maryati et al (2006) also suggested examples of system quality measures, such as usefulness, availability, ease of use, ease of learning, response time, reliability, completeness, system flexibility, and ease of access to help. Baoming et al. (2005) stated that mobile ECG has potentially resolved the difficult problem for human heart function monitoring in special mobile environments, and their developed system was expected to improve efficiency of telemonitoring used in various medical and healthcare areas; however, there is no evidence that current developments in mobile DSS support health professionals, particularly for ECG diagnosis.

The overall justification for this research is based on the need to broaden the scope of studies conducted in healthcare delivery, specifically as a means of creating totally new mobile environments and reducing complications encountered in original diagnostic systems. The findings of this study will enable future academics and practitioners to advance the field of mobile health development. Justification for this research can be viewed from expected contributions to theory and to practice, as detailed below.

1.4.1 Expected Contribution to Theory

According to William (2000), a mobile ECG (M-ECG) device will become a major mode of healthcare delivery for cardiac patients, but patient and clinician acceptability and system infrastructure efficacy need to be assessed. The conceptual model for a M-ECG DSS is designed to test the dimension of acceptance in order to observe *'user behaviour'* and to increase *'user satisfaction'* as well as improving quality of care for cardiac infarction sufferers. The research expects to contribute to existing studies in telehealth evaluation. It is also expected to contribute to the literature by applying the TAM (refer to Figure 2.12) and ISSM models (refer to Figure 2.14) to telemedicine and forms part of evaluating the acceptance of a M-ECG DSS. Those models theorise an individual's behavioural intention to use a system. Based on research by Kjell et al. (2009), there is already a significant quantity of published clinical data, but randomised trials are needed to better define medical and economic benefits of mobile ECG devices. This study is one trial that can add to the extant literature in this growing area of research.

When technology adoption begins, innovators and early adopters, with their strong technology orientation, may be able to get by on their own initiative. This project examines the possibility of a new mobile technology implementation to a critical health area and offers an innovation in ECG diagnosis. Identified ECG functional characteristics and DSS system characteristics for decision support used will also be investigated through this research study in order to speed up decision-making and increase quality of diagnosis. This research will look into the ECG functional characteristics needs and implement a user interface of the mobile health system (DSS system characteristics) to offer necessary data of patients (identified ECG functional characteristics) for decision support of CVD diagnosis. An expected contribution will also be in the form of a new conceptual model that is a combination of two models (TAM and ISSM) which will forecasts the relationship between system characteristics and users in understanding acceptance of IT use by individuals and the influencing variables in the relationship.

1.4.2 Expected Contribution to Practice

The ECG monitor should always be connected to the cardiac patients; therefore, ECG telemonitoring systems have been introduced using diverse wireless network technologies. In terms of new 12-lead ECG systems (producing better quality data for monitoring than 3 and 5 leads), there is a need for research that can bring the newest application of mobile technology to provide more information to monitoring cardiac patients remotely. This could reduce patient morbidity and improve care to reduce healthcare costs through reduced stays in hospital.

According to the World Health Organisation (WHO), three-quarter of the world's population appear to have no access to medical diagnostic imaging technologies such as radiology, ultrasound, magnetic resonance and ECG systems (LeVine III 2010). But thanks to the proliferation of cellular and other wireless networks, researchers are stepping up efforts to deliver crucial medical services from afar (Olga 2008). Based on network services, this research considers a ubiquitous mobile technology to increase the level of telemedicine treatments.

The continuous oscilloscopic ECG is one of the most widely used anaesthetic monitors. According to EBME (2009), a 12-lead ECG recording provides much more information than is available on a theatre ECG monitor and should, where possible, be obtained pre-operatively for any patient with suspected cardiac disease. Therefore, this research develops a combination of web browser and mobile native applications (apps) to display 12-lead ECG data in order to demonstrate the possibility of mobile diagnosis, as well as decision-making.

The research uses a mobile phone network with ECG technology as an approach to collecting and analysing the ECG data to assist physicians diagnose patients faster and mobilise resources in anticipation of a patient's arrival, rather than reacting once the patient is already in a hospital or clinic. The study is expected to contribute to Australia's healthcare, particularly to CVD care. This research will determine the best practice of mobile technology for meaningful uses such as decision-making and knowledge sharing in health services. The study aims to improve the success of mobile implementations, as it will identify aspects that the health sector should consider when implementing new services. Importantly, this study also aims to appraise a new mobile 12-lead ECG systems implementation; an understanding of how to diffuse and increase the use of health technologies and its acceptance, and gain an understanding of the barriers to acceptance of the system to improve its chances for successful implementation. Moreover, the study is likely to influence an increase in the interaction between clinicians and mobile technology and lead to successful diagnostic outcomes. This will accomplish by developing innovative web and native applications together to overcome different requirements from cardiologists, doctors and nurses.

1.5 Study Scope and Delimitation

The scope of this research involves development of an interface system that will integrate an existing 12-lead ECG instrument with current mobile phone technology. This study also aims to understand the need of ECG functional characteristics and incorporate them into a mobile-based DSS to provide CVD diagnoses. Furthermore, this study will only focus on evaluating main constructs to analyse the value of a M-ECG DSS as perceived by users based on a prototype and not a full implementation (perceived acceptance). In addition, the research is limited to Australia and Taiwan cardiologists, doctors and nurses who have knowledge of remote medical diagnoses and have used pre-hospital (medical treatment before arriving at hospital) services. The research only uses synthetic ECG data for the purposes of a benchmark set of data to demonstrate the M-ECG DSS. Moreover, this research does not look at how ECG data is collected from subjects or examine the devices and electrodes attached to the subject.

There are many applications and systems that can be implemented for remote delivery. Telemonitoring has largely featured in research, but this technology is on the cusp of becoming mainstream, and likely to result in a major change to the care of heart failure patients (The Medical News 2009). The M-ECG DSS could be particularly helpful in heart failure where the condition of a patient may change and carers can identify those who need the most help. For this study, only health professional's feedback on using the prototype of M-ECG DSS is measured and their expectations will meet their needs. No real patients are involved as the study focuses solely on how well it distributes a patient's detail to clinicians.

1.6 Conclusion

The main objective of this thesis is to facilitate greater understanding of the role of mobile implementation in healthcare and to offer an innovative system which displays the relevant information graphically and in real-time, particularly in CVD diagnosis. The study can be broken down into three main research areas, as follows:

- Identifying the ECG functional characteristics needs and DSS system characteristic requirements for mobile adoption;
- Seeking a way to bridge the gap in mobile health practice through the development of prototype M-ECG DSS; and
- Testing the acceptance of M-ECG DSS.

These objectives have been achieved by stating the research problem and by providing a justification for the study in terms of making both theoretical and practical contributions. The following chapter reviews previous literature and current trends in mobile health services.

Chapter 2 Literature Review

2.1 Introduction

The literature has identified the fact that, currently, information technology does not play a very significant role in the health industry (Martin 2007), although the development of information technology applications have radically affected healthcare delivery (Chris 2009). Staff in hospitals may be concerned that using mobile technology in healthcare will have negative reaction for patient care and medical treatment (Boland P 2007; Mobile Health News 2009). However, recent developments in telemedicine using mobile technology have identified benefits from the use of electronic communications and information technologies to provide clinical services when participants are in different locations (The Medical News 2009). There is a growing demand for developing personalised, non-hospital based care systems to improve the management of cardiac care (Los Angeles Times 2010) as heart disease is the biggest killer (34 per cent of all deaths in 2008) in Australia.

A number of studies in Electrocardiography (ECG) telemonitoring evaluation have been reviewed to gain a better understanding of mobile ECG evaluation domains and factors that lead to successful implementation and use of mobile ECG systems. Jen-Hwa (2003) postulated that evaluation of telehealth acceptance and effectiveness are fundamental challenges for health care organisations. Baoming et al. (2005) stated that mobile ECG has potentially resolved the difficult problem of human heart function monitoring in mobile environments, and such a system is expected to improve efficacy and feasibility of telemonitoring used in various medical and healthcare areas. This chapter provides a review of the literature related to adoption of mobile technology in healthcare and evaluates what research has been undertaken on the acceptance of mobile ECG decision support applications. Before turning to reviewing technologies, it is important to justify why this study focuses on one area of healthcare, namely cardiac care.

2.2 Incidence of Cardiovascular Disease in Healthcare

According to the World Health Organisation (WHO), cardiovascular diseases (CVD) are the cause of more than 50% of deaths, not only in the developed countries but also in low-and-middle-income countries. These countries are disproportionately affected with 82% of deaths being attributed to CVD (Ivan 2010). Within healthcare services, extensive clinical and epidemiological studies have identified several risk factors that significantly increase the risk of cardiovascular disease (Table 2.1).

Table 2.1: Major risk factors of cardiovascular disease in healthcare services

Major risk factors		**Epidemiological study on healthcare services**
Unchangeable	Increasing age	Over 83 per cent of people who die of coronary heart disease are 65 or older.
	Gender	Men have a greater risk of heart attack than women, and they have attacks earlier in life.
	Hereditary (including Race)	Children of parents with heart disease are more likely to develop it themselves. This is partly due to higher rates of obesity and diabetes. Most people with a strong family history of heart disease have one or more other risk factors.
Changeable	Tobacco smoke	Smokers' risk of developing coronary heart disease is 2–4 times that of non-smokers. Cigarette smoking is a powerful independent risk factor for sudden cardiac death in patients with coronary heart disease; smokers have about twice the risk of non-smokers. Cigarette smoking also acts with other risk factors to greatly increase the risk of coronary heart disease.
	High blood cholesterol	As blood cholesterol rises, so does the risk of coronary heart disease. When other risk factors (such as high blood pressure and tobacco smoke) are present, this risk increases even more.
	High blood pressure	High blood pressure increases the heart's workload, causing the heart to thicken and become stiffer. When high blood pressure exists with obesity, smoking, high blood cholesterol levels or diabetes, the risk of heart attack or stroke increases several times.
	Physical inactivity	An inactive lifestyle is a risk factor for coronary heart disease. Regular, moderate-to-vigorous physical activity helps prevent heart and blood vessel diseases. The more vigorous the activity, the greater benefits received.
	Obesity and overweight	People who have excess body fat are more likely to develop heart disease and stroke even if they have no other risk factors. It also raises blood pressure, blood cholesterol and triglyceride levels, and lowers HDL ('good') cholesterol levels.
	Diabetes mellitus	Diabetes seriously increases risk of developing cardiovascular disease. Even when glucose (blood sugar) levels are under control, diabetes increases the risk of heart disease and stroke, but the risks are even greater if blood sugar is not well controlled. About three-quarters of people with diabetes die of some form of heart or blood vessel disease.

Source: American Heart Association (2011) and Scott et al. (1999)

In cardiac healthcare services, improved glycaemic control, better control of hypertension, and prevention of atherosclerosis with cholesterol-lowering therapy may prevent or mitigate cardiomyopathy (Scott et al. 1999). Therefore, there is an urgent need to improve detection of CVD and prevent disease occurrence. With an increased demand for healthcare services for CVD, there will be a significant shortage of physicians trained in critical care. Kjell (2009) states that it has been estimated that by 2020, there will be a deficit of intensivist care equal to 22% of demand, and by 2030, this deficit will approach to 35%. To cover this deficit, increased medical resources will need to be allocated to provide healthcare service using information and communication technology to reduce time taken in diagnosis and treatment of patients, especially due to the projected rapid increase in cardiovascular diseases (David et al. 2011; Department of Foreign Affairs and Trade 2008; Hanley 1976). Use of technologies in healthcare has increased generally, not only to benefit patients but also to overcome human and financial resource shortages.

2.3 Information Technology in Healthcare

Information technology in healthcare has increased rapidly in the past ten to fifteen years, from robotic and laparoscopic surgery to the use of complex ECG instruments. However, information technology applications in healthcare lag well behind other sectors in investment (Chairman & David 2011). Even with low investment in the healthcare sector, there are still new innovations and developments needed to make the revolution of telemedicine happen and to provide humanity with the best possible medical care.

Molly (2010) has stated that ‘more than 200 million mobile health applications are in used today’, and that the number is expected to increase threefold by 2012. According to a report from Pyramid Research (2010), healthcare solutions delivered via information technology are creating a new frontier of innovation that is driving down costs, increasing access, and improving quality of care. This also opens up many opportunities for mobile network health solutions, such as mobile device based ECG analysis systems, mobile health recorders and mobile health scheduling of appointments (Banderker & Belle 2009; Katza & Rice 2009; Menon-Johansson et al.

2006; Qiang et al. 2008). Mobile technologies and telecommunication providers are also well positioned to develop, extend, and market mobile health services through established relationships with healthcare providers (Pyramid Research 2010).

According to Molly (2010), the new innovations in information technology have the potential to create mobile health solutions that combine voice, message, data, security, and other offerings, which will increase customer loyalty and create value-added services for the healthcare industry. The general structure of a mobile healthcare system using information technology is depicted in Figure 2.1 as an ecosystem comprising of companies and research organisations that sit atop this system (Christensen et al. 2009). This can create proprietary applications for data storage and transmission in a healthcare environment.

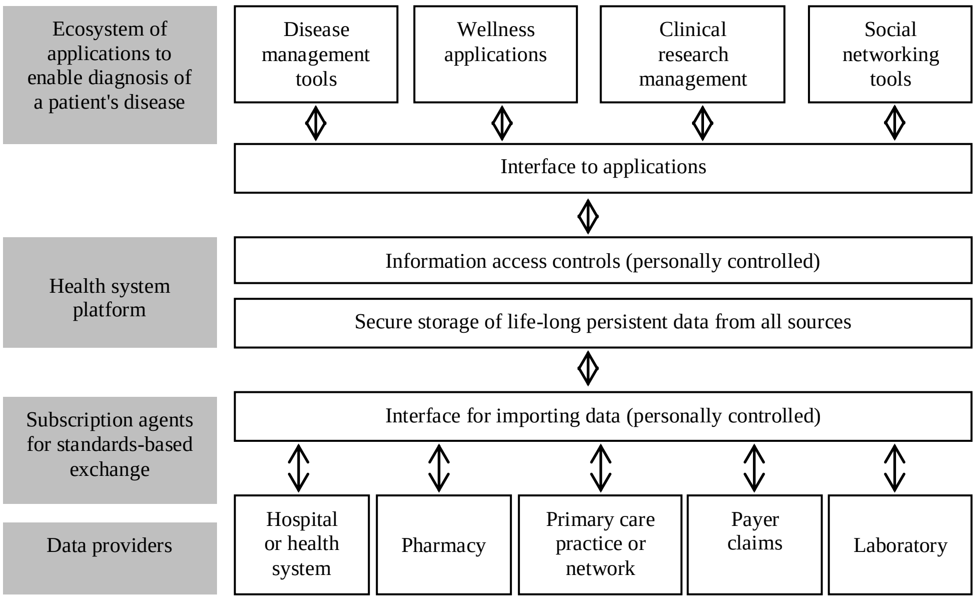


Figure 2.1: Structure of mobile healthcare system in Information Technology
Source: Christensen et al. (2009)

It is clear that mobile health applications have been discussed extensively and have evolved to allow data transfer electronically by adopting wireless technology for healthcare solutions. However, Shroff (2011) found that in order for e-health and telemedicine to emerge as viable alternative modalities for delivering medical care and expertise, there are a few preconditions that have to be met. These include:

1. Adaptation of Information technology (IT) by hospitals especially in terms of networking and hospital management systems;
2. Increasing awareness of IT among medical professionals;
3. Improved Internet access - possibility the advent of broadband that can transfer video files faster;
4. Standardisation of various protocols (like Digital imaging and communications in medicine (DICOM) (Mildenberger et al. 2002) in telecardiology) and acceptance of these protocols by relevant equipment manufacturers; and
5. Lower-priced telemedicine hardware to make it more financially viable.

As discussed above, health information technology has the potential to transform healthcare delivery, bringing information to where it is needed and refocusing healthcare around a patient. Despite a few preconditions that have to be met to develop telemedicine, its benefits still need to be proven and the technical maturity of applications is still growing (Kjell, Nikus et al. 2009). Therefore, changes to healthcare services will be accompanied by a use of information technology and the Internet but will pose challenges to long-standing assumptions and practices (Shroff 2011).

2.4 Mobile Technology Adoption in Healthcare

Internet communications to a number of Internet users and network information services (such as the pervasive telemedicine application system over communication networks) have became increasingly popular (Hsu-Yang et al. 2005). With mobile technology, users are able to communicate with smart phones, computers and other mobile enabled devices to access medical information via a healthcare provider or hospital for telemedicine services (Banks 2008; Kjell, Nikus et al. 2009; Wua et al. 2007). Telemedicine is the provision of healthcare services through the use of information and communication technology, in situations where the healthcare professional and the patient are not in the same location (Kjell, Nikus et al. 2009). Healthcare professionals have the ability to access and input medical or patient information from anywhere, at any time, including during their daily ward rounds

(Wua et al. 2007). There are several articles that indicated a mobile phone health service enriches healthcare telemedicine (Table 2.2).

Table 2.2: Mobile health services and telemedicine applications

Healthcare Services	*Relate literature/Example*
Real-time Health Recording Services	
Health services with mobile application	(Rodriguez et al. 2005)
	(Katza & Rice 2009)
	(Baoming et al. 2005)
	(Galbiati et al. 2004)
	(Chung et al. 2007)
	(Banderker & Belle 2009)
	(Ekström 2006)
Managing Healthcare Services	
Scheduling appointments	(Menon-Johansson et al. 2006)
Delivering appointment reminders	(Maria et al. 2010)
Delivering medical test results	(Fieldsoe et al. 2009)
Delivering Health Information	
Delivering health education resources	(Nesaar & Jean-Paul 2009)
	(Kjell, Nikus et al. 2009)
Delivering patient status updates	(Cheng et al. 2006)
Delivering local information relevant to health conditions	(Maryati et al. 2006)
Assisting Health Actions	
Facilitating healthy behaviour	(Jason et al. 2005)
Providing reminders for medication schedules and medical procedure	(Hsu-Yang et al. 2005)
Monitoring health status and providing guidance	(NIDAMED 2010)
Facilitating interactions with health professionals	
Collecting and sharing health measurements	(Cledand et al. 2007)
	(Cledand et al. 2007)
Sending information to contribute to diagnosis	(William 2000)

With hospital competition and the popularity of the Internet and mobile devices, there is a need to understand the factors which would entice health professionals to use mobile healthcare systems (Wua et al. 2007). A number of studies have looked at adoption of mobile health technologies. Banderker and Belle (2009) found, through mobile health systematic analysis of surveys, healthcare providers adopted smart phones at a rate that varied between 45% and 85% in developed countries in 2006. For example, in a longitudinal study of mobile technology, 33% of Canadian doctors reported use of a mobile device in their clinical practice in 2003, up from 19% in 2001 and 28% in 2002 (Martin 2003). According to an online survey (Chris 2009), smart phones used by health profession were the top desired technology-enabled tasks for medical image viewing and patient records (Figure 2.2).

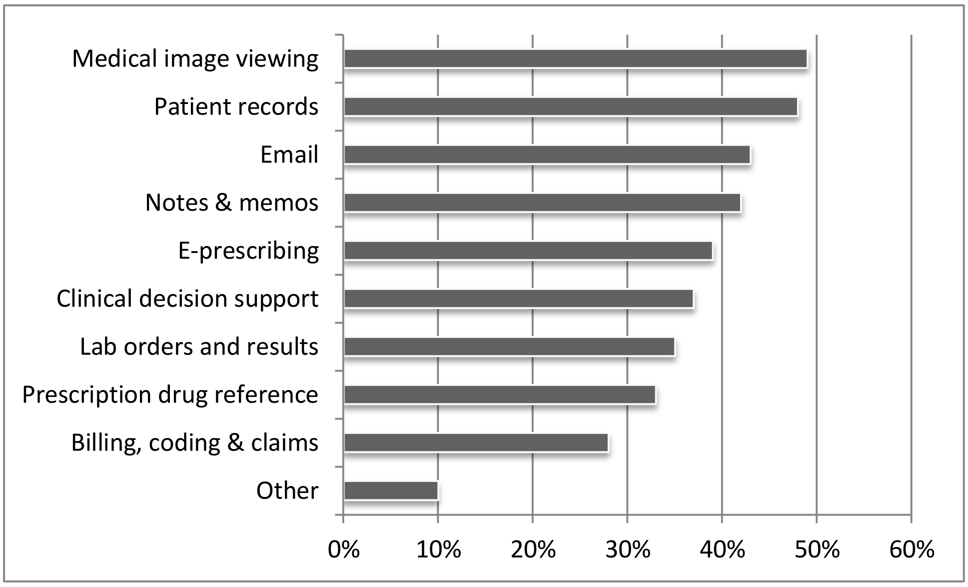


Figure 2.2: Smart phone uses by hospital professionals
Source: Mobile Health News (2009)

Mobile technologies have brought benefits to the healthcare environment because of information intensiveness. This means that mobile technologies can provide patient information to doctors who do most of their work at the point of care and are able to move around between wards, outpatient clinics, diagnostic and therapeutic departments and operating theatres. According to Hsu-Yang et al.(2005) and Nesaar and Jean-Paul (2009), the mobile medical system can solve healthcare problems and accomplish real-time medical services efficiently. Mobile technology in the health sector comprises of two major components. First, an Internet Medical Information System provides necessary information about patients, such as schedules of doctors and processes of registration. Such a system is able to complete functions of patient management and provide some statistical data related to general hospital operations. Second, a Mobile Distance Medical Information Service provides mobile telemedicine services where users can apply handheld devices such as smart phones, personal digital assistants (PDAs) or tablets to communicate with a healthcare centre and to access patient information via a mobile connection (Fieldsoe et al. 2009; Jen-Hwa 2003; Kjell, Nikus et al. 2009). Therefore, the possible benefits of the adoption of mobile technologies in healthcare need to be evaluated.

2.5 Implementation of Mobile Applications in Healthcare

Mobile IT/IS applications in healthcare can be recognised as both emerging and enabling technologies that have been applied in several countries for emergency care and general healthcare (Wua et al. 2007). For example, a variety of wireless technologies such as mobile computing, wireless networks and global positioning systems (GPS) have been applied to ambulance care in Sweden (Ulf Bjornstig 2004) and emergency trauma care in the Netherlands (Jan ten Duis & Van der Werken 2003). One study among American paediatricians found that 'The most commonly used applications were for drug reference (80%), followed by scheduling (67%), medical calculations (61%), prescription writing (8%), and billing (4%)' (Julie et al. 2006, p. 2). However, the recent growth of smart phone devices has increased the capacity to adopt mobile health applications in hospital and healthcare centres. For instance, the number of emergency patients suffering accidents is increasing every year. However, medical staff, restricted by distance and space, cannot give patients the best treatment and fail to save many lives (Hsu-Yang et al. 2005). Therefore, a number of efficient emergency rescue systems have been developed using mobile technologies via recent innovations in wireless communications such as wireless ECG devices, web-based medical diagnosis decision support system and a drug reference management system (Chung & Hsueh-Ming 2009; Ekström 2006; Julie et al. 2006). These devices tend to increase flexibility of healthcare delivery through wireless or mobile communications.

2.5.1 Current Trends

Current research indicates that the use of smart phones or PDAs can improve the quality of care. However, this depends on several factors, including the type and number of applications available, the technology competency of medical staff, and the perceived areas of patient care that will benefit from PDA use (Rosenthal 2003). Moreover, mobile devices are also 'categorically different forms of technology with different behavioural consequences that map into the double-loop learning' (Vogel et al. 2007, p. 557). Across every role in the healthcare industry, software was the major reason for purchasing a specific phone. Results of an online survey (Chris

2009) show that of each group surveyed a majority of respondents indicated that OS was the most important factor when using a smartphone (Figure 2.3). Thus, mobile health application systems could provide a useful solution for healthcare sector if the software is appropriate and easy to use. Mobile Operating System (OS) choice could have different levels of user satisfaction and affect the implementation of mobile applications in healthcare.

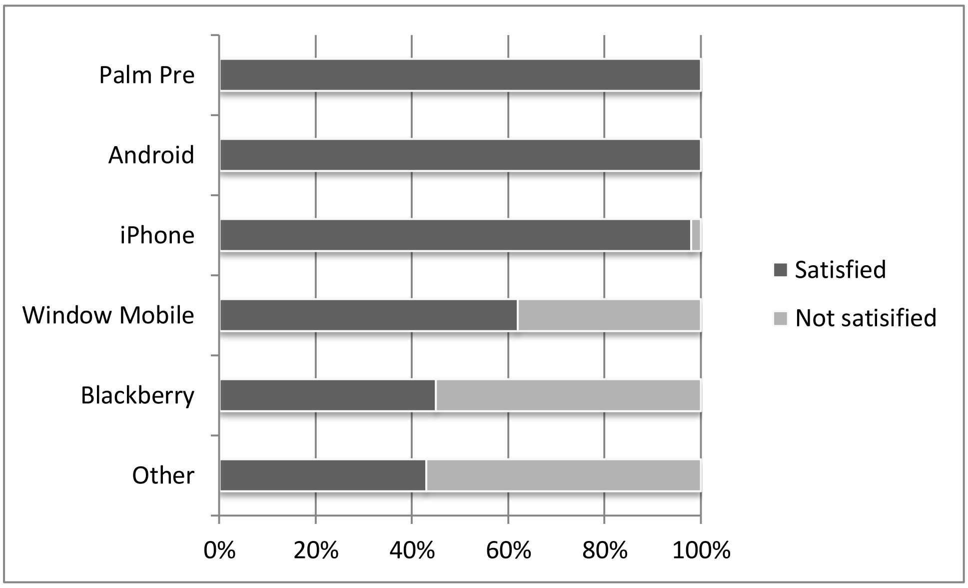


Figure 2.3: Satisfaction with smartphone OS types in healthcare industry
Source: Mobile Health News (2009)

The user experience of the mobile device is currently the strongest factor in deciding whether a mobile application will experience real mainstream adoption in the healthcare industry. The load time (responsiveness) and navigational structure of mobile application offerings are the two most critical aspects needing to be addressed from a technical point of view for implementation of mobile health technologies (Martin 2007).

There are several studies identifying which particular healthcare profession is driving the use of smartphones as mobile device to hospital settings. Some studies have looked at implementation of mobile applications from the perspective of nursing staff (Alive Technologies 2009; Galbiati et al. 2004; Gururajan 2009; Jason et al. 2005; Maryati et al. 2006; Tam 2008). Figure 2.4 shows that a majority of respondents (hospital professionals) indicated that software was the most important factor (51 per cent) in using a telehealth mobile device.

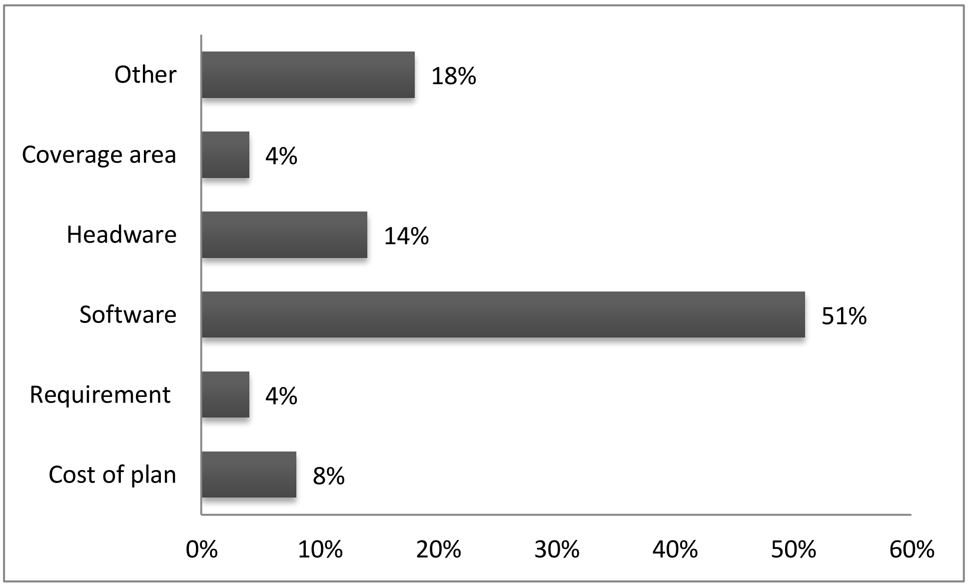


Figure 2.4: Important factor for telehealth mobile device
Source: Mobile Health News (2009)

With access to mobile networks, mobile telehealth can deliver health information and communicate with healthcare providers. Implementation of the new generation wireless technology with mobile health applications to support professionals in medical diagnosis has been recently raised as a healthcare issue (Banderker & Belle 2009). From Figures 2.3 and 2.4, it can be seen that successful mobile health applications depend on what type of operating system a mobile device uses. For instance, Android is sitting at 36% of market share in Q2 2011 (Figure 2.5) while iPhone has fallen to 26% (Henry 2011). This information shows that use of smart phones is depend on user satisfaction and experience of OSs. Meanwhile, Nielsen data shows that 23% of mobile consumers now have a smartphone (Q1 2010), up from just 16% in Q2 2009 (Osprey 2010). According to Alto (2011) the fourth quarter of 2010 shows the worldwide smart phone market continuing to soar, with shipments of 101.2 million units representing year-on-year growth of 89%. The final quarter took shipments for the year to fractionally below 300 million units, with an annual growth rate of 80% over 2009. It can be concluded that users buying smart phones are not just using them for calling or sending messages. Use of a smart phone device for data communication and information transfer via mobile networks has also increased year to year.

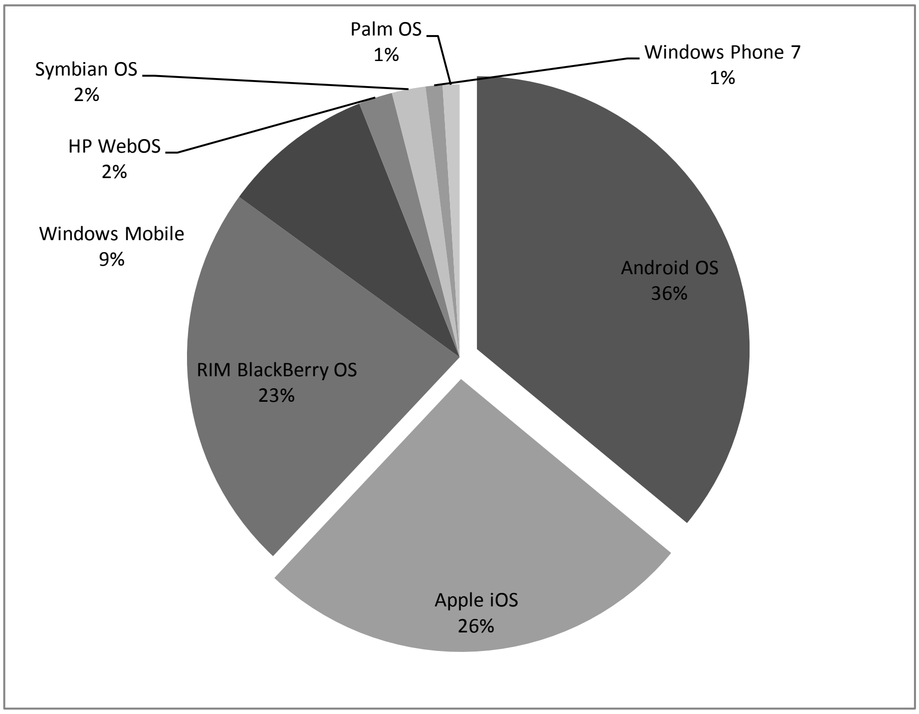


Figure 2.5: Smartphone operating system market share
Source: Henry (2011)

Katza and Rice (2009) state that doctors have a positive interest in the potential of mobile services. Potential uses identified include 36.2% for monitoring health, 46.3% for alerting users to potential health problems, 47.6% for storing medical information, 54.3% for obtaining lower cost medical insurance, and 58.2% for receiving personalised health information. Doctors would prefer to use mobile health applications for ‘alerts’, ‘monitoring’ and ‘retrieving’ patient health information on smart phones. In terms of using mobile technology for health information, users who are attentive to privacy concerns are the most interested in personally utilising new mobile technology in ways that can minimise privacy risks while improving healthcare (Katza & Rice 2009). Therefore, OS and software design for new mobile applications in the health sector are important in gaining acceptance and needs to be addressed.

2.5.2 Mobile Applications in Healthcare Adoption and Acceptance

Nesaar and Jean-Paul (2009) identified mobile health adoption factors for delivery of telemedicine services (Table 2.3). These factors form part of a generalised technology acceptance model for innovative technology in the public healthcare sector.

Table 2.3: Mobile health adoption factors to deliver telemedicine services

Factors	Discussion/Comments
Perceived usefulness of a mobile devices	Doctors perceive the device as being able to provide them with relevant information either via the Internet or software on the device. They perceived the device as a reference tool, patient information tool and even contemplated its use as a decision support tool that could help in diagnosis and medication prescription.
Social influences	Doctors display a professional maturity that does not allow factors like image or subjective norm to influence them.
Perceived user resources	Lack of resources to support their use of devices by hospitals did not negatively influence their intention to use. This could be attributed to social circumstances where doctors have learnt to cope with limited resources on a daily basis, despite their extremely pressurised work environments.
Task/technology fit	The medical profession is a very information intensive one and doctors realise that a mobile health device would be able to help to keep abreast of the latest medical knowledge.
Result demonstrability	Doctors believe that the technology would be able to help them deliver better quality care to their patients.
Fear of legal action	Underlying doctors’ perceptions of the device as an information tool is an unease in respect of malpractice legal suits. It is thought that the technology could aid the decision support. This could help reduce the possibility of incorrect diagnosis and treatment, and perhaps legal action against a doctor.
Doctor-patient relationship	Where doctors do not interact with patients, a number of the above factors are not applicable. Thus this can be seen as a moderating variable or factor on the other factors.

Source: Nesaar and Jean-Paul (2009)

Timmons (2003) investigated the implementation of a new system in a hospital and found various examples of doctors’ and nurses’ resistance to technology. Examples of resistance included: refusal to use systems, attempts to minimise use of systems, and criticism of systems. Therefore, an evaluation of usability and acceptance of mobile health applications will need to consider these factors.

The influence of mobile technology towards healthcare services is not limited to wireless communication or data recording but also includes user attitude while using mobile applications in delivery of health services. That is, the benefit of using mobile technology should be overall enhanced healthcare. It is very likely that if functionality and usability of a mobile health application are perceived to be good, it will increase the health profession's satisfaction by decreasing workloads and making personal development possible (Engstrom et al. 2005).

Alasaarela et al.(2009) stated that the process of change from a doctor's point of view is great. Among the technical challenges, usability of the mobile user interface is seen as the most difficult. Security of patient data is no longer among the top three challenges. They analysed differentiating challenges of mobile technology acceptance in health services and identified six problems:

1. Usability of the mobile user interface;
2. Stability of connection;
3. Usable but reliable authentication;
4. Security of patient data;
5. Process change from the nurses' point of view; and
6. Process change from the doctors' point of view.

Patient and medical information includes many different categories such as patient health history, prescription system, inventory system (CPOE - Clinical and pharmacy order entry and management systems), and medical database records. Therefore, mobile access to information, as well as untethered patient monitoring may provide benefits to a great number of areas like intensive care unit (ICU), ward and home monitoring. By selecting the type of mobile services in healthcare sector, Alasaarela et al. (2009) believe that the choice of application should be known and easily understood. They selected the following five applications for evaluation:

1. Mobile access to patient health record;
2. Location and tracking services for process enhancement;
3. Vital signs (health) real-time monitoring;
4. Alarm and calling services; and
5. Comfortable home monitoring.

Based on the discussion above, it is clear the term 'usability' has an influence on how well mobile technologies are adopted in healthcare service. The concept of a mobile application focuses on the data communication using wireless network, while the concept of healthcare focuses on the capability of a health service to provide best quality medical treatment for patients. How can these two concepts work together to deliver remote health services? Dena et al. (2006) stated that the delivery of remote health services is used for a variety of purposes (Table 2.4):

Table 2.4: Purpose of remote health services

Purposes	Discussion/ Services
Specialist referral services	Typically involve a specialist assisting a general practitioner in rendering a diagnosis. This may involve a patient 'seeing' a specialist over a live, remote consult or the transmission of a diagnostic image and/or video along with patient data to a specialist for viewing later.
Direct patient care	Such as sharing audio, video and medical data between a patient and a health professional for use in rendering a diagnosis, treatment plan, prescription or advice. This might involve patients located at a remote clinic, a physician's office or home.
Remote patient monitoring	Uses devices to remotely collect and send data to a monitoring station for a specific vital sign, such as blood pressure, glucose, ECG or weight. Such services can be used to supplement the use of visiting nurses.
Medical education and mentoring	Ranges from the provision of continuing medical education credits for health professionals and special medical education seminars for targeted groups to interactive expert advice provided to another professional performing a medical procedure.
Consumer medical and health information	Includes the use of the Internet for consumers to obtain specialised health information and on-line discussion groups to provide peer-to-peer support.

Source: Dena et al. (2006)

After reviewing previous studies to address factors of usability in mobile health applications, acceptance of mobile health implementations needs to be identified to directly determine the influences on a user's behaviour. A number of studies have looked into adoption and acceptance of mobile health technology services. In contrast, user acceptance of mandated technology implementations in mobile healthcare systems (Jason et al. 2005) resulted in identifying the important factors for acceptance, namely, ‘ease of use’ (49%), ‘training’(84%), ‘technical support’ (86%) and ‘system capabilities’ (67%). Both studies show quite a sharp increase in mobile device technology adoption by health professionals.

2.5.3 Decision Support System and Its Use in Supporting CVD

In order to adopt mobile technologies to assist physicians and other health professionals with decision-making tasks such as determining diagnosis from patient data, decision support systems (DSS) have the potential to bridge the knowledge gap by ‘organising and presenting the appropriate information sources to the user so that they are able to make clinical decision with reduced error and increased accuracy’ (Karin & Michael 2007, p. 761). DSS can be based on communication tools, documents, databases, models or any combination of these functions. A more robust DSS will enhance information gathering, sorting and modelling needed to improve situational awareness (Julie et al. 2006). Chung and Hsueh-Ming (2009) also investigated the needs of heart failure (HF) practitioners and the effective benefits assured by a DSS. Four clinical problems were identified as highly beneficial from a decision support point-of-care intervention system. These can be referred to as large-scale demand and include: (i) HF diagnosis, (ii) prognosis, (iii) therapy planning, and (iv) follow-up. In order to design a superior DSS to support CVD, Guilan et al (2008) introduced a general model of clinical DSS (Figure 2.6).

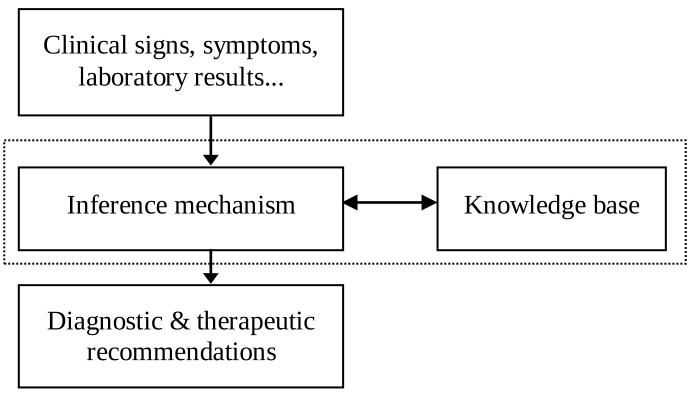


Figure 2.6: General model of clinical decision support systems (DSS)
Source: Guilan et al (2008)

The ‘inference mechanism’ addresses the symptoms of ‘what to do next’ while ‘knowledge base’ provides related solutions to address the need for medical diagnosis. Detailed decision problems in relation to CVD were identified by Chung and Hsueh-Ming (2009) for specifying domains, focusing as much as possible on medical users’ needs. Examples are:

- severity evaluation of heart failure;
- identification of suitable pathways;
- planning of adequate, patient specific therapy;
- analysis of diagnostic examinations; and
- early detection of a patient’s condition.

There are several articles in the literature that have described the development of decision support systems to support cardiac patients, focusing on cable/wireless transmission and their application (Table 2.5).

Table 2.5: List of wireless cardiac disease decision support systems

Cardiac and network related DSS	*Relate literature*
Cardiac Decision Support System	
ECG makeup language DSS	(Gonçalves & Andreao 2008)
ECG based robust clinical DSS design / QRS detection and delineation techniques	(Afsar & Arif 2007)
Wireless ECG DSS on Bluetooth protocol	(Rodriguez et al. 2006)
Multimodal Mining for Cardiac DSS	(Syeda-Mahmood et al. 2007)
ECG and Echocardiography Processing for DSS	(Chiarugi et al. 2008)
ECG based analysis and diagnosis system	(Afsar 2007)
Cardiovascular Risk Stratification in DSS	(Atoui et al. 2006)
Network Decision Support System in Health	
A SOA-BASED medical DSS	(Chung & Hsueh-Ming 2009)
DSS for optimal design of health info networks	(Berman et al. 2001)
A mobile device based ECG analysis system	(Fang et al. 2008)
Health Disease Support System	
PHAiRS – Public Health DSS	(Hudspeth et al. 2005)
Clinical Decision Support Systems	(Guilan et al. 2008)

A previous study by Daniel (2011) emphasises the advantages and disadvantages of decision support systems. The benefits of using DSS for healthcare have been identified as time saving, enhancing effectiveness, improving interpersonal communication, competitive advantage, cost reduction, increasing decision maker satisfaction, promoting learning, and increasing organisational control. A DSS in healthcare should accomplish the purpose of adding value and helping doctors and specialists deliver quality healthcare. It is important to examine the impact of implementing DSS from cardiologists', doctors' and nurses' points of view. Based on experience and research of computerised DSS (Daniel 2011), DSS can create not only advantages for organisations and have positive benefits for professionals, but can also create negative outcomes in some situations. Some disadvantages have been identified by Daniel (2011) when using DSS in healthcare area including:

- overemphasise on decision-making;
- assumption of relevance;
- transfer of power;
- obscuring responsibility;
- false belief in objectivity;
- status reduction; and
- information overload.

For successful implementation of DSS in healthcare, the system should assist decision-making rather than replacing the human decision-maker. Therefore, CADRC (2011) has provided 10 guiding principles for the design of computer-based functions of DSSs as follows:

- emphasis on partnership;
- cooperative and distributed;
- an open architecture;
- tools, not solutions;
- high level of internal representation;
- embedded knowledge;
- decentralised decision-making;

- emphasis on conflict identification;
- the computer-user interface; and
- functional integration.

It can be seen that the achievement of a cooperative DSS architecture is necessary for integration in order to share knowledge and support decision-making. DSS in healthcare today may need to be combined with mobile technology to support medication prescribing, and in clinical laboratories and educational settings to provide better diagnoses. Fang, Sufi and Cosic (2008) also stated that the newest technology of mobile system focused on telemedicine could have good extensibility.

Studies relating to the impact of DSSs on the efficiency of healthcare delivery have focused on the execution of patient care, particularly in relation to communicating with medical instruments, and increased use of mobile technology in the health area (Chiarugi et al. 2008; Galbiati et al. 2004; Qiang et al. 2008; William 2000).

According to Berman (2001), the successful use of mobile technology in other industries has prompted the health sector to look into health networks as one important approach in developing DSS to deal with complex diagnosis factors. When faced with medical decisions, physicians will be able to use a DSS to organise and record patient information as well as offer a diagnosis, in order to increase diagnostic accuracy. It is important to understand that a medical DSS is one of the tools available to assist physicians in monitoring patients and helping save lives. In particular, Chiarugi et al. (2008) also states that the integration of medical DSS should evaluate a multilevel conceptualisation strategy which distinguishes between the knowledge and processing components to provide an implementation-independent description of the role that various knowledge elements play during decision support processes.

2.6 Issues of Cardiovascular Disease Support and Current ECG Monitoring

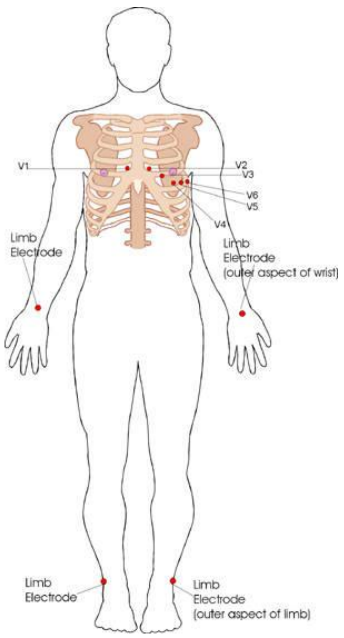
Since the introduction of Electrocardiography (ECG) by Einthoven at the turn of the 20^{th} century, its use, importance and acceptance have rapidly expanded. A non-invasive, simple, inexpensive and reproducible procedure allows an ECG signal to be recorded and provides sufficient cardiac information to permit an initial, tentative diagnosis (William 2000). Due to logistical problems of obtaining ECGs from hospital inpatients, Einthoven also presented an approach in 1906 characterised by the transmission of ECG information over telephone wires (Snellen 1995). The general principles of remote ECG transmission were established despite that absence of advanced telemedicine at the time (Dena et al. 2006; William 2000). From improvements in network service developed within virtually a century, technological developments have provided advanced portable recording systems for ECG use, such as the application of mobile technology as a telemonitoring device and standard desktop personnel computers (PCs) as a display instrument.

2.6.1 From 3- to 12-lead ECG System

Previous studies have emphasised the importance of ECG telemonitoring systems during and after implementation (Chung et al. 2007; Ekström 2006; Georgios & Ivan 2008; Qiang et al. 2008; Rodriguez et al. 2005). In the past decade, there were a number of researchers who intended to allow ECG instruments to communicate with mobile devices and transmit data through wireless technology. Moreover, ECG instruments have increased the number of leads that can be attached to the body's surface (3 leads, 5 leads to 12 leads), with the higher number producing better quality data for monitoring.

According to Dean and Stephen (2009), there are three standards of ECG instruments. A 3-lead ECG is usually used in ambulances, and monitors two different areas of the heart (one lateral=RA, two inferior=LA, LF). A 5-lead ECG is preferred in an ICU (intensive care unit), to monitor the third (anterior=front) area. With the 5-lead ECG, a carer can keep an eye on the three areas of the heart and identify changes in any area. A 12-lead ECG provides a more detailed look at the heart's three areas (anterior=front, lateral=side, inferior=back); and changes in certain segments of an ECG reading in the related leads for each area suggest the area of concern. There are immediate advantages in 12-lead monitoring for the detection and localisation of cardiac disease in patients. Kligfield (2001) indicated that 12-lead recording represents a potentially unified signal acquisition method that can be utilised for bedside monitoring, for ambulatory recording (measure changes in the heart's electrical activity and recovery) or telemetry (a communication technology that enables measurements to be used at a distance through public communication systems for remote medical care), for exercise testing, and with modification, also for standard electrocardiography.

Each of the 12-leads represents a particular orientation in space, as indicated below (RA = right arm; LA = left arm, LF = left foot) (Figure 2.7):



Bipolar limb leads (frontal plane):

Lead I: RA (-) to LA (+) (Right left, or lateral)

Lead II: RA (-) to LF (+) (Superior Inferior)

Lead III: LA (-) to LF (+) (Superior Inferior)

Augmented unipolar limb leads (frontal plane):

Lead aVR: RA (+) to [LA & LF] (-) (Rightward)

Lead aVL: LA (+) to [RA & LF] (-) (Leftward)

Lead aVF: LF (+) to [RA & LA] (-) (Inferior)

Unipolar (+) chest leads (horizontal plane):

Leads V1, V2, V3: (Posterior Anterior)

Leads V4, V5, V6: (Right left, or lateral)

Figure 2.7: Particular leads on the body's surface for 12-lead ECG used
Source: Zoll Mseries (2002)

Each lead records the electrical activity of the heart from a different perspective, which also correlates with the different anatomical area of the heart for the purpose of identifying acute coronary ischemia (a condition that occurs when blood flow and oxygen are kept from a particular part of the body) or injury (Afsar 2007). During exercise, the signal is distorted because of muscular activity, respiration, and electrode artifices due to perspiration and electrode movements (Afsar 2007). This way, the presented signal wave of an ECG shows on an ECG device and will be able to detect heart disorders or rhythms. A typical ECG tracing of a normal heartbeat consists of a P wave, a QRS complex and a T wave. A standard to represent each mV on the y axis as 1 cm and each second as 25 mm on the x-axis (printing speed of 25 mm/s) (Figure 2.8).

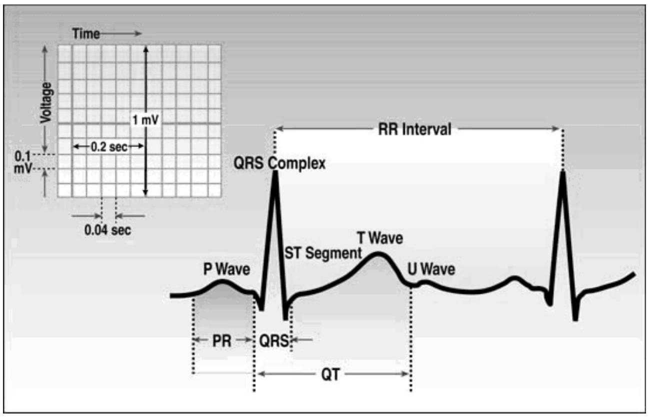


Figure 2.8: Components of a typical ECG signal waveform shown for diagnosis
Source: Rondoni (2002)

An ECG reflects the sequence of depolarisation and repolarisation (muscle fibres contracting and producing motion) over the contractile chambers (as a pump and a reservoir for blood) of the heart and is measured using body-surface electrodes (Staib & Lynch 2007). A doctor may recommend using an ECG instrument if a patient is experiencing symptoms such as shortness of breath, chest pain, dizziness, or fast or irregular heartbeats.

Interpretation of the ECG relies on different leads and views the heart from different angles. Doctors can interpret the results of ECG based on a depolarisation waveform. Table 2.6 lists a depolarisation waveform moving perpendicular to a positive electrode that creates a phasic image complex.

Table 2.6: Relationship between each wave and complex

Depolarization	Description
P wave (Atrial Depolarization)	The PR interval corresponds to the time lag from the onset of atrial depolarisation to the onset of ventricular depolarisation. This time lag allows atrial systole to occur, filling the ventricles before ventricular systole. Most of the delay occurs in the AV node. A long PR interval corresponds to impaired AV conduction.
QRS complex (Ventricular Depolarisation)	The QRS interval represents the time it takes for ventricular depolarisation. Normal depolarisation requires normal function of the right and left bundle branches. A block in either the right or left bundle branch delays depolarisation of the ventricle supplied by the blocked bundle, resulting in a prolonged QRS duration.
T wave (Ventricular Repolarisation)	The QT interval represents the time of ventricular depolarisation and repolarisation. It is useful as a measure of repolarisation and is influenced by electrolyte balance, drugs, and ischemia. The QT interval is inversely related to heart rate. A QT interval corrected for heart rate can be calculated.

Source: Staib and Lynch (2007)

2.6.2 Holter (or Ambulatory) ECG Monitor System

Under ambulatory cardiac disease monitoring of an ECG, a Holter recording (Figure 2.9) is for short-team monitoring of electrical activity of the heart (The Children's Hospital 2011). The device can continuously record heart rhythms and electrical activity onto a tape or disk over a 24 or 48-hour period. Recorded signals are then analysed off-line using dedicated diagnostic systems. Afsar (2007) has also stated that it is the most widely-used method to evaluate symptoms suggestive of cardiac rhythm disturbances (palpitations, dizziness, presyncope).

Figure 2.9: Example of a Holter monitoring device
Source: ECG Holter Monitor (2010)

According to Jovanov (1999), monitoring of the electrocardiogram during normal activity using a Holter ECG device has become standard procedure for detection of cardiac arrhythmias, transient ischemic episodes (blood flow to a part of the brain stops for a brief period of time) and silent myocardial ischemia (the most common manifestation of coronary heart disease). However, several limitations have been raised (Table 2.7) to its acceptance and usefulness in documenting an adequate control of the ventricular rate in patients (diagnosis). The list of disadvantages indicates a lack of real-time data as well as a DSS for a Holter ECG device, which are common for supporting cardiac diagnosis. Even though it can record data on heart activity during a patient's typical daily life, a more flexible and mobile solution is required.

Table 2.7: List of Holter ECG disadvantages

Types	*Disadvantages (issue of decision support in Holter ECG devices)*
For monitoring patients	• Most types are used for 24 hours only and it is unlikely in most cases that clinical signs will occur while patient is wearing a Holter ECG. • The way to keep a Holter ECG and electrodes attached to the patient during monitoring. • Excessive motion artefact resulting in lost data and ECG quality cannot be viewed during recording. • Lack of correlation between arrhythmias suppression after an intervention and subsequent outcome. • Uncertain guidelines for the degree of suppression required demonstrating an effect.
For documenting an adequate control of the ventricular rate in patients (diagnosis)	• Cannot measure several diseases with a Holter ECG e.g., axis deviation for which it has to look at lead I and AVF and this is not possible with this device. • Cannot be used as screening tool for detecting coronary artery disease • Cannot be used for evaluating severity of ischemia in an individual patient. • Can detect ventricular hypertrophy using Holter ECG because it cannot distinguish left ventricle hypertrophy from right ventricle hypertrophy.

Source: Afsar (2007), Jovanov et al. (1999) and Brownlie (2010)

2.7 Wireless ECG Telemonitoring Systems

A mobile technology, incorporating technologies such as Bluetooth, GPRS, GSM or Wi-Fi, allows wireless communication with health centres and medical professionals. Several groups (Rodriguez et al. 2005) have developed applications to monitor ECG using mobile devices, where samples have been obtained from standard databases or they have developed an ECG module to maintain ECG data from wireless transmission. Work of researchers has shown the implementation of healthcare with wireless technology capabilities (Bluetooth, GPRS/GSM and Wi-Fi) in the real-time

ECG visualisation on mobile devices (Bai et al. 1999; Ekström 2006; Georgios & Ivan 2008; Hung & Zhang 2003; Reinharz 1992; William 2000).

Initial ideas for connecting an ECG system to a mobile phone with an application for graphical presentation of data were found to be most difficult to develop as a standard solution (Georgios & Ivan 2008). What has been identified as needed is an advanced and reliable alarm function for a 12-lead mobile ECG system, connected to Bluetooth, GPRS/GSM or perhaps to GPS delivered on a handheld mobile phone device that incorporates a DSS application as the user interface. This section details different types of wireless communication for mobile ECG systems in use for medical diagnosis.

2.7.1 Bluetooth ECG Telemonitoring System

Rodriguez et al. (2006) and Ekström (2006) introduced a system which consists of three modules: the patient's acquisition and processing board (PAP-BT), the medical control unit in the PC (MCU-PC), and the medical control unit in the mobile phone (MCU-MP) (Figure 2.10).

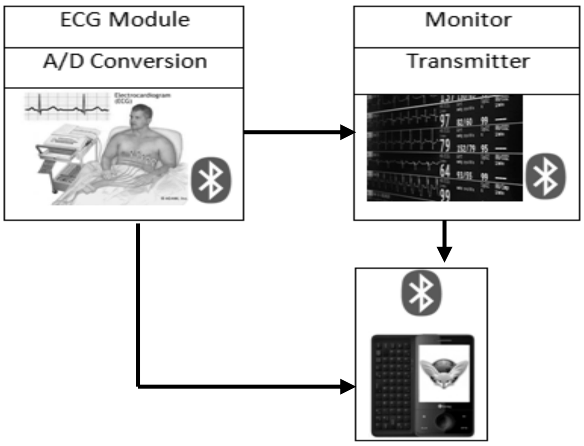


Figure 2.10: ECG monitoring system using Bluetooth
Source: Rodriguez et al. (2006)

These researches used the MCU-PC module to provide a user interface that simulates an ECG monitor and offers Bluetooth communication, GSM/GPRS with the PAP-BT as functionalities for data storage, ECG reception, and visualisation. The application running on a mobile terminal also runs on a mobile phone or PDA equipped with Bluetooth. Its user interface allows communications with other devices, reception of cardiac signals and real-time data signal visualisation.

Although ECG telemonitoring systems by Bluetooth have made it easy for technological updates and future developments to provide more intelligence to the system, new innovations in software and hardware tools both for computers and mobile devices have enabled a large range of application scenarios (not tested by past published studies). According to John (2006), several high capacity network technologies such as High-Speed Downlink Packet Access (HSDPA) mobile phones, dual-mode handsets supporting both GSM and Wi-Fi technologies, and handsets capable of downloading data through 'super 3G' (3.6Mps) networks have been on the move. In terms of developing ECG telemonitoring systems, choosing Bluetooth as a transmission protocol could be one option for communicating with ECG instruments. However, the use of Bluetooth will limit the ECG-sensor system primarily at maximum data rate of 750 kbps and 10 metre range (Ekström 2006). Therefore, identifying the possibility of wide range telemonitoring for health delivery has not yet been examined based on this adoption.

2.7.2 Wi-Fi (WLAN) ECG Telemonitoring System

According to Tam (2008), the first and oldest wireless technology used in medical applications is wireless local area network (WLAN). The standards for WLAN were first introduced in 1997, namely IEEE 802.11. The capacities of IEEE 802.11 standards included 1-2Mbps in the initial version to 54Mbps in IEEE 802.11a and IEEE 802.11b. IEEE 802.11a has a range of 30 metre and 802.11b has coverage of 106 metre outdoors and 45 metre indoors. After the introduction of 802.11a and 802.11b, the Wi-Fi Alliance formed and started its work certifying wireless based devices. Many extensions of WLAN were released including 802.11g, and were added to in 2003 with capacities of 54Mbps transmission working on 2.4GHz band at range of 106 metre outdoors and 13 metre indoors; then followed 802.11n with higher throughput of up to 200Mbps.

The advantage of Wi-Fi (WLAN) has encouraged a number of groups to introduce ECG telemonitoring systems with WLAN communication technology. William (2000) and Georgios et al. (2008) introduced communication interfaces to transmit an ECG signal to another local device by using WLAN technology. The transmission method provides the capability not only to transmit an ECG from the database but also to communicate between GPs and cardiac patients remotely. Complicated information communication (capture an ECG device, retrieve information from ECG device or record data in remote locations) increases the level of transmission capability. Figure 2.11 shows the conceptual schema of an ECG telemonitoring system with WLAN technology based on these researchers' work. However, based on a review of the extant literature, it appears that this still depends on the availability of IP network access.

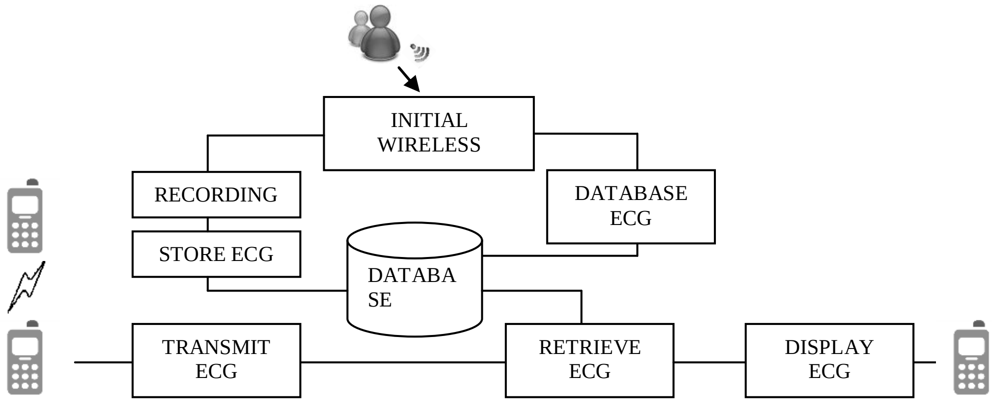


Figure 2.11: ECG telemonitoring systems with WLAN

2.7.3 GSM/GPRS ECG Telemonitoring System

Communications technology itself is rapidly advancing. Third-generation (3G) systems allow greater bandwidth permitting more information to be exchanged (William 2000). By using remote portable devices that wirelessly communicate with far end systems or devices via GSM/GPRS mobile phones, previous studies (Alasaarela et al. 2009; Dena et al. 2006; William 2000; William et al. 2002) effectively demonstrated the plausibility of integrating mobile communications and the Internet in telemedicine. However, these ideas of using a mobile phone application for ECG devices was only as a wireless modem for downloading data from an ECG monitoring system, not for direct display of real-time data on a hand-held device.

Research studies by Baietc al (1999) and Hung and Zhang (2003) provided very limited mobility for a patient. The ECG was equipped with an indoor, wireless transmitter for feeding monitored data to a network connected PC. A GSM modem was equipped with a PC for real-time transmission of ECG data from a moving ambulance vehicle. The focus of the design was on transmitting ECG data for consultation while transporting patients in emergency cases. This approach was adopted because using GSM network was costly and the data transmission rate was low. According to William (2000), restrictions by incorporating digital communication technology over the 900 MHz GSM cellular network could also decrease the quality of data transmission. However, there is an advantage in using these network services. For instance, an ECG telemonitoring system for secondary care, in a home environment, mobile cardiac care unit, or indeed any location which has GSM coverage, will provide healthcare services for patients. A system that can handle multiple mobile network standards and not inhibit patient and carer mobility could provide advantages and a higher level of care.

Thanks to innovations such as 3G and HSDPA (High-Speed Downlink Packet Access) in mobile technology, high capabilities with lower cost of mobile network technologies are now available throughout the world. A new mobile function called 'PUSH FUNCTION' has also resulted in the ability to communicate messages or receive/send data at any time. Thus there is always a connection between a server and a mobile device. Taking advantage of these innovations could provide better and real-time monitoring of ECG data using a mobile monitoring system with 12-lead instruments. However, this combination of technologies used to deliver ECG readings to ubiquitous devices appears to have not been evaluated. Their needs to be a better understanding of information requirement of healthcare professionals before these technologies can be put to effective use.

2.8 Information Needs and Decision Support

Signal and imaging investigations are 'currently a basic step of diagnostic, prognostic and follow-up processes of heart diseases' (Massimo et al. 2010, p. 3). In the cardiac health decision support area, the development of mobile-aided diagnosis schemes is still attracting a lot of interests and efforts. Due to developments in computer technology, medical DSS have surfaced to assist medical practitioners primarily in two areas: data interpretation and diagnosis (Chung & Hsueh-Ming 2009). DSS in healthcare can be divided into two categories: diagnosis and decision-making. Through this approach, it provides the ability to 'analyse and scrutinise diseases and help medical practitioners effectuate their operations and reduce misjudgements' (Chung & Hsueh-Ming 2009, p. 923). Any investigations of the clinical workflows on ECG signal and patient information will need to be carefully considered in the design of the DSS to allow users to input data and interact with it. As an application of the decision support system, the medical DSS was developed to solve problems in specific areas. Features of the cardiac health decision support as a medical DSS include the following (William et al. 2002):

- through the computer, it can effectively and, in a timely manner, store patients' medical records;
- ease of access to knowledge and solution needs from the clinical database or information system;
- automatic analysis of examination outcomes;
- determining appropriate medication or dose; and
- assist doctors with decision analysis.

Sprague and Carlson (1982) state that DSS is a computer-based support system for decision-making to support users who are dealing with semi-structured problems. The purpose of DSS is to help physicians with issues pertinent to diagnosis decisions. Though this system users could obtain a more accurate diagnosis and enhance the quality of medical treatments (Geoffrey et al. 2008). DSS comprise 'a class of information system that draws on transaction processing systems and interacts with the other parts of the overall information system to support the decision-making activities' (Sprague & Carlson 1982, p. 1). However, in order to gain new technology adoption, there is a need to evaluate acceptance of any DSS developed to ensure successful implementation in a particular context. Therefore, this research employs several theories in its investigation to identify the acceptance factors in cardiac diagnosis and to determine if users view any developed system as beneficial.

2.8.1 Theories and Models of Acceptance and Use of IT

Extensive research of user intentions to adopt new technologies exists and much of this research has been conducted in environments where adoption is voluntary (Brown et al. 2002). Jason (2005) explained that a voluntary use environment is defined as 'one in which users perceive the technology adoption or use to be a wilful choice; a mandated environment is where users perceive use to be organisationally compulsory'. In this environment, the new information system must be able to complete job tasks that are tightly integrated with tasks of multiple workers (Brown et al. 2002).

There are several theories proposed in IT research that have been found to explain acceptance of information technology and its adoption (Table 2.8).

Table 2.8: Theories and models of acceptance and use of information technology

Theory/Model	Explains
The theory of Planned Behaviour (TPB)	The TPB helps in understanding how information technology can change the behaviour of people. It is a theory that predicts deliberate behaviour, because behaviour can be deliberative and planned. TPB holds that attitudes, subjective norms and perceived behavioural control are direct determinants that in turn influence behaviour (Christopher & Mark 2001).
The Unified Theory of Acceptance and Use of Technology (UTAUT)	UTAUT explains user intentions to use technology and actual behaviour. It is meant to be adjusted to fit the technology being queried and therefore a certain amount of rewording is expected. The theory includes four key constructs: performance expectancy, effort expectancy, social influence and facilitating conditions. UTAUT is a synthesis of eight existing models of technology acceptance — including TAM. UTAUT also integrates elements from: Theory of Reasoned Action, Motivational Model, Theory of Planned Behaviour (TPB), a combined TAM and TPB model, Model of PC Utilisation, Innovation Diffusion Theory, and Social Cognition

	Theory (Lidia et al. 2007).
Innovation Diffusion Theory (IDT)	Innovation diffusion is defined as the process by which 'an innovation is communicated through certain channels over time among the members of a social system'(Donghyun 2009). Its primary intention is to provide an account of the manner in which technological innovation moves from the stage of invention to widespread use. These categories are: innovators, early adopters, early majority, late majority and laggards. IDT also posits four innovation characteristics that affect diffusion: relative advantage, complexity, trial ability and observability (Rogers 1983).
Technology Acceptance Model (TAM)	The TAM was specifically developed with the primary aim of identifying the determinants involved in computer acceptance in general; secondly, to examine a variety of information technology usage behaviours; and thirdly, to provide a parsimonious theoretical explanatory model (Davis et al. 1989). This model specifies causal relationships between system design features, perceived usefulness, perceived ease of use, attitude towards using, and actual usage behaviour (Rogers 1983). The TAM provides an informative representation of the mechanisms by which design choices influence user acceptance, and should therefore be helpful in applied contexts for forecasting and evaluating user acceptance of information technology (Lidia et al. 2007).
Technology Acceptance Model 2 (TAM2)	TAM2 is an extension of the TAM model. It is able to provide more detailed explanations for the reason participants found a given system useful (Venkatesh & Davis 2000). TAM2 also added 'a variable meant to capture the social influence that compels end users to positively evaluate and accept IT' called subjective norm (SN) (Richard & Ben-Tzion 2010, p. 160).
Information System Success Model (ISSM)	The ISSM explains interrelationships among four constructs representing the success of a specific IS (user satisfaction, system use, perceived usefulness, and system quality), and relationships of these IS success constructs with four user-related constructs (user experience with ISs, user training in ISs, user attitude towards ISs, and user participation in the development of the specific IS) and two constructs representing the context (DeLone & McLean 2002).

The aim of these models and theories is to explain user acceptance, the goal being to achieve 100% acceptance of a 'delivered' system if attention is given to key factors in any development of a system. It is proposed that this research uses the Technology Acceptance Model (TAM) and Information System Success Model (ISSM) as primary underpinning theories to evaluate the acceptance of mobile technology in a healthcare environment. With over twenty studies testing TAM and ISSM models in healthcare and dozens more empirical and theoretic health IT papers mentioning these theories, TAM and ISSM are increasingly portrayed as fitting theories for the healthcare context (Richard & Ben-Tzion 2010).

User acceptance of new IT/IS is the primary factor in IT/IS success (Wua et al. 2007). Among technology acceptance theories, there are common theoretical themes focusing on behavioural intentions and individual reactions. In order to evaluate the acceptance of a new mobile application, TAM (Figure 2.12) and ISSM can be used to determine an individual's behaviour while using a system.

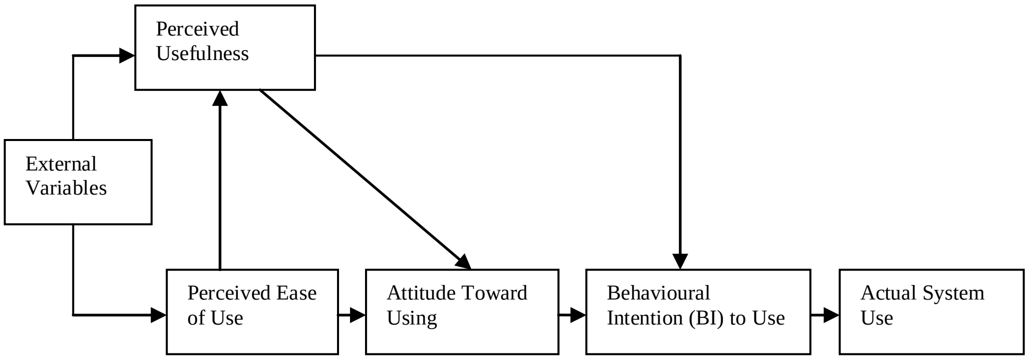


Figure 2.12: Technology Acceptance Model (TAM)
Source: Davis et al. (1989, pp. 982-1003)

The most proximal antecedent of IT use is 'behavioural intention to use' (BI), and this is now commonly taken to be what is meant when one refers to 'acceptance', although another common conceptualisation of acceptance is 'end-user satisfaction' (Richard & Ben-Tzion 2010). The TAM theory also goes through a number of changes from time to time. An updated version of TAM called TAM2 (Figure 2.13) has removed the 'attitude' component from the model, which originally mediated some of the influence of 'perceived usefulness' and 'perceived ease of use'. TAM2 includes a variable meant to capture 'social influence' that compels an end user to positively evaluate and accept IT (Mei-Ying et al. 2008). Karsh et al (2006) have identified a possible solution of primary care physicians' and nurses' perceptions by using TAM2 as an instrument to reveal perceptions of *usefulness* (improved care, suggestions for improvement) and *ease of use* (easy and quick to use, minimal extra workload, good instructions), as well as subjective norms (colleagues, supervisors, internal and external organisation).

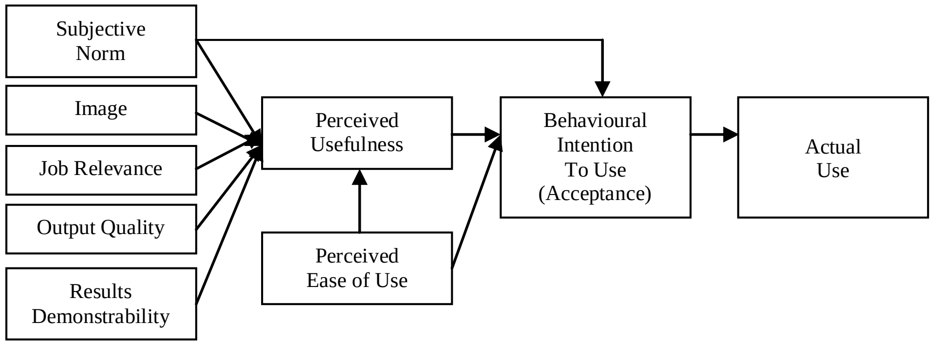


Figure 2.13: Technology Acceptance Model 2 (TAM2)
Source: Richard and Ben-Tzion (2010)

Richard and Ben-Tzion (2010) indicate that health information technology (HIT) is is the basis of convergence between international definitions of HIT and health/medical informatics. It provides 'the umbrella framework to describe the comprehensive health information management' via computerised systems and its secure exchange between users, providers, government and so on (Rajesh 2010). When technology adoption begins, innovators and early adopters, with their strong technology orientation, may get by on their own initiative. Two illustrative definitions of health IT are:

- 'The application for information processing involving both computer hardware and software that deals with the storage, retrieval, sharing, and use of healthcare information, data and knowledge for communication and decision-making' (Richard & Ben-Tzion 2010, p. 161).
- 'The knowledge, skills and tools which enable information to be collected, managed, used and shared to support the delivery of healthcare and promote health' (Richard & Ben-Tzion 2010, p. 161).

According to Hu et al. (1999), telehealth could greatly depend on information systems (IS) in most cases. Delone and McLean's (1992) IS success model appears to be another significant framework to evaluate system success in the healthcare area.

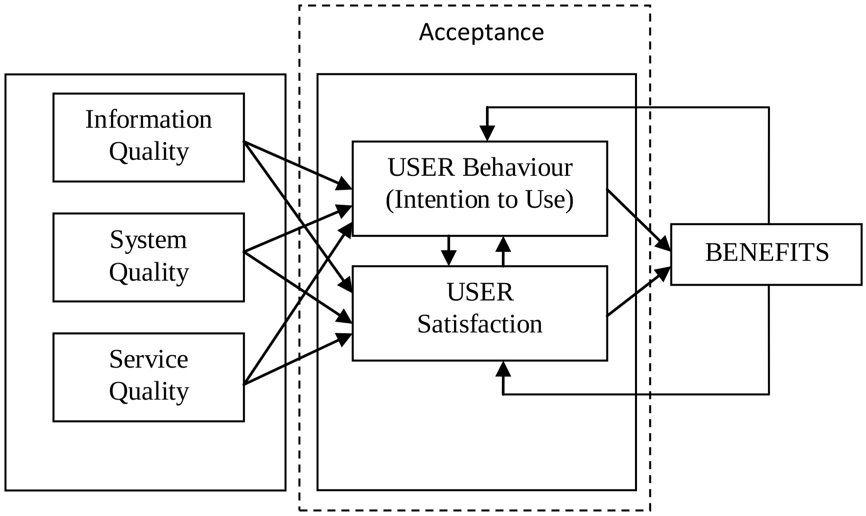


Figure 2.14: The reformulated IS Success Model (ISSM)
Source: DeLone and McLean (2002)

The IS Success Model (Figure 2.14 – right-hand side) illustrates clear, specific dimensions of success or acceptance and the relationships between factors (DeLone & McLean 1992). In the IS Success Model, intention to use or user satisfaction is determined by 'information quality', 'system quality' and 'service quality' (DeLone & McLean 2002). By combining all these independent factors, the reformulated model can better represent factors that determine 'intention to use' or behavioural intention of the user of the system and identify 'benefits' from intended use and user satisfaction of the system.

In order to improve new technology adoption usage and acceptance, DeLone and McLean (1992, 2002) refer to the overall level of 'user satisfaction' and also consider it as an important means of measuring users' behaviour (opinions). Mustansar and Zulfiqar (2010) explain it, in a given situation, as the sum of one's feeling and attitudes towards a variety of factors affecting the situation of acceptance. However, user attitudes can be defined as a subjective assessment of various consequences, evaluated using a 'pleasant' and 'unpleasant' continuum (Seddon 1997). For measuring acceptance using the IS Success Model, 'user behaviour' and 'user satisfaction' have been used by past research studies (Table 2.9).

DeLone and McLean (2002) explained that the construct in relation to acceptance that '*use'* must occur before '*user satisfaction*' as in procedure logic positive experience with '*use'* will lead to higher user satisfaction in a causal sense. Therefore, increased user satisfaction is purported to lead to higher acceptance and ultimately will have an effect on '*use'* beyond intention to use (Mustansar & Zulfiqar 2010).

Table 2.9: Some uses and user satisfaction measures

IS Success Model in the field of Acceptance		**Author**
User behaviour	**Description of the measures**	
Online transactions via mobile commerce	Frequency of use	(Jen-Her & Shu-Ching 2005)
Microcomputer usage	Self-reported daily use, self-reported frequency of us	(Igbaria et al. 1996)
Information system use	Frequency of use, heavy or light user	(Hartwick & Barki 1994)
Use of E-learning system	Frequency of use, voluntariness, dependency	(Wang et al. 2007)
User satisfaction	**Description of the measures**	
Satisfaction in e-service context	I am satisfied with this e-service. The e-service is successful. The e-service has met my expectations.	(Pin & Hsin-hui 2003)
End users computer satisfaction	Relevancy of output information is useful. Does the information content meet users' needs; output Information is relevant. Completeness of output information **Accuracy**: Output information is accurate. Accuracy of output information is satisfactory **Format**: Format of output information is useful. Format of output information is clear **Ease of Use**: System is user friendly. System is easy to use	(Doll & Torkzadeh 1988)
Assessing effect of satisfaction in behavioural intention in service industries	My choice to purchase this service was a wise one. I think that I did the right thing when I purchased this service. This facility is exactly what is needed for this service	(Cronin et al. 2000)

Source: Mustansar and Zulfiqar (2010)

2.8.2 Acceptance of Wireless ECG Telemonitoring Systems

Telemedicine generally brings together use of communications and information technologies in order to deliver healthcare. ECG telemonitoring systems have been rapidly increasing in number and acceptance in Australia over the last decade, improving access to cardiac patients. According to DEEWR (2009), ECG Australia is keen to be involved in having further input into changes to the system and the resource allocation processes in order to provide a perspective from communities that are reliant on quality education and training for their growth and development.

ECG telemonitoring is just one example of cutting edge technology that is becoming integrated into every day cardiology practice. Telemonitoring has largely featured in research trials, but this technology is on the cusp of becoming mainstream, and likely to result in a major change to work practices of heart failure nurses (The Medical News 2009). ECG telemonitoring systems enable a higher proportion of cardiac patients to be monitored by specialist services. A Medical News (2009) article points out that telemonitoring is particularly helpful in heart failure where conditions of patients may change and carers can identify those who need the most help. In terms of monitoring cardiac patients remotely, it also helps cardiac patients on how to live with and self-manage their heart conditions.

According to Hu et al (1999), user acceptance is a critical success criterion for HIT adoption and can be sufficiently explained, accurately predicted and effectively managed by means of a host of relevant factors. Acceptance and utilisation of IT/IS in the healthcare environment have also been central themes in the information systems literature (Gururajan 2009).

In terms of addressing some of the short-comings and better understand interaction dynamics for IT/IS in healthcare, stakeholder network analysis has most recently been applied to identify medical services, information, patients participation and benefit value flows between stakeholders for mobile IT adoption (Arvind 2009). This method has an ability to create a value network that produces relative importance of stakeholders from various perspectives and an importance of the direct and indirect value within a system. This assistance has potential to provide risk management, opportunities and barriers to effective IT adoption in healthcare (Stuart & Byron 2009). In addition, Arvind (2009) states that stakeholder network analysis is also a useful method for decision-making. However, this research focuses more on acceptance of new IT adoption from medical specialists (no patients are involved) and less involved with stakeholder interactions. Therefore, there may be a greater chance to explore interaction dynamics between hospital administrators, specialists and patients in future studies.

2.9 Research Gaps

Various points of view in the literature (e.g., (Cheng et al. 2006; Galbiati et al. 2004; William et al. 2002) promote the ability and development of ECG telemonitoring systems that can be implemented with mobile technology for data transmission. According to Galbiati et al. (2004), it was only less than 10 years ago that researchers from Texas demonstrated the ability to transfer ECG data via wireless technology to hand-held computers where it could be reliably interpreted by cardiologists. Moreover, new innovations in network services bring the potential to offer better mobility and ubiquity of service by using mobile technology in a large range of application scenarios. There are several articles in the literature that have described the development of DSS to support cardiac patients (Afsar 2007; Afsar & Arif 2007; Atoui et al. 2006; Gonçalves & Andreao 2008; Syeda-Mahmood et al. 2007), focusing on mobile ECG transmissions (Berman et al. 2001; Chung & Hsueh-Ming 2009; Qiang et al. 2008). However, scant prior research exists indicating the advantage of mobile adoption as a DSS to provide new functionality (tools and applications) in health service (Banderker & Belle 2009; Baoming et al. 2005; Chung et al. 2007; Ekström 2006; Galbiati et al. 2004; Katza & Rice 2009; Rodriguez et al. 2006). Thus, based on these reviews there appears to be no complete model to support mobile-based DSS and provide 12-lead ECG signal data across 3G (3rd generation mobile telecommunications) / Internet telecommunications networks and to evaluate system characteristics needed in mobile health services.

The Lewin Group Inc. (2000, p. 21) mentioned that clinical acceptance of a telehealth application may depend on the degree of confidence clinicians have in their clinical findings from using a system as well as a clinician’s satisfaction with the encounter in the absence of face-to-face interaction with patients. However, only a few published studies address acceptance of mobile health services (Anil 2010; Gururajan 2009; Jason et al. 2005; Wua et al. 2007), particularly within mobile DSS and 12-lead ECG telemonitoring (Cheng et al. 2006; Rodriguez et al. 2006;

Rodriguez et al. 2005). In order to provide more patient care, mobile communication and localisation technology are able to perform automatic monitoring for human ECG signals at any time and place via a number of wireless transmission methods (Baoming et al. 2005). Hence, the acceptance by users (diffusion) of mobile technology needs to be evaluated to determine the degree of confidence that clinicians have their clinical findings (e.g., diagnosis) from using a mobile application. Due to the non-existence of a similar model of M-ECG DSS, there appears to be no evaluation of it system to enhance CVD diagnosis outcomes and the possibility of implementing mobile technology within a hospital's practices. The review suggests the following four major gaps in the literature:

1. With enhanced mobile technologies starting to be used in healthcare delivery, little published research has been undertaken to evaluate users' needs in the form of functional characteristics to improve acceptance of health technology, particularly for mobile ECG cardiac diagnosis using 12-lead data readings.
2. There appears to be little to no published research on use of DSS design concepts that support healthcare of CVD patients who are remote from clinicians.
3. There appears to be little to no published studies on the combination of M-ECG with DSS to deliver CVD data to clinicians and what M-ECG DSS system characteristics are acceptable delivering ECG diagnostic data to users.
4. There appears to be no studies that combine systems and technologies for delivering ECG readings on ubiquitous mobile devices to enhance clinicians' diagnostic capabilities remotely.

Based on the above discussion, interrelationships among different factors and system characteristics of the DSS need to be investigated to identify user acceptance by clinicians. This necessary level of integration has not been empirically examined to date. As a result, understanding of a configuration for a mobile ECG decision support system (M-ECG DSS) and its ability to successful deliver medical services appears incomplete. To fill these gaps, this research focuses on developing a M-ECG DSS to evaluate system characteristics and its acceptance in telemedicine by applying diagnostic and management decisions, as suggested by previous studies

(Ekström 2006; William 2000). Apart from this, a study to exam the use of mobile ECG DSS and measure potential factors of user acceptance would be extremely valuable for system development. Thus, the research design and methodology employed for this study to fill these gaps is outlined in the following chapter (Chapter 3).

Chapter 3 Research Design and Methodology

3.1 Introduction

A review of relevant literature, presented in the previous chapter, outlines the acceptance of health related technology developments in a mobile environment and addresses acceptance factors which influence acceptance. The review further emphasises that acceptance of mobile health implementations could be associated with *user behaviour* and *user satisfaction*. Thus, this research aims to examine the delivery of mobile healthcare (particularly in cardiac care) through the use of mobile ECG decision support systems (M-ECG DSS) for communication and decision-making. This chapter explains the research design and methodology for evaluation of the prototype M-ECG DSS.

3.2 Study Design

The literature review found limited and fragmented information about the link between mobile technology and healthcare. This research is an exploratory study as it is 'aimed at gaining understanding of a complex and not well-understood phenomenon' (Yin 1994). It uses qualitative and quantitative research methodologies to investigate acceptance factors and has divided into five stages. The study mainly uses a qualitative approach to offer flexibility in design and application which is more sensitive to the complexities of users' behaviours. The quantitative method supports the findings from the qualitative method, which helps to triangulate conclusions reached. This approach is suited to research that solely seeks to observe and gather data, rather than impose influence on research subjects (Yin 2008). The five stages of this study's design are: 1) Preparation and Exploration; 2) Conception; 3) Development; 4) Evaluation and Practice; and 5) Analysis and Report.

First, the research identifies the issues from literature and current developments. A review is used to explore the research directions and emerging research issues. Second, a conceptual model is developed based on the two technology acceptances models (TAM and ISSM) and mobile health adoption factors to answer the research questions identified as gaps in the literature. Third, a prototype is developed and tested internally in the lab as well as by one cardiologist. Fourth, broader testing of the initial prototype is conducted using interviews and surveys. This stage is used to support and/or reengineer the initial prototype as well as evaluate acceptance. Fifth, all data collected are analysed. This stage synthesises all findings to arrive at possible solutions for a M-ECG DSS. Figure 3.1 shows all stages of the study design.

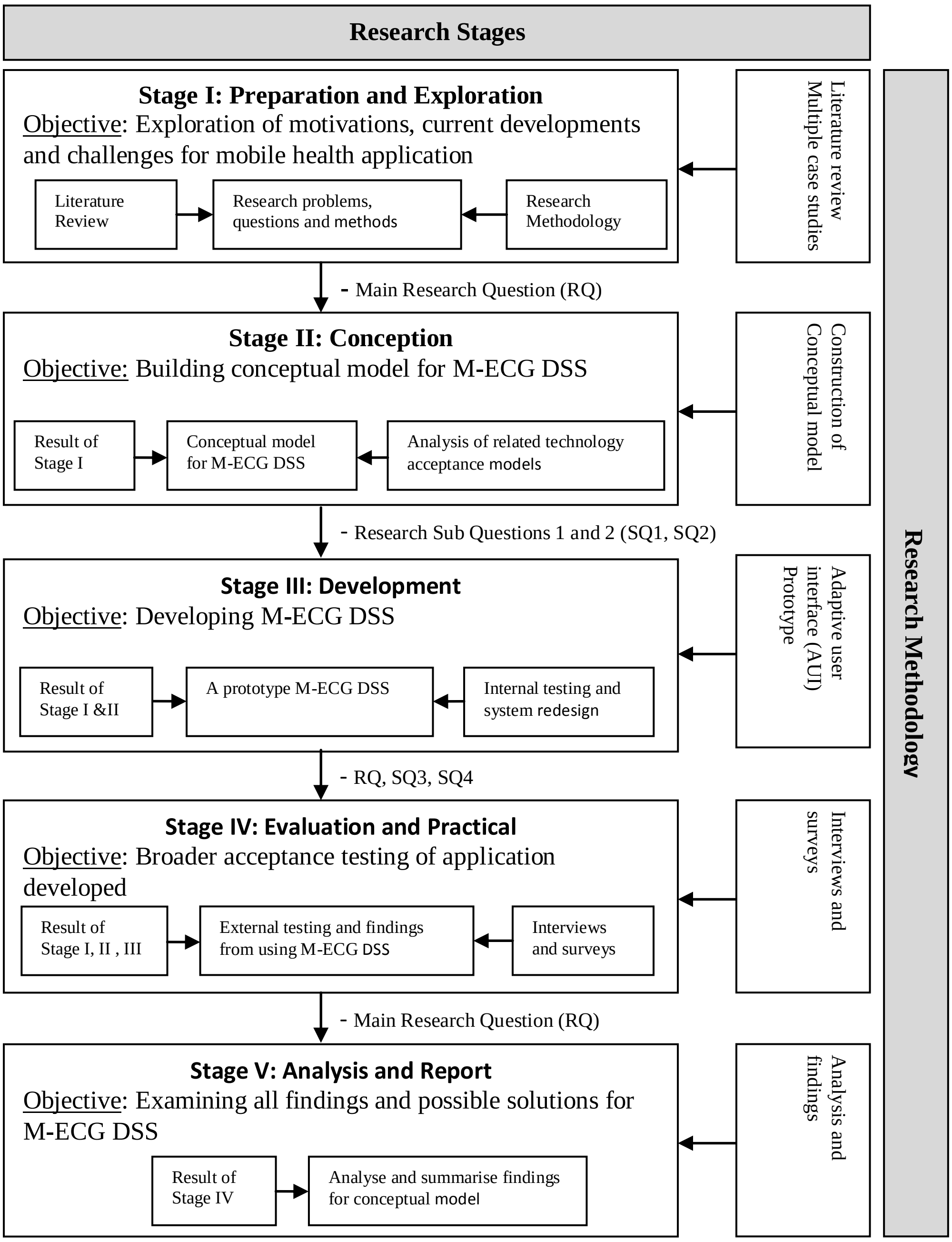


Figure 3.1: Stages of study design

3.3 Research Design

This research seeks to answer one main research question by identifying the key factors of acceptance of a M-ECG DSS. It also explores system characteristics at the intersection between health services data and mobile technologies. In order to provide a better solution for ECG decision-making, mobile application characteristics need to be identified and evaluated so that the most appropriate information can be captured and displayed in the decision support system (DSS).

3.3.1 Research Questions

The level of acceptance is the most critical criterion that telehealth communication developments tend to use and is the degree to which clinicians, or other health professions are satisfied with a service and willing to use it (Health Canada 2000, p. 24). In order to address and evaluate this research objective, the main research question (RQ) is addressed by a set of sub-questions (SQ). Thus, this study will be able to enunciate the required ECG functional / DSS system characteristics best suited to meet health practitioners' needs and factors that contribute to mobile technology acceptance in healthcare services. The main research question is:

RQ: Can a M-ECG DSS that encapsulates key functional and system characteristics improve user acceptance of health technology for monitoring of cardiac patients remotely?

The present research addresses why users accept or reject information systems and how user acceptance is affected by system design features and characteristics (Fred 1993, p. 475). Thus, this research tests how well the prototype M-ECG DSS is accepted by actual users. According to TAM and ISSM models, attitude theories from psychology provide a rationale for the flow of causality from system characteristics through perceptions to attitude and user acceptance (Davis & Venkatesh 2004; DeLone & McLean 2002). Davis et al. (1989, p. 988) also identified that external variables for user acceptance could be system features, functional characteristics and organisational structures. From a practical standpoint, a significant link between system characteristics and attitude towards using a system needs investigation. To achieve effective development of the M-ECG DSS, four research sub-questions are addressed to identify potential functional/system characteristics that may influence users' perceptions and acceptance of mobile technology innovation in healthcare support. The concept of adopting mobile DSS for ECG diagnosis can be referred to Figure 1.1.

SQ1 What ECG functional characteristics are needed by users to improve acceptance of health technology for monitoring cardiac patients?

A number of information system (IS) studies have undertaken extensive testing of multidimensional relationships among the measures of IS success (Brown et al. 2002; DeLone & McLean 1992; Maryati et al. 2006; Wang et al. 2007). The question seeks to evaluate what the main ECG functional characteristics needed by users for cardiac diagnosis, and what the right system requirements are to be included to support patient diagnosis using the newer 12-lead ECG data. From the literature, the characteristics of a standard ECG are rhythms and symptoms detection, diagnosis interpretation and major transitions identification in an ECG chart and images. The question also seeks to establish if there are any other characteristics needed for diagnosis process. Recognising the difficulty of specifying the right system requirements is based on 'their own logic and intuition, designers are seeking methods for evaluating the acceptability of systems as early as possible in the design and implementation process' (Fred et al. 1989, p. 982). Health Canada (2000, p. 35) also stated that system requirements for remote diagnosis, follow-up, and education must be identified, and the technical capabilities of the system must be fully exploited. This sub-question helps to address the broader issue of improving acceptance of technology in healthcare delivery through providing information that a user needs for CVD care.

SQ2: What DSS system characteristics can be incorporated in a M-ECG DSS using mobile technology for monitoring cardiac patients remotely?

Delivery system characteristics, 'including poor coordination of care, long waiting times for appointments and inadequate numbers or kinds of specialists' in evaluating access to healthcare need to be considered in a telehealth evaluation framework

(Health Canada 2000, p. 24). Langley (1999, p. 358) also stated that ‘a software artefact improves its ability to interact with a user by constructing a user model based on partial experience with that user’. DSS adoption can be performed based on: ‘1) user data (various characteristics of the user); 2) environment data (all aspects of the user environment not related to users themselves; and 3) usage data (data about user interaction with the system)’ (Kobsa 1993, pp. 112-28). But what ECG functional characteristics can be applied and integrated in to mobile environment as well as a DSS for monitoring cardiac patients at remote locations? By using DSS design concepts (content adaptation, structure adaptation and presentation adaptation), users can be provided with on-demand, in real-time patient data, including past history, to help diagnostic decision-making. Thus, full patient data can be in the palm of a clinician. Understanding what ECG data is required (SQ1) and how it can be presented in a DSS interface is critical to acceptance. Thus, this sub-question seeks to evaluate DSS system characteristics to provide patient and ECG data (from SQ1) on a mobile platform.

SQ3: What M-ECG DSS characteristics are acceptable to deliver ECG diagnostic data to users for cardiac monitoring?

One objective of this research is to identify a set of acceptance characteristics that may influence the use of mobile technology in a healthcare environment. It is extremely valuable to understand carers’ acceptance of and satisfaction with using a M-ECG DSS for monitoring patients’ heart conditions by observing their behaviour. Therefore, this research will combine identified ECG functional and DSS system characteristics together to develop a M-ECG DSS and assess usage. Not having a traditional print-base plot as well as a small screen may reduce what can be viewed on screens. This may decrease acceptance of a M-ECG DSS. According to William (2000), there are a number of acceptability measures for evaluating developments of personal communications technology such as mobile phones. William also believes that personal telemedicine will become a major mode of healthcare delivery if patient and clinician acceptance, privacy and security, and supportive infrastructure are considered. To be acceptable, it is purported that the M-ECG system needs to present data in a decision support format that is ‘user friendly’ enough to approach ‘user behaviour’. This question will test the ‘usefulness’ of M-ECG DSS in its acceptance.

SQ4: Does the introduction of ubiquitous mobile technologies enhance ECG diagnostic capabilities remotely for cardiac monitoring?

Ubiquitous mobile technologies which ‘provide healthcare services at anytime anywhere have become more favourable nowadays due to the emphasis on healthcare awareness and also the growth of mobile wireless technologies’ (Pei-Cheng & Wan-Young 2011, p. 6799). Recent developments in mobile applications and new innovations in mobile operating systems (OS) such as iOS (iPhone OS) and Android (Google mobile OS) have the potential to offer mobility and ubiquity of services by using mobile technology to help monitor patients remotely. These technologies, in terms of being constantly within reach of the users and continuously connected to a broader communications network, ‘give them a unique status in the realm of technology support’ (Vogel et al. 2007, p. 557). Recent advances in mobile power, technologies and data communication are leading to possibilities of advanced telemedicine applications (Tam 2008). Little research has been published on whether the introduction of advanced technologies improves acceptance of technology in healthcare delivery. This understanding is less clear when it comes to use of ubiquitous mobile hand-held devices, particularly for remote monitoring of cardiac patients. Thus this sub-question asks whether ubiquitous mobile technology increases the acceptance of technologies and whether it could enhance cardiac diagnosis.

3.3.2 Conceptual Model

The research study uses a mobile phone network with ECG technology as an approach in collecting and analysing ECG data to help physicians diagnose patients faster and, in some case, mobilise resources in anticipation of a patient’s arrival at hospital, rather than commencing care upon arrival at a hospital or clinic. Even though Williams (2000) predicted that a mobile ECG device would become a major mode of healthcare delivery for cardiac patients, little progress has been made in the last decade due to patient and clinician acceptance and support of health technology.

This study uses several approaches, theories and models to develop a prototype M-ECG DSS and evaluate its acceptance.

The conceptual model for the study is developed for the following reasons. First, research and development using the new mobile medical concept 'has not been well-designed for mobile ECG real-time monitoring'. This is because 'the computing power and the advantage of current mobile operating systems have increased considerably' (Qiang et al. 2008, p. 320). Therefore, there is a need to develop new forms of delivery of health services as technologies increase to explore future applications. However, in order to provide a better DSS and increase mobile technology acceptance by health professionals, it is necessary to design and evaluate acceptance of different types of adaptive user interfaces. Kun (2007, p. 220) has stated that the role of causality of acceptance, in particular, needs to be tested within the context of a user interface and user acceptance of a system.

Second, little prior research exists on ECG DSSs that associate new mobile technology with current popular smart mobile operating systems (OS). Moreover, using mobile networks may create a level of latency in transmission of health data, which could influence the acceptance of using mobile technology but this does not appear to have been evaluated and published in the literature. The model that framed the development of the prototype M-ECG DSS is described in Chapter 4. Below is the conceptual model for testing its acceptance.

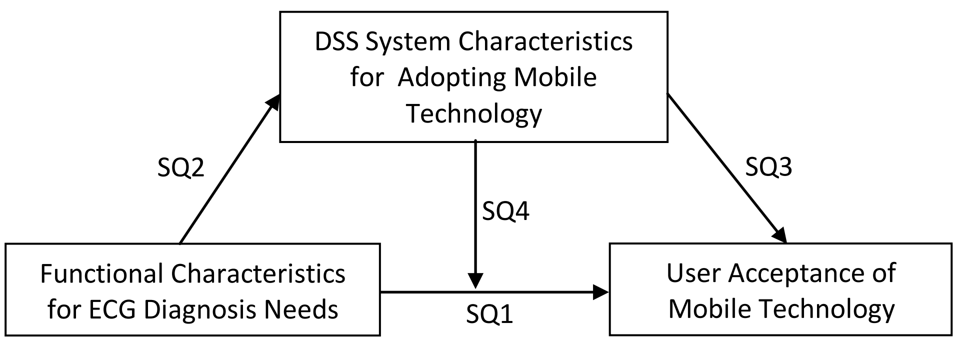


Figure 3.2: Conceptual model of this research

This study creates a conceptual model for implementing a DSS (Figure 3.2) in mobile health technology using the application of the prototype M-ECG developed in order to improve the quality of care for cardiac infarction sufferers. Hence, the research is not only able to identify ECG functional / DSS system characteristics but also test user acceptance. By implementing mobile technology to deliver ECG diagnosis, the conceptual model gathers together the significant technology acceptance models, which relate to mobile adoption and health acceptance factors discussed in Chapter 2. These portray possible relationships between functional / system characteristics and users to understand acceptance of IT use among individuals. However, it is unclear whether mobile technology and DSS positively mediate (SQ2, 3) or moderate (SQ4) the relationship between information needs (system characteristics) for ECG diagnosis and acceptance (SQ1).

The most frequently used theories are contained in the Technology Acceptance Model (TAM 1 and TAM2) and Information System Success Model (ISSM). Moreover, 'a number of individual factors are related to technology acceptance and use' (Anil 2010, p. 23). The conceptual model includes functional characteristics needed for ECG diagnosis to identify effects of end users' participation in the development process and encourage use of the system while adopting mobile technology (Figure 3.3). Details of measures used in each construct are explained in the research methodology section. Figure 3.3 shows general determinants of user acceptance conceptual sub-models (details are discussed later in Table 3.2).

In the conceptual sub-model, ECG functional characteristics are included to obtain the performance of DSS in mobile technology and count as variables for data delivery. 'Content quality of output, work relevance and subjective norm' are individual factors (Richard & Ben-Tzion 2010, pp. 160-1) for new technology implementation. Therefore, this research looks into 'perceived usefulness' and 'perceived ease of use' in order to indicate means of content and benefits of the support system, and the barriers and facilitators to the implementation of the system (Davis et al. 1989). The study examines the application functionality referred to as *'user behaviour'* with and *'user satisfaction'* of the system. Viewed from a technology acceptance theory with mobile adoption perspective, user behaviour and satisfaction are used to represent level of acceptance by measuring users' opinions.

Thus, this research divides behaviour and user satisfaction into seven mobile health adoption factors (Nesaar & Jean-Paul 2009) to form part of a generalised technology acceptance model to evaluate the delivery of telemedicine services.

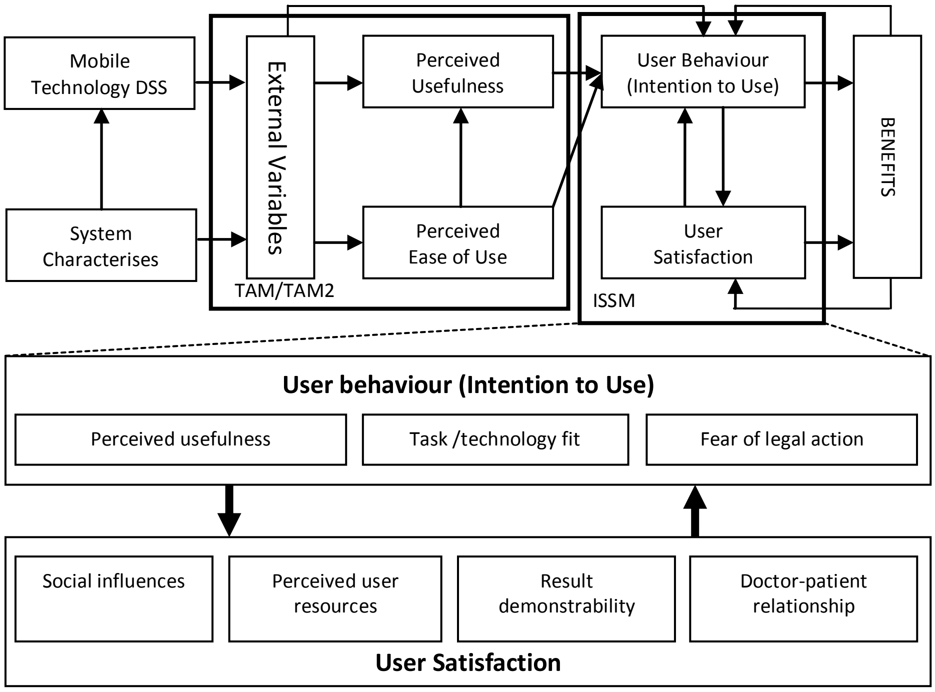


Figure 3.3: User acceptance conceptual Sub-Models

3.3.3 Research Propositions

The research posed four propositions that focus on characteristics needed in the research sub-questions: identifying ECG functional characteristics, and DSS sytem characteristics, acceptance of these characteristics, and mobile technology. The propositions addressed in this study directly focus on a particular aspect within the scope of the research to reflect the results of research questions posed.

> ***P1****: The ECG functional characteristics required and necessary for incorporation in a M-ECG DSS are to detect rhythms/symptom, to interpret leads, and to identify major transitions in the ECG charts and images.*

There is a wide range of normal variability in the 12-lead ECG. This study takes considerable ECG reading experience to discover all necessary ECG functional characteristics. This will help make this research a valuable clinical tool. The study also needs to consider the various ECG findings with the particular patient's clinical status for diagnosis. In addition, there are more and more clinicians requiring diagnostic assistance other than the standard ECG display. Therefore, a M-ECG DSS is developed as a diagnostic tool to help cardiologists, doctors and nurses and in their decision-making. This research identifies the ECG functional characteristics needed and integrates them into the M-ECG DSS for data presentation and cardiac diagnosis. The following proposition then focuses on using DSS concepts to incorporate identified ECG functional characteristics to support decision-making and increase quality of diagnosis.

> ***P2:*** *The DSS system characteristics that need to be incorported into a M-ECG DSS are to reduce time taken in diagnosis, provide ability to access medical history data, provide ease of use and enhance the performance of decision-making in change management processes of patients for day-to-day interactions.*

There are more and more clinicians requiring delivery of healthcare every day, so ‘the need for remote system[s] to deliver high quality, patient-specific information just when it is most useful continues to grow’ (Peter et al. 2010, p. 772). Pauline et al. (2010) also state that mobile DSS is a useful and time-saving tool for clinicians in healthcare when obtaining profiles of patients’ medical data. It is able to detect medication errors thus reducing diagnosis failures. One of the important goals in developing a user interface for mobile health DSS is to take special perceptual aspects into account so that this development can allow participants to use a DSS more efficiently, with minimal errors and frustration. By using DSS design concepts (content adaptation, structure adaptation and presentation adaptation), users should be able to benefit from several features in M-ECG to help diagnostic decisions, such as:

- real-time data delivery;
- scalable interface and ease of use;
- more accurate interpretation of data; and
- integration with all other patient information.

'The user interface should provide content adaptation by adaptive selection and prioritisation of the most relevant items when a user searches for relevant information and includes the adaptation of visible components layout' (Ekaterina et al. 2005). As a result, the introduction of an Adaptive User Interface (AUI) for mobile DSS could change the way health processes are managed and increase the quality of decision-making. AUI has the ability to interact with a user by constructing a user model based on practical experience of that user to create a better solution for a user-friendly interface and receive usage data (data about 'usefulness' and 'ease to use') (Langley 1999). This research identified DSS system characteristics for integration into a UI of a mobile health system to offer necessary patient data (identified ECG functional characteristics) for decision support and enable DSS to interact with users.

The function of a DSS is to explore methods and act as a tool to assist doctors in their clinical diagnoses towards best practices. Moreover, exploring the use of user-centred design by using an AUI technique for developing the requirement of DSS system characteristics is part of this research study to improve quality, structure and process of DSS delivery. To be successful, 'DSS should integrate into other wide applications such as electronic medical records, which satisfy the cultural, social and organisational pressures of the clinical setting and integrate into workflow' (Karin & Michael 2007, p. 760). Thus, the way of implementing DSS during the development process is likely to increase the interaction between the clinician and mobile technology and lead to successful diagnostic outcomes. It is important to invest adequate time in identifying DSS system characteristics for ECG best practice. The next proposition is created to identify acceptance of a developed M-ECG DSS.

> ***P3**: The ECG functional and DSS system characteristics identified in P1 and P2 respectively are acceptable to users based on observed behaviour and empirical data in a M-ECG DSS.*

In the field of technology acceptance research, the Technology Acceptance Model (TAM1 & TAM2) and Information System Success Model (ISSM) are the most frequently used in health technologies (Davis & Venkatesh 2004; DeLone & McLean 2002; Richard & Ben-Tzion 2010). These models help to analyse acceptance characteristics that influence IT adoption in a health service setting. Porn and Patrick (2002) and Hameed (2003) also identified functional / system characteristics of a mobile device needed in healthcare settings that could lead to successful implementation (Table 3.1):

Table 3.1: Systems needed in healthcare applications

Systems Needed	Description
E-prescription	This allows doctors to access basic patient information and check formulary compliance before writing the prescription.
Charge capture	This application allows a doctor to view schedules, capture patient charges and access or update patient information all at the point of care.
Order entry	Applications to order certain tests could be scheduled, and delivered to a central processing unit and acted upon. This will reduce errors due to misplacement of application forms.
Test result reporting	Test result reporting. The results of the tests can be delivered directly to the mobile device. This will free doctors from having to refer to a specific PC workstation to retrieve test results.
Medical information	Access to the latest medication formulary, disease description, symptoms and treatment as well as access to clinical procedures can be provided on a mobile device.

Sources: Hameed (2003), Nesaar & Jean-Paul (2009) and Porn & Patrick (2002)

In order to observe user behaviours in the usage of M-ECG DSS, this research looks at individual factors that may drive mobile technology adoption in CVD care. According to Nesaar and Jean-Paul (2009, p. 39), 'to realise the full potential and promise of healthcare information systems technologies and applications, a better understanding of the organisational context as well as people and social issues is required'. Thus, developing a M-ECG DSS involves both organisational and individual aspects such as *fear of legal action* from an organisational aspect and *perceived usefulness* from an individual aspect. Relevant acceptance factors for evaluation - identified from TAM and ISSM models in the health field (Davis et al. 1989; Nesaar & Jean-Paul 2009; Richard & Ben-Tzion 2010) - are shown in Table 3.2.

The research compares these acceptance characteristics and identifies specific acceptance factors for M-ECG DSS to determine the degree of confidence that it can add value. Consequently, this proposition (perceived from user behaviours) helps facilitate the implementation of a M-ECG DSS approach with increasing ‘usefulness’, ‘fit task/technology’, and reducing ‘fear of legal action’ (Table 3.2), in monitoring cardiac patients remotely.

Table 3.2: Acceptance factors from TAM and ISSM models in healthcare

Acceptance	Factors	Description
User Behaviours	**Perceived usefulness**	‘Defined as causing to enhance a doctor’s productivity by being relevant to her/him’
	Task/technology fit	‘Doctors would more likely adopt a new mobile technology if it fits closely with their current workflows’
	Fear of legal action	‘This helps reduce the possibility of incorrect diagnosis and treatment and perhaps legal action against a doctor’
User Satisfaction	**Social influences**	‘Doctors could influence each other by their opinions of the usefulness of device’
	Perceived user resources	‘Individual believes that they have organisational and individual support to use the device’
	Result demonstrability	‘The technology should improve a doctor’s quality of care and increase their effectiveness’
	Doctor-patient relationship	‘Influence of the use of a mobile technology device by **doctor’s perceptions** only’

Source: Davis et al. (1989), Nesaar & Jean-Paul (2009) and Richard & Ben-Tzion (2010)

> ***P4:*** *Delivering ECG data via ubiquitous mobile technologies adds perveived value and user satisfaction that could enhance CVD diagnostic capabilities.*

The M-ECG DSS is part of a medical telecommunication service which focuses on enabling mobility in healthcare delivery. With the ability to use mobile technology to access historical medical data and services, the M-ECG DSS looks at how to achieve *‘meaningful mobility’* in CVD care. As a recently released mobile health service study stated, ‘meaningful mobility is defined as native mobile technology that improves clinical decision-making at the point of care through data transformation and secure, real-time, and ubiquitous delivery of visually compelling intelligence by incorporating evidence-based medicine and knowledge-based prompts' (AirStrip 2011). The integration of mobile and ECG services may not only enhance satisfaction of a physician's decsion-making, but may also create value as mobile access provides remote real-time diagnosis.

This research focuses on increasing users' satisfaction with meaningful uses for decision-making and knowledge sharing. Thus, the proposition aims to examine technology acceptance from 'social influences', 'perceiving user resource', 'result demonstrability' and 'doctor-patient relationship' (Table 3.2) in a mobile health environment for the user to perceive value and satisfaction. Further research is required in this respect to provide a comprehensive understanding of ECG functional / DSS system characteristics and acceptance factors in developing a M-ECG DSS.

3.3.4 Research Design Summary

The study has outlined the research problem and stipulated the relationship among concepts in a conceptual model for the study. The research will identify needs of ECG functional characteristics and requirements of DSS system characteristics together to meet health practitioners' expectations; and to offer decision support in a mobile device. The study also tests technology acceptance to evaluate the delivery of telemedicine services and formulate the propositions in order to fill gaps in the literature and ECG practices, as well as gain insights to mobile technology adoption in the healthcare sector generally.

3.4 Research Methodology

This research is designed to identify characteristics of a M-ECG DSS and acceptance factors that improve the use of mobile technology in healthcare services. The research methodology used is mixed methods (qualitative and quantitative) to triangulate results and supports or reject propositions.

3.4.1 Methodology Design

Based on TAM and ISSM models, the research first identifies functional / system characteristics of ECG from literature and experience from specialists (based on interviews to explore cardiologists' ECG system needs). Gervasio and Langley (1998), Langely and Fehling (1998) and Thompson (2004) also identified best practice in building decision support systems for diagnostic programs in mobile environment. The research adopts adaptive user interface (AUI) concepts as artificial intelligence application for developing DSS. DSS concepts in mobile health service aim to include: 1) content adaptation, 2) structure adaptation (adaptive navigation support), and 3) presentation adaptation (Abidi & Han 2003).

This study aims to find a best solution to integrate ECG functional characteristics in a DSS application to improve decision-making and to display the appropriate ECG data for medical diagnosis. Thus, this research develops an initial prototype M-ECG DSS with an AUI and tests its stability, which is carried out in the lab. With regard to functionality, the DSS development grew with each successive version as interactions between components with selected mobile operating systems and DSS applications were tested. To be able to address the complexity, this research developed a highly scalable interface to meet mobile operating systems requirements and increased the ability to customise the interface to users' needs. From this stage, a new innovation was developed - *a digital multi-touch measuring scale tool* - to improve doctors' and nurses' ability to gain more accurate interpretation of ECG output in CVD diagnoses. This prototype M-ECG DSS not only covers every major function normally found in ECG devices but also enriches the interface by having the capacity to display, organise and parameterise ECG readings based on the specific process chosen by a user. The prototype also has the ability to retrieve previous ECG data so that a user can easily compare it with the current reading.

The M-ECG DSS development also combines mobile web browser (web app) and native app with DSS together for the first time to give health professionals non-delay access, fast interpretation (advantage of web app), offline support, and push notifications and multitasking features (advantage of native app) to support diagnosis on a mobile device. According to Rakkhi (2010), web app provides compatibility and scalability to users while native app provides use of device features, multitasking, better performance and offline use to users.

One of the metrics in developing an AUI that can be determined from testing the prototype is the average time that it takes a user to find any random element within a system menu (Alex et al. 2006a, pp. 2-3). Pilot testing the initial prototype M-ECG DSS with a focus group of cardiologists, doctors and nurses provided the opportunity to adjust functionality of the system with users' input. Cardiologists, doctors and nurses were then given opportunities to gain 'hands on' experience with the developed prototype M-ECG DSS. Based on feedback, refinements were made to functional characteristics. The DSS then revised to meet their expectations. According to Robert (2011, p. 751), a system design may analyse outliers to detect, measure and visualise spatial correlation from small data sets. Therefore, development of the prototype M-ECG DSS continued using small groups of clinicians until results obtained were similar, emphasising perceived *'behaviour'*, *'satisfaction'* and intuitive digital ECG measuring tools. In addition, the functionality, content and benefits of M-ECG DSS were evaluated to see if they met doctors and nurses' expectations.

User evaluations were carried out using mixed methods with samples of users in Taiwan and Australia. Their attitudes towards technology acceptance were measured using Nesaar & Jean-Pual's (2009) mobile health adoption factors based on Davis's (1989) TAM model and DeLone & Mclean's (1992) ISSM model theories. *Satisfaction* is defined as a technology acceptance of the DSS and identified ECG functional characteristics. Observed individual *behaviour* using the DSS has been generalised as intention to use system. The research methodological design is described in Figure 3.4.

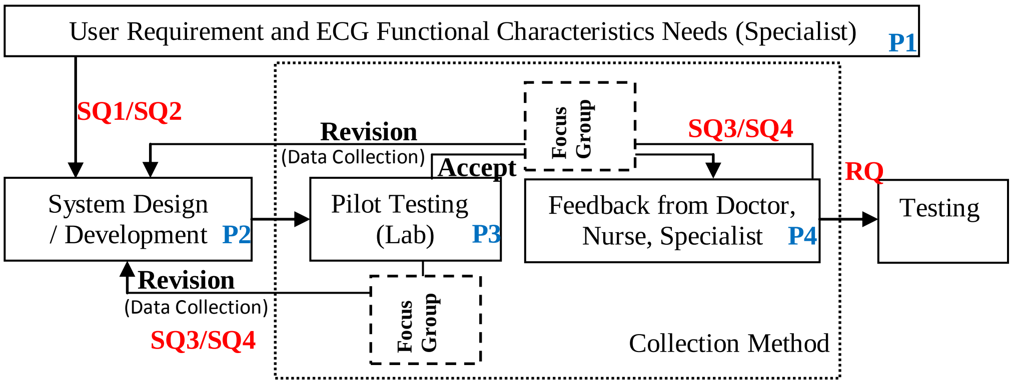


Figure 3.4: Design of the research methodology

3.4.2 Data Collection

Before data collection, the researcher conducted pilot testing of a M-ECG DSS to evaluate the need for ECG functional and DSS system characteristics in order to provide a better solution for mobile delivery. A study of a multinational organisation is used to gather data on events to describe how individuals experience a specific phenomenon (Yin 2008). Data collection methods employed in this research encompass interviews and surveys from the selected health organisations. This study approach facilitates understanding context-specific attributes and inter-contextual relationships in the healthcare domain.

Pilot testing of M-ECG DSS

According to Robert and Reiss (2007, p. 8), the protocol for operationalizing pilot testing addresses the parameters to be analysed, equipment to be tested, operational procedures, the start-up/shut-down/cleaning procedures, and testing matrix. A pilot study is a representation of the project vision and serves as a key planning tool to fill in details related to finance, design, and public outreach (Robert & Reiss 2007, pp. 2-3). During the development of a prototype, conducting a qualitative pilot study is suggested as an effective means of initiating wider development. Based on feedback, the pilot prototype is modified and evaluated by users to arrive at a more acceptable solution.

According to Barbara and Michael (2000), the process of conducting a pilot test consists of:

1. development of a preliminary structured application;
2. testing the validity of an application using a small number of users;
3. observations of the system in use and documenting reactions;
4. analysis of pilot test data to modify system based on feedback;
5. redesign or modify application; and
6. back to step 2.

The study developed a mobile application interface based on AUI principles to build the prototype M-ECG DSS. Oppermann (1994, pp. 98-9) states that AUI consists of ‘three high-level components: 1) observes and records user’s behaviour and system reactions; 2) analyses recorded data to draw conclusions and decide how the system should adapt to the user; and 3) adapts the system’s behaviour to the user’. The purpose of conducting pilot testing is to identify the appropriateness of selected mobile application platforms and the technical robustness of the system, as well as the user interface (decision support system) and ability to replicate or enhance what users normally receive from current ECG devices. Robert and Reiss (2007, p. 10) state that the specific information obtained through pilot testing can be leveraged to answer questions in almost all areas of project planning and can move a project to the next level of completion.

Samples

A small number of users were selected from clinical staffs including cardiologists, doctors and nurses to undertake pilot testing in the second stage. Data was then collected through semi-structured interviews with doctors and nurses who have ECG experience in hospitals. This approach enabled further refinement of the propositions while the research was in progress (Bryman & Bell 2007; Veal 2005). The sample size was limited, but mobile health technology development usually involves a small number of participants due to the need to instruct and provide support to participants (Lindquist et al. 2008, p. 31).

The research sample is based on the most appropriate in view of the purpose of the present study selection. This study carried out interviews in three medical departments (Intensive Care Unit, Emergency and Cardiology) and three different hospitals, which deal with cardiac patients. There are two criteria for sample selection in this research. First, participants have experience in remote diagnosis as well as using mobile technologies in medical services or are interested in using mobile healthcare in the near future. Second, participants need to be a medical specialist who has good knowledge of cardiac diagnosis or has provided medical treatment for cardiac patients. With these criteria and selection guidelines, there are only a few departments dealing with cardiac patients regularly in hospitals such as Intensive Care Unit (ICU), Emergency Department (ED/A&E) and Cardiology Department (CD), therefore, this research has selected doctors and nurses in those departments for interviews. Cardiologists, doctors, and nurses were chosen as respondents in selected hospital during the time of data collection; and no real patients were involved. This approach of using qualitative method 'makes it possible to consider and understand the phenomenon from the participants' point of view (Denzin & Lincoln 2000, p. 643).

This way, a view to generating insights from individuals is expected to provide rich information based on their knowledge and experience rather than attempting to draw a representative sample (Gall et al. 1996, pp. 154-5; Patton 1990). Interviews were conducted to meet seven technology acceptance factors (Table 2.3) to gain an understanding of differences across three statuses (cardiologists, doctors and nurses) in three departments (ICU, ED and CD). Therefore, interviewing cardiologists, doctors and nurses continued until such time that no new information or future discussion emerged.

This research selected Taiwan and Australia for comparative purposes to evaluate acceptance under ECG diagnosis. According to Jonathan (2009), 'Taiwan has one of Asia's most highly-praised health systems'. Moreover, 'Taiwan has moved energetically into the 'next generation' of mobile technology and services over the past decade and entering 2011, and is a country leading in mobile technology use' (Paul Budde Communication Pty Ltd 2011). Taiwan's advanced telecommunications networks have created opportunities to evaluate the acceptance of mobile health services. In addition, a disease surveillance team has been organised and used to establish a hospital emergency department-based syndrome surveillance system (ED-SSS) capable of automatically transmitting patient data wirelessly from the hospitals responsible for emergency care throughout the country to the Centres for Disease Control in Taiwan (Taiwan-CDC) (Tsung-Shu et al. 2008). Prior research (Jen-Her et al. 2007, p. 66) in Taiwan also found out that Mobile IT/IS applications in healthcare can be recognised as both emerging and enabling technologies to apply in several countries for emergency care or general healthcare.

In contrast, Australia faces growing pressures on healthcare because of technological changes, new models of mobile care, increasing patient expectations and, an ageing population among other things (Department of Foreign Affairs and Trade 2008). However, 'a recent survey revealed that 94 per cent of GPs in Australia are computerised and nearly 80 per cent use broadband connections' (Ochre Media 2011). Moreover, Australian government's emphasis on expanding mobile coverage and funding of IT education has had an impact on the growth of telehealth (Ochre Media 2011). The use of mobile health in Australia is however patchy. Therefore, there are opportunities to expand the use of mobile technologies to improve health service delivery to the many sparsely populated areas of the country. While mobile technologies are being increasingly used in Australia, 'the novel use of wireless technologies, mobile phones and the Internet have potential to allow a more flexible approach to cardiac rehabilitation programs' (David et al. 2011, p. 4). There are lessons that can be learnt from Taiwan's mobile healthcare. Their frequent use of mobile technologies in healthcare provides this research with valuable comparisons with the less sophisticated use in Australia. Thus collecting data from medical specialists in Taiwan and Australia to test acceptance has been well justified.

Instruments and measures

In addition to notes taken during observations of use of M-ECG DSS, three sets of data collection instruments were employed. *Instrument set A* is a questionnaire focussed on acceptance of a M-ECG DSS. *Set B* is an interview checklist to gather a user's demographic data. *Set C* is a questionnaire to identify ECG needs and motivations of technology acceptance for cardiac diagnosis.

Instrument set A (Appendix C^A) is a questionnaire for evaluating acceptance of new mobile adoption from a doctor or nurse's point of view. This is administered after use of the device. Items are grouped under sub-headings to help respondents gain an easy grasp of questions asked (Zikmund 2003). The questionnaire is divided into two categories (user behaviour and user satisfaction) to identify different acceptance factors, such as *usefulness, social influences, user resources, technology fit, result demonstrability, fear of legal action and doctor-patient relationship.* Measures in the questionnaire are used to collect data on views of users' attitudes toward using a M-ECG DSS. The research uses this method to narrow down a very broad field of research into DSS to evaluate mobile technology acceptance in ECG diagnosis. To enhance validity, items in the instrument were adapted from prior cardiac health studies (Afsar 2007; Joanne 2006; The Medical News 2009) and a mobile technology acceptance study (Nesaar & Jean-Paul 2009) in the health environment. The research selected relevant items and modified wording and response formats for instrument set A to the study context. However, instruments used in these previous studies (Afsar 2007; Joanne 2006; The Medical News 2009) have not yet been used to measure mobile health adoption in the ECG diagnosis area. A 5-point Likert-type scale with response options ranging from 'Strongly Agree' (coded as 5) to 'Strong Disagree' (1) is adopted. Using this type of scale, respondents are able to provide opinions at varying levels of acceptance.

Instrument set B (Appendix C^B) consists of interview checklists employed to collect information from health workers. This method provides more realistic responses to fit an entire research purpose. According to Rebecca and Dawn (2010, pp. 412-4), doctors and nurses are increasingly using computerised decision support systems to support their practices. Several studies (Atoui et al. 2006; Chiarugi et al. 2008; Karin

& Michael 2007; Robert et al. 2011) have highlighted important factors that contribute to successful implementation of new technologies in mobile healthcare. In addition, health and medical decision makers need accurately, timely information during diagnosis and treatment (Geoffrey et al. 2008, p. 778). Also, ECG diagnosis and decision support functions are important contributors to reduce 'Dead on Arrival' (DOA) cases and time taken for urgently needed diagnosis (Georgios & Ivan 2008, pp. 778-80). Therefore, the design of instrument *set B* is based on these factors. The interviews with hospital members of three different professional medical associations supplemented results. An interview with a participant from cardiology took about 1 hour; and with a doctor or nurse it took about 40 minutes. The purpose of using these time frames in interviews is to gain a more thorough understanding of a cardiac situation or specific cases, which could reveal richer information about cardiac disease and how a M-ECG DSS could improve diagnosis with subsequent acceptance of mobile technologies in health delivery.

The questions in *instrument Set C* (Appendix C[C]) is focused on evaluating the needs of ECG functional characteristics and motivations of technology acceptance. The interview questions are built based on literature, and guide the direction of data collection and analysis. The variables of technology acceptance factors are identified from Nesaar and Jean-Paul (2009) and explored from multiple sources of evidence. Analysis of data collected on variables will help validation of research propositions.

Participants were asked about their involvements in medical instrument conferences in relation to new healthcare service, new mobile medical technology acceptance interest and attitude towards mobile adoption. Interviews lasted 45 minutes on average; minimum and maximum durations were about 40 and 70 minutes respectively. The interviewer asked all questions as presented in the interview checklist. Interviews were digitally recorded to ensure accuracy of transcription and supplementary notes were made of non-verbal behaviours during use of DSS. All recordings were then transcribed on the same day of each interview and focus group data were collected between November and December 2010 in Taiwan and between February and April 2011 in Australia. Users practised using the M-ECG DSS with guidance from the interviewer. While using the M-ECG DSS, a user was asked questions about the capability of the M-ECG DSS to provide diagnosis support using the multi-touch function, ease of viewing therapeutic records, and acceptance of the device for mobile adoption in cardiac care.

This research aims to add to current knowledge of the determinants of the TAM and ISSM models for qualitative data analysis. The approach used was able to identify external variables: *'perceived user behaviour'* and *'perceived user satisfaction'* (Davis & Venkatesh 2004, p. 46) from M-ECG DSS adoption. Figure 3.5 shows components of a multiple level independent variable (department and status) to predict the value of a dependent variable (technology acceptance factors).

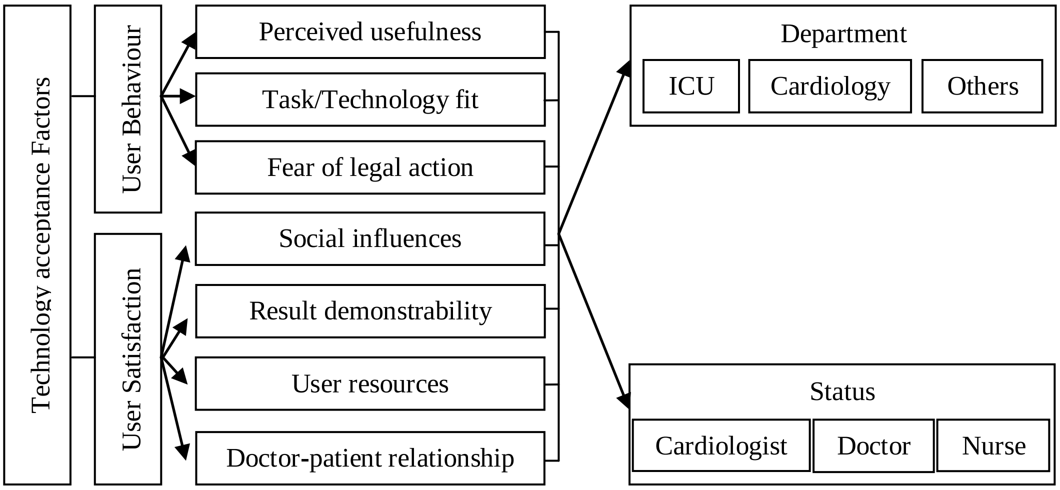


Figure 3.5: Multiple level of dependent and independent variable

In addition, the result also considered aspects of decision-making in a medical environment to fit the attributes of the individual user and the decision support processes. In the case of developing M-ECG DSS, it was used to ensure that benefits for doctors and nurses in medical diagnoses can increase user acceptance of the devices. Therefore, the study population consisted of cardiologists, doctors and nurses who have knowledge of remote medical diagnosis and have used pre-hospital (medical diagnosis before arriving hospital) services.

Collection methods

Yin (1984, p. 23) explains 'the qualitative study method as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used'. She also suggests that a qualitative study is not intended to study an entire organisation but rather, is intended to focus on a particular issue, feature or unit of analysis. In addition, 'to investigate the phenomenon of intrinsic motivation in technology-supported environments, it can examine factors that support individual intrinsic motivation in discussions' (Shroff et al. 2008, p. 111). Many organisational features appearing to facilitate the successful use of DSS across four different areas, including the role of clinical involvement, hospital strategies for procurement, and evaluation and implementation of information technologies (Geoffrey et al. 2008; Guilan et al. 2008; Rebecca & Dawn 2010; Syeda-Mahmood et al. 2007). Therefore, this research uses quantitative method to triangulate results of acceptance of new technologies in the process of decision-making and implementation of IT systems. According to Patton (2002), at the simplest level, a questionnaire or interview that asks both fixed choice questions and open-ended questions is an example of how qualitative inquiry and quantitative measurement are often combined. In addition, small refinements to the development of the M-ECG DSS are based on collected qualitative and quantitative data results.

The mobile acceptance adoption factors in medical services consist of two types of scales: *behaviour* (three factors) and *satisfaction* (four factors). This research aims to simply evaluate participants' responses for each factor throughout a whole interview process and thus may lead this research to the underlying importance of each factor (advantage and disadvantage). This procedure helps to strengthen the validity of the inferences made from the data to support qualitative data analysis.

Cardiologists, doctors and nurses who have knowledge on remote medical diagnosis and have used pre-hospital (medical diagnosis before arriving hospital) services are interviewed to obtain multiple perspectives on the research problem. Different levels of responsibility to healthcare from specialists were studied to facilitate detailed analysis of the influence of mobile implementation across various hierarchical levels. This approach was chosen for this research because of the broader relevance and significance of the findings to mobile implementation as well as potentially for other developments within similar research (Bryman & Bell 2007). This multi perspective approach is employed to induce increased understanding of the research study and findings (Bryman & Bell 2007; Yin 2008).

According to Richards and Schwartza (2001), interviews is the commonest qualitative method in health services research and particularly well suited to the collection of data on sensitive topics. In-depth interviews provide ‘an opportunity to obtain more detail about an issue or experience’, and are especially useful for exploring experiences of healthcare (Pope et al. 2002). Therefore, the qualitative method of face-to-face semi-structured interviews was employed. The interviews continued until such time that no new information or future discussion emerged.

This research focuses on the perspectives of cardiac diagnosis from doctors’ and nurses’ points of view under the same conditions using a prototype M-ECG DSS. Aware of doctors and nurses’ workload and concerned about M-ECG DSS best practice, this study sent out project details and system information before the interviews was conducted. In addition, interviewees were allowed to select the venue where they felt most comfortable to discuss and disclose their ideas. Denzin and Lincoln (2000) illustrates that in-depth interviews is identified as an excellent method in investigate participants’ experiences and idea. Norman and Yvonna (2003, p. 83) state that ‘interviewees can show their human side and can answer questions and express feelings using face-to-face in-depth interviews’. Most of the interviews were conducted with single respondent; however, by respondents’ request, two or three respondents were interviewed together at the same time. Interestingly, the majority of participants chose to be interviewed in a hospital during their work break. Therefore, this research integrates with other procedures to strengthen causal inferences for acceptance.

3.4.3 Data Analysis

The data analysis consists of qualitative and quantitative methods to evaluate each proposition from the interview and survey data. As the number of participants is small, basic quantitative analysis is undertaken. This analysis is used purely to triangulate findings from in-depth interviews.

Mixed methods

A combination of qualitative and quantitative approaches is recommended to triangulate findings (Daniel et al. 2005, p. 36). Qualitative data helps this research evaluate technology acceptance by exploring participants' responses from in-depth interviews. In-depth interviews remain an important tool for researchers exploring more directly how individual-level cognitive processes and effects relate to message characteristics (Daniel et al. 2005, p. 9).

Using quantitative data analysis in this study is the systematic and replicable examination of symbols of communication, which can be assigned numeric values according to valid measurement rules, and the analysis of relationships. This involves values using statistical methods, describes the communication, draws inferences about its meaning and infers from the communication to its context, both of production and consumption (Daniel et al. 2005, p. 33).

The use of both methods is also considered to provide counter-balance to limitations of one approach to another and increase reliability of results. This approach enables detailed interpretation to help understand research findings. As Miles and Huberman (1994, p. 42) also believe, both qualitative and quantitative data analysis can be productive for descriptive, reconnoitring, exploratory, inductive and opening purposes. Based on these approaches, this research describes a study in which variables were chosen and 'measured' after the messages were observed. Thus, the decisions on variables and measurement were made before the observations began (Kimberly 2002, p. 11).

According to Kimberly (2002, p. 12), the entire process of in-depth interview may be viewed as a combination of induction and deduction. There are four important and fundamental principles of measurement techniques, which enhance understanding of qualitative studies.

> **Reliability**: Reliability has been defined as the extent to which a measuring procedure yields the same results in repeated trials. Without acceptable levels of reliability, in-depth interview measures are meaningless (Carmines &

Zeller 1979, p. 124). This enables the study to indicate the level of agreement among two or more factors.

Validity: Validity refers to the extent to which an empirical measure adequately reflects what humans agree on as the real meaning of a concept. Determining the validity of a given measure can be described as a theoretically oriented problem, because validity assessment involves the assessment of the extent to which an indicator is useful for a particular purpose, rather than the extent to which it is universally ‘true’ or reliable (Paul 1998). Thus, validity is only meaningful in the context of a particular set of underlying concepts; a given indicator may be highly valid as a measure of one concept but may have little or no validity as a measure of another (Carmines & Zeller 1979, pp. 15-7). Assessing the validity in this research requires a focus on the extent to which data set is a meaningful representation of the research objectives and underlying the issues to be captured.

Generalizability: Generalizability of findings is the extent to which they may be applied to other cases, usually to a larger set that is the defined population from which a study’s sample has been drawn (Myers 2000). After completing data collection and analysis, this research seeks to apply findings to other cases of acceptance of mobile technology in medical services.

Replicability: The replication of a study is a safeguard against overgeneralising findings of one particular research study. With enough planning and detail in designing coding rules and procedures, a careful study should be able to produce a reliable measure that can be replicated quite accurately by another study (Paul 1998).

Based on the above discussion, participants’ responses were identified for a variety of acceptance characteristics based on an overall intensity index from interviews for qualitative data analysis.

Qualitative data analysis

In the qualitative approach, data was collected using in-depth interviews. According to Cavana et al. (2001), a great advantage of interviews is that they take less time while removing conversation barriers and encourages the flow of information. Qualitative data analysis of this research demonstrated how the complex and context-based raw data was transformed into meaningful and convincing interpretations. This study was conducted with in-depth interviews manually, which involved the researcher's experiences, perceptions, judgements and understandings to interpret the interviewees' responses. The research organised interview data by factors. Participants' comments (pre-determined/determined by specific factors) emerged in each interview to a variety of questions and were important to the factors used for the responses from the questions.

This research was conducted using a small number of interviews requiring the researcher's comprehensive interpretation of the responses from interviewees, as well as extracting emerging developments enlightening this research. A qualitative data analysis software package is unlikely to achieve the comprehensive understandings required by this research (Myers 2000). According to Easterby-Smith, Thorpe and Lowe (2002, p. 129), qualitative data analysis with a computerised software package is likely to overlook the 'understandings of the quality of ideas and experiences'. Therefore, to interpret specific and proper descriptions in a comprehensive and systematic way, this study conducted the qualitative data analysis manually.

Data are expected to group around seven factors (Table 2.3) making up aspects of acceptance. Seven factors represent the key contributors to acceptance and perception of the M-ECG DSS. This method is used to determine the presence of key words, concepts and categories within text (Arnit 2004) to identify each variable that plays a role in user acceptance of mobile health technology.

Quantitative data analysis

One way to measure reliability in this research is to measure the percentage of agreement with each factor (Weber 1990, p. 15). Thus, adding up the number of agreement or disagreement to each variable and dividing by the total number of cases is used to generate a mean rate of agreement. This instrument has been used generally to evaluate technology acceptance factors by different departments (ICU, Cardiology, Others) and status (Doctor, Nurse) and it is conceivable that the test is able to provide confirmatory information on user behaviour and satisfaction.

As the sample is small, analysis can only show basic trends and help triangulate findings from qualitative analysis. Quantitative data were collected though *instrument Set A and C* from four hospitals and departments from cardiologists, doctors and nurses. Analysis of the data generated from surveying different departments and professional status was conducted using nonparametric statistics. The method gives approximately unbiased and statistically consistent estimates of the proportion of all data in each category (Daniel & Gary 2010, pp. 229-30). Figure 3.6 shows how the individual acceptance factor is classified by departments and status and produces the aggregate proportion of each factor within each category.

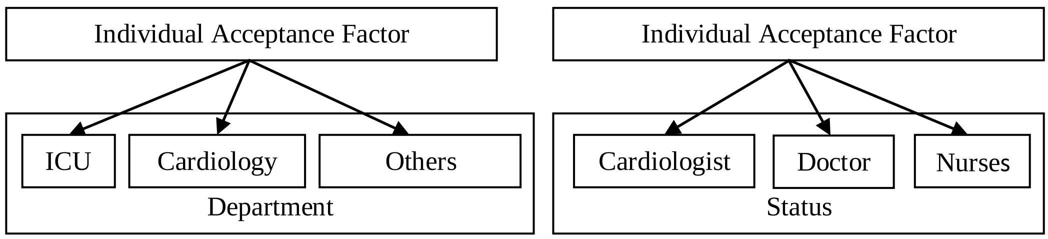


Figure 3.6: Individual acceptance factor classified into departments and status

When participants responded or expressed their vies to particular questions, statistical analysis will be used to compute descriptive statistics. Selected participants were those with knowledge of remote medical diagnosis and who have used pre-hospital services. These factors are based on their attitudes toward using devices and their satisfaction levels. It is uncommon for them to receive neutral responses from users. Category NA occurs commonly if a participant is talking primarily about something rather than the subject of the research. This coding scheme represents the users' attitudes towards and behaviour from using the prototype M-ECG DSS. A fuller explanation of this aspect is provided in Chapter 5.

3.4.5 Ethical Considerations

For this research, the user group is defined as clinicians and nurses. No actual patients are involved. It uses synthetic electronic records so that the system developed can be tested to see how well it distributes a patient's detail to clinicians. Implementing and analysing a M-ECG DSS to provide better diagnosis would be extremely valuable, providing validation of the conceptual model developed.

According to Australian ethical protocols (NHMRC 2011), no statement from an ethical commission was needed because the research did not focus on real patients. Ethics approval was obtained from University of Southern Queensland Ethics Committee and individual cardiologists, doctors and nurses in 2010 for attitude scale and testing. Basic principles of research ethics relating to general ethical guidelines and legislation on healthcare studies were followed (NHMRC 2011; World Medical Association Declaration of Helsinki 2008). Approvals were obtained from hospitals and cardiac surgeons to undertake interviews and surveys. Ethical considerations, the selection of research topic and future publication of research findings have been emphasised in this research. The M-ECG DSS development and its acceptance were chosen to address end user concern in mobile health technology adoption and ultimately enhance the deliverability of a system that provides a 'decision-making' tool, which meets the needs of the end user. The purpose of the research is to improve the quality of cardiac care and increase ECG monitoring access to support specialists' competency in diagnoses.

Participation by healthcare workers was voluntary and they could withdraw at any time without fear of any consequences. This is clearly stated in the Participant Information Sheet and Consent Form. The consent form for interviews/ focus groups was delivered to the targeted interviewees before interviews were conducted. Interviewees were given enough time to decide if they were willing to participate in this research. In order to enhance the reliability and quality of interview data, digital recordings were taken during interviews. However, if interviewees felt uncomfortable about recording sessions, the researcher took notes instead. Consequently, at the beginning of each interview, interviewees were asked whether they would allow recording. Ethical procedures adopted ensure confidentiality of participants' information.

(1) Interview data collected and stored in a coded form.

(2) Conclusions of the study are drawn in aggregate terms.

(3) All data collection (including interviews), data coding and data analysis are undertaken personally by the researcher.

The researcher is an outsider to organisations involved in this research; in this way, 'the research is able to contribute to a confidential atmosphere and a neutral attitude towards the study during data collection and analysis' (Polit & Beck 2004, p. 334). The interview was accompanied by a covering letter including research information and objectives; outlining the procedures and risks involved in taking part in the research; and interviewees have a right of consent to participate (NHMRC 2011; World Medical Association Declaration of Helsinki 2008).

3.5 Chapter Summary

The chapter provides a description of the research design and methodology used. The research design outlines the research questions, links the relationships among concepts in a conceptual model, defines general mobile technology acceptance variables and states research propositions. The conceptual model is developed from TAM and ISSM models. The research propositions test the model to evaluate the prototype M-ECG DSS and its acceptance to answer the research sub-questions. Methodology includes data collection from health workers using interviews, focus groups, observations and questionnaire. Interview data are content analysed while survey data are used to triangulate findings from interviews, focus groups and observations of use of M-ECG DSS.

The research methodology discusses data selection, sample selection and data collection procedures as well as pilot testing a new M-ECG DSS. The research sample is based on the most appropriate in view of the purpose of the present study. In depth interviews and statistical methods are described in data analysis. Before in-depth discussion of qualitative and quantitative analyses, the following chapter (Chapter 4) provides details of M-ECG DSS development and its architecture design.

Chapter 4 Decision Support System and Architecture Design

4.1 Introduction

In order to build a mobile decision support system application, potential examples or styles that could be used have been sought. One of the ways to develop a complex model of decision support systems (DSS) is to make the support readily available through multiple, different user interfaces and to determine the degree of confidence that users have in using the application. The main research objectives and design of propositions were based on how adapted mobile technology which incorporates a decision support system can help and improve cardiac diagnosis. According to the roles of decision support systems in cardiac care (Chung & Hsueh-Ming 2009), the prototype development would need to focus as much as possible on the medical users' needs such as: (1) analysis of diagnostic examinations; (2) early detection of deteriorating health of patients; (3) evaluation of the severity of heart failure; (4) identification of suitable pathways, and (5) planning of adequate patient-specific therapy.

The development of mobile DSS uses adaptive user interface (AUI) to interact with a user by constructing a user model based on practical experience to improve user experience for learning and obtaining high asymptotic performance (Langley 1999). Artificial intelligence methods in mobile devices have been used in decision support systems; and diagnostic programs and other methods have adopted AUI as best practice in building decision support systems (Gervasio & Langley 1998; Langley & Fehling 1998; Thompson 2004). This research uses this approach of unobtrusive personalisation to develop a prototype M-ECG DSS that automatically learns about users from interacting with them. These include an adaptive ECG monitoring system, a personalised ECG study reference, an adaptive digital multi-touch measuring tool, and a real-time mobile ECG signal tracker. It helps doctors and nurses to identify cardiac symptoms in patients. This study focuses on a smart phone OS environment that makes the construction of such decision support interfaces efficient and effective. However, this research also developed a more diverse version of M-ECG DSS to provide a better solution in a smart mobile platform. The chapter begins with the role of decision support systems knowledge to provide a pattern to design and implement the M-ECG DSS. Then a description of how the diagnosis strategy of the DSS is implemented in the mobile application is provided. This includes a description of its main application modules and a discussion on the design of the AUI. This is followed by professional feedback from cardiologists in order to identify the roles for CVD diagnosis, followed by a description of the evolution of the M-ECG DSS application. This research would need to undergo different stages of pilot testing before it can be accepted for use in clinical practice.

The chapter uses the following structure to underpin the mobile development and its design.

- Mobile software and application
- System architecture (web and native applications)
- User interface design
- ECG signal analysis
- Digital multi-touch measuring scale tool development
- Decision support system implementation

With an innovative **digital multi-touch measuring scale tool**, a M-ECG DSS gives health professionals the first opportunity to interpret amplitude of signal for more accurate diagnoses on a mobile device (refer to Figure 4.19). Moreover, this prototype provides the ability to analyse any heart condition under different network conditions by using a combination of web and native applications (apps). This chapter describes a portable decision support system with mobile technology capabilities for the processing, storing and visualisation in real-time ECG signals to smart phone devices.

4.2 Mobile Software and Application

In order to employ the mobile software and application, the MVC (Model View Controller) software architecture model has been used to divide each function for running the application. It considers an architectural pattern used in software engineering. MVC pattern creates applications that separate the different aspects of the application, such as ‘input logic’, ‘business logic’, and ‘UI logic’ (Enode Inc 2002). According to Garlan (1994, p. 726), it is normal to split an application into its main functional objects. Moreover, a system design that allows designers to exploit recurring models of system organisation is extremely useful during development of applications. The MVC pattern hinges on a clean separation of objects into one of three categories - models for maintaining data, views for displaying all or a portion of the data, and controllers for handling events that affect the model or view (Enode Inc 2002). The M-ECG DSS uses this concept to separate objects/classes to create multiple views and controllers with the same mode. As a function of using MVC, this application is able to provide new types of views (interface) and controllers (ECG signal analysis) that can interact with a model without forcing a change in the application design itself. The mobile ECG DSS software architecture abstraction can be graphically represented in figure 4.1.

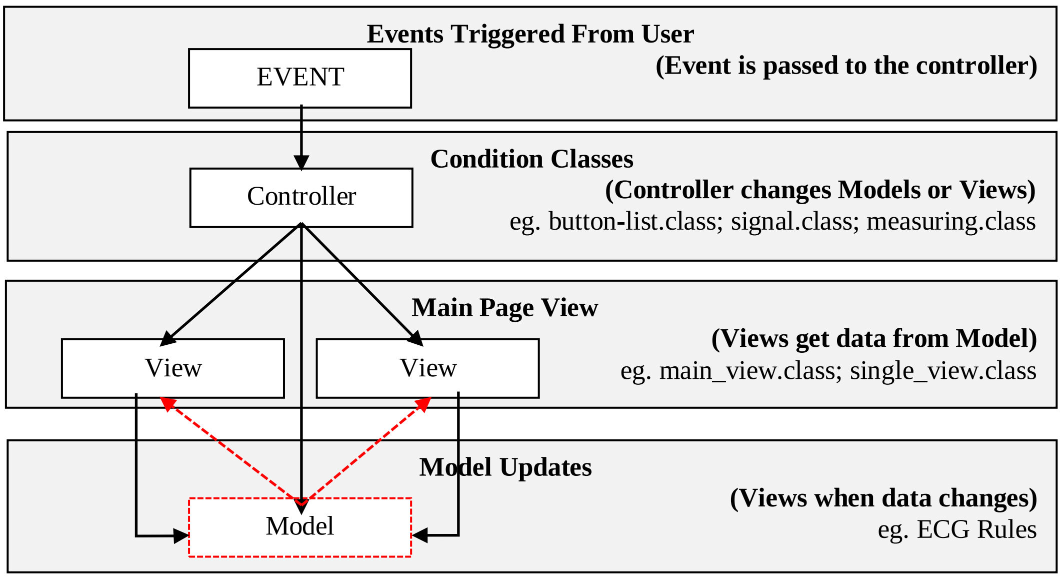


Figure 4.1: Model View Controller diagram of the M-ECG DSS
Source: adopted from Enode Inc (2002)

The *model* is a knowledge based set of ECG rules and it processes for manipulating an application. The *controller* operates to provide the specific function for viewing an application. When a page view is required, a controller will act as a bridge to call a class and obtain data from a model for viewing. The *view* is responsible for the dialogue and interface with a user and gets its feedback from a controller. For example, when launching the M-ECG DSS application, an *event* has been triggered and calls a *controller* (button-list class) to provide data used in a decision support interface. In the decision support system, the model consists of experts' rules of ECG diagnosis that have been encoded in DSS in the application. Thus, ECG data is held in a model that is shared with the button field. A button field provides a view of the current value. Each button-list is an event source that is able to be actioned every time it is clicked. *EVENT* receives activity requirements and routes them to an action listener (controller) that eventually handles an event. For example, when the ECG lead II (button-list) is clicked, the *event* has been triggered again and calls the signal class (controller) to calculate ECG data to present an ECG lead II waveform and change the model for viewing. Figure 4.2 shows an example of an action event.

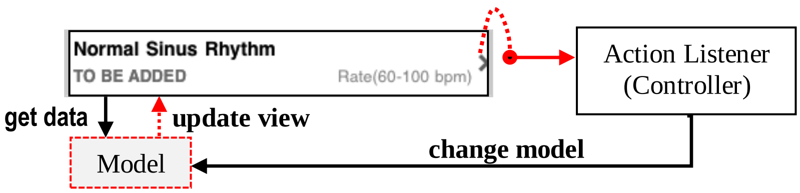


Figure 4.2: Example of an action event

4.2.1 Mobile Platform Applicability

The decision support system interface is the point of contact between the user and the application itself. When designing the M-ECG DSS application, consideration has been given to using a familiar style so that a user is able to take advantage of human recognition. This design guideline was followed in this research for developing the user interface of decision support system in a mobile environment. In addition, the mobile decision support system was derived from cardiologists' requests and feedbacks received early on in the research. Based on what specialists need and mobile technologies' capabilities for launching all DSS functions, there are limitations to display the application in a mobile browser using current mobile devices. One of the major developments from this project is an interpretation of ECG signals. As a consequence of one of the gaps in the literature review, there is a need to measure various components of the ECG using measuring tools in order to diagnose ECG arrhythmias, conduction blocks, and other abnormalities. Thus, this research decided to use a multi-touch approach applying three dimension layers as a measuring scale tool for interpreting ECG signals. Currently, there are only a small number of smart phones that have these capabilities to meet this condition. The following specifications are required for launching the M-ECG DSS.

- Mobile browser with HTML5, JavaScript and CSS3 enabled.
- Support multi-touch interaction on mobile screen panel.
- Able to provide a location service (included GPS module).
- Allow for auto screen rotation (included G-sensor).
- High speed data transmission (HSDPA/ 3G transmission).

This study aims to use 3G/mobile network as a transmission intermediary to transfer ECG data. According to the above specifications, this research selected iPhone and Android devices as testing platforms to develop the prototype M-ECG DSS because these devices have the ability to provide and run all functions required. The study did not select Window Mobile as a testing platform because it fails to support some of the above specifications such as multi-touch interaction using HTML5.

4.2.2 Fixable Application in Mobile Operating System (OS)

Slow or lost data connections happen sometimes while using mobile technologies. Ideally, mobile applications should detect such connections and provide a recovery mechanism to deal with them; however, there is still an issue in keeping data connections all the time. According to Rob (2011), it is still common for a mobile device to lose connection to the Internet. Therefore, the M-ECG DSS application is not always assured of access to online ECG data when a user needs it most.

Mobile applications such as mobile web browser (web app) and native apps are creating their own benefits and drawbacks to user experience and accessibility. A web app refers to a web-based application opened by mobile web browser and a native app appears to integrate fully an application within an operating system of a device. A comparison of web apps and native apps identifies these attributes, as shown in Table 4.1.

Table 4.1: A comparison of web apps and native apps

	Web Apps	**Native Apps**
Benefits	Web apps make it unnecessary to have a device with excessive built in memory and the ability to access content from multiple devices.	The major benefit of native apps is that they can be integrated fully within the operating system of the device. This increases simplicity for the user in that one can use the same set of commands regardless of which app they are using.
Drawbacks	The major drawback to web apps is their complete reliance on constant Internet connectivity. While continuous mobile broadband connectivity is available in most highly populated areas around the world, it is not the case that it is available everywhere.	One major drawback is that devices have limited storage – only so many apps and so much content can be saved on any one device. Another major drawback is that if the native app does not have an accompanying web app, then one’s content is locked to the device and can only be accessed by that one device.

Source: adopted from Rob (2011)

Based on the above discussion, this research adopts both web and native apps to support decision-making processes and its application’s accessibility. By using web apps, users can connect to the M-ECG DSS application from wherever they are, using whatever mobile device they happen to be using. By adopting native apps, the M-ECG DSS can be always available in their mobile device, regardless of whether the device is connected to the Internet or not. Ultimately, the development of the prototype M-ECG is a hybrid app that uses both native apps and web apps to support medical diagnosis. This would ensure that mobile ECG DSS ‘remains available regardless of internet connectivity and still accessible through other devices by saving copies in the cloud’ (Rob 2011). According to Anna (2011, p. 49), ‘native apps means less data to download, and faster response’. Another big advantage of this is that data can be stored on a user's device for offline browsing. From the above finding, the research development evaluated a possible way of increasing user experience from use of the prototype mobile ECG DSS. Figure 4.3 shows a schematic of the M-ECG DSS applying hybrid apps in the application. This puts a possible solution on an equal footing with native apps to involve the process of a decision-making base for automatic adjustment of content to different devices. For example, when the mobile connection is offline, doctors and nurses are still able to retrieve the ECG application or read ECG recordings from earlier downloaded data to provide support for a decision on a diagnosis based on a patient's condition.

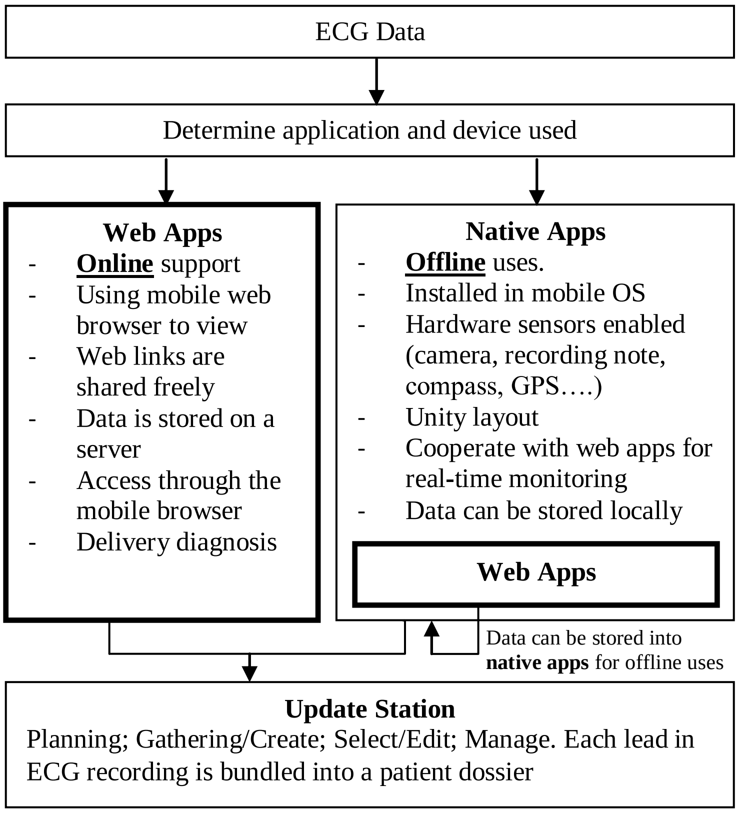


Figure 4.3: Schema of mobile ECG decision support system hybrid apps

4.3 System Architecture

The M-ECG DSS uses MS-SQL database and ASP.NET language for sending and receiving ECG signal data in a web service to provide M-ECG DSS to remotely monitor patients in real-time using multi-touch support functions. JavaScript client side language also plays a significant role in this system. In this M-ECG DSS, patients' records from a mobile ECG device are pre-analysed using a multimodal analysis engine. The results extracted from different modalities are used to create a multimodal metadata repository, along with a multimodal feature index for efficient searching. The M-ECG DSS support interface uses Cascading Style Sheets 3 (CSS3) and HTML5 language to support a physician's examination of a patient's record. According to Anna (2011, p. 43), 'CSS3 and HTML5 give more control over how the material is displayed and are standardised solutions' Moreover, with both scripting languages, 'it can animate content such as text, graphics, pictures, as well as continuous media' (Fabien et al. 2011). With CSS3 and HTML5, this research can take advantage of the clean presentation, as well as many other web features. This way, when a physician selects each ECG lead's recording, the current patient data is retrieved from the multimodal index and establishes a graph looking much like a 'line graph', 'composite inline', 'box plot' and 'pie chart' to support diagnosis. Physician can retrieve ECG data from different places such as data from database that has been recorded and stored in data centre or data from real-time ECG devices where patients are currently attached to monitors. The DSS report generation module pools the diagnosis graphs associated with a patient record to form statistical summaries of the possible diagnosis. The overall architecture of the M-ECG DSS is illustrated in Figure 4.4.

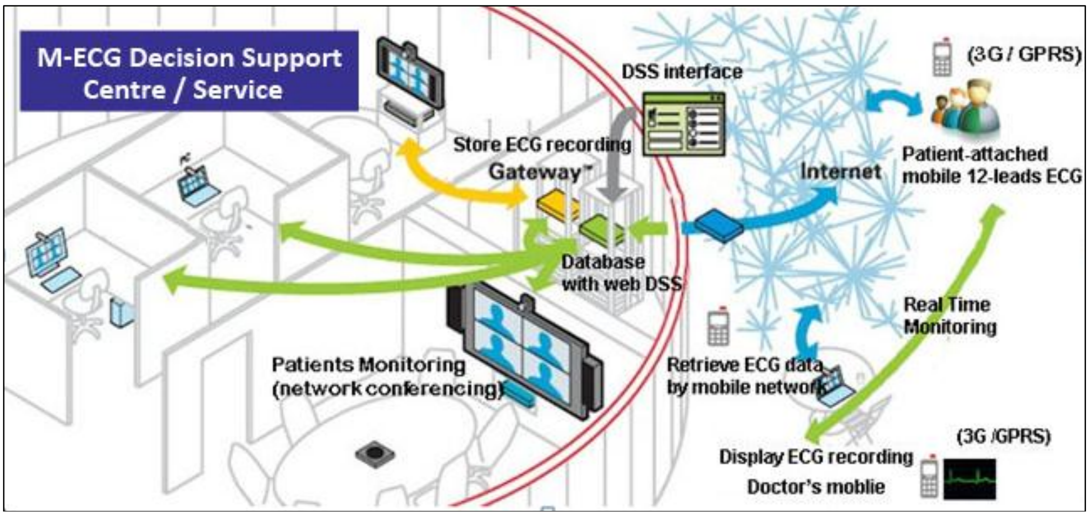


Figure 4.4: Overall system architecture of the mobile ECG DSS

In order to provide the DSS interface, HTML5 and CSS3 play an important role in the development of M-ECG DSS. HTML5 is the next major revision of development which defines a single markup language to be written in either HTML or XHTML (Content Factors 2011). HTML5 supports detailed processing models and includes more interoperable implementations. It also extends and improves the markup language available for documents and Application Programming Interface (API) for complex web applications. API is a specification for interacting with software application or service programmatically. The most obvious advantage of using HTML5 in this mobile research development is that it introduces a number of APIs that can be opened up for mobile web applications (using mobile web browser to view applications). HTML5 can be used to deliver the new elements introduced for M-ECG DSS through the APIs, for example:

- API for generating ECG line graph, composite inline, box plot and pie chart to support diagnosis (decision-making);
- API that enables the transfer of data to native apps for offline use;
- API with an interactive mode to support adaptive user interface (AUI);
- API for location service (GPS locating);
- API that enables communication with the mobile OS and other control programs (database management system, DBMS).

HTML5 has functionality to allow a user to browse through old data while staying offline. According to cardiologists' requests and feedback that occurred early on in the research, this is a significant feature that a DSS should encompass in a mobile application. Anna (2011, p. 23) has stated that 'this can be seen as a first step towards bridging the gap between desk and the web, and it gives ways for the future with web application'. Thus, the research implemented this method to enrich mobile ECG content and its decision support capabilities.

There is an associated method that cooperates with HTML5 called WebKit, a layout engine designed to allow web browsers to render web pages (Maciej 2011). It provides a set of classes to display web content in windows, and implements browser features. This method is used in CSS (Cascading Style Sheet), the language for describing the presentation of web pages, including fonts, colours and layout. Therefore, this research project employs CSS3 as a user interface markup tool to format the presentation to different types of devices, from large screens or desktops to small screens of mobile handsets and tablets. According to W3C (W3C 2010), using CSS3 to cooperate with HTML5 sites makes it easy to maintain sites, share content styles across pages, and establish pages to associated environments. The official CSS3 (2009) site states that HTML5 and CSS3 not only reduces the time taken to load pages, but also maximizes the performance of web pages. Members of system architecture supplied to the development of a prototype M-ECG DSS is discussed in the following sections.

4.3.1 User Interface: Decision Support System Design

The usability of user interfaces is often neglected in the design and development of software applications (Alex et al. 2006b). Therefore, the role of this mobile DSS is to improve a user's experience and enhance the user interface (UI) of ECG to support and improve medical diagnoses. According to Alex et al. (2006b), improving the user interface (UI) usability in DSS is more of an art than a science due to the human factors involved. Based on this viewpoint, there are several plug-ins that can be integrated to increase functionality and meet user requirements:

- The Adaptive User Interface (AUI) developed runs in the background to collect statistics on how a user interacts with a menu system and provides alternative ways to manage ECG diagnosis (Langley 1999). For example, a user can reduce the size of menu elements and allow quick access to menu elements that are most frequently used.
- The User Menu System (UMS) improves UI usability to achieve acceptance and satisfaction in a specified context of use in a mobile environment (Nielsen 2003). For example, a user is able to learn an application's functionality easily and increase the level of productivity attainable.
- The Event Handler (EH) takes all incoming event data and calls to store it into a database. For example, a DSS has been notified to update the menu system or store diagnosis content into a database when the EH has been triggered.

These plug-ins have their own components, which further compound the problem. The overall architecture for these plug-ins are depicted in Figure 4.5.

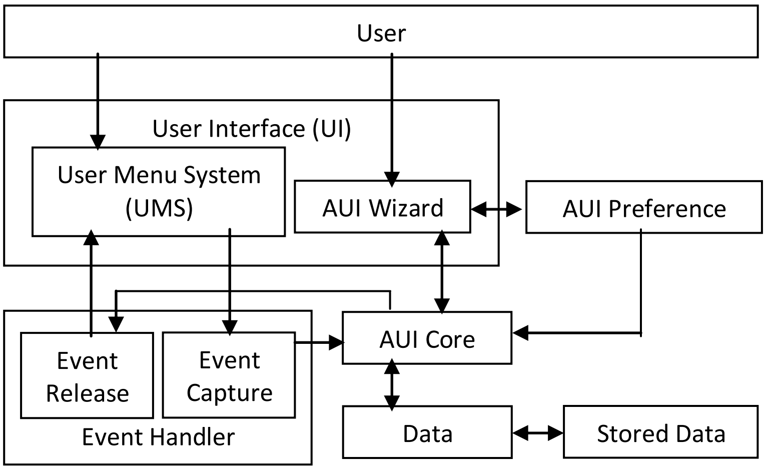


Figure 4.5: Architecture for Adaptive User Interface (AUI), User Menu System (UMS) and Event Handler (EH) plug-ins

Source: adopted from Langley (1999) and Nielsen (2003)

The DSS architecture in a mobile environment has adopted these components to increase acceptance and usability of the menu system. This establishes quantitative measurements to construct a simplified user model that establishes how a 'user interacts with a mobile system and maintains knowledge of a user's usage patterns' (Nielsen 2003, p. 2). Considering the user interaction with the menu system, the following steps show how this development takes place from a user's aspect.

1. A user selects the menu they wish to view using fingers on a mobile device's touch screen. Considering user interface (UI) design, the name of the menu is located at the top of the workspace (screen) since this is a standard UI for every type of window/mobile platforms. Sample output from the M-ECG DSS is displayed on a smart phone (iPhone) (Figure 4.6)

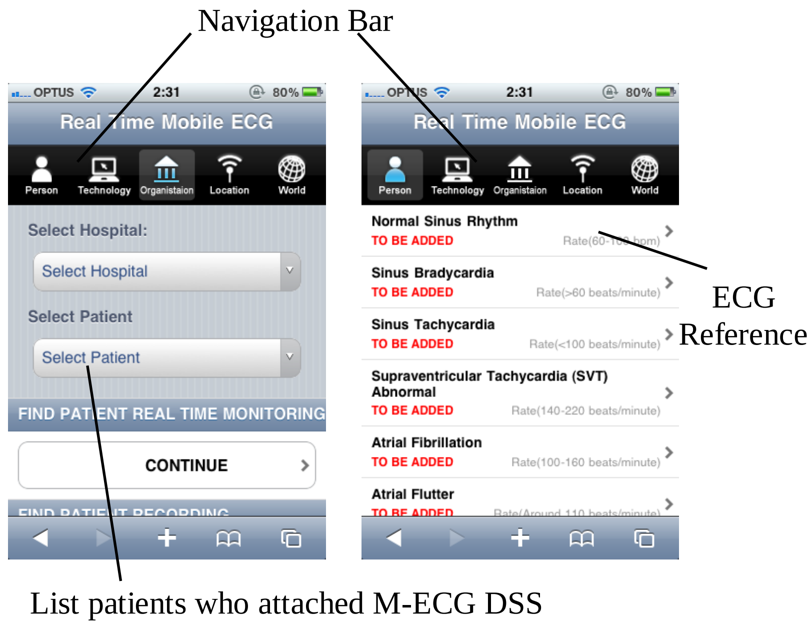


Figure 4.6: The user menu system in a mobile device

2. Once the menu has been selected, a user's focus is located to the whole screen on the mobile device. According to Chae and Kim (2004, p. 5), an 'efficient menu structure, one that took into consideration the small screen and the complex nature of the tasks users can perform on the mobile is presented to users in the form of one-path navigation'[sic]. One way to improve user experience in a mobile environment is to design a more efficient menu selection than a linear list (Nikola et al. 2011). Therefore, to support only a line-based navigation menu system, this research respectively displays a page at the next level down, the page directly above, the next page on the same level, or the previous page on the same level. Figure 4.7 shows the horizontal and vertical depths of menu system design.

In terms of mobile DSS structures, 'the size of a screen affects users' navigation activities and perceptions' (Elin & Ida-Maria 2007, p. 6). Mobile screen size menu should preform as simple as possible for menu invocation and menu item selection (Nikola et al. 2011). To reach the page where list X is, a user has the ability to scroll down through three levels of *vertical depth* (x->y->z) or move through two more levels of *horizontal depth* (y1->y2->y3). The menu system development refers to the depth that exists between pages within a single level of the menu hierarchy as *horizontal depth,* distinguishing it from *vertical depth*. Providing 'decision-making' with end user needs, there are several categories to be included in the M-ECG DSS, which are required to cover every major function of a normal ECG device. These categories are divided into multiple pages that sit on the same level of the information hierarchy (e.g., Symptom reference, Real-time monitoring and Login function) and each category has *vertical depth* to take more steps to find a target (e.g., from the category of 'Symptom Reference' to the page of 'Rhythms' and to the page of 'Rhythm Guideline').

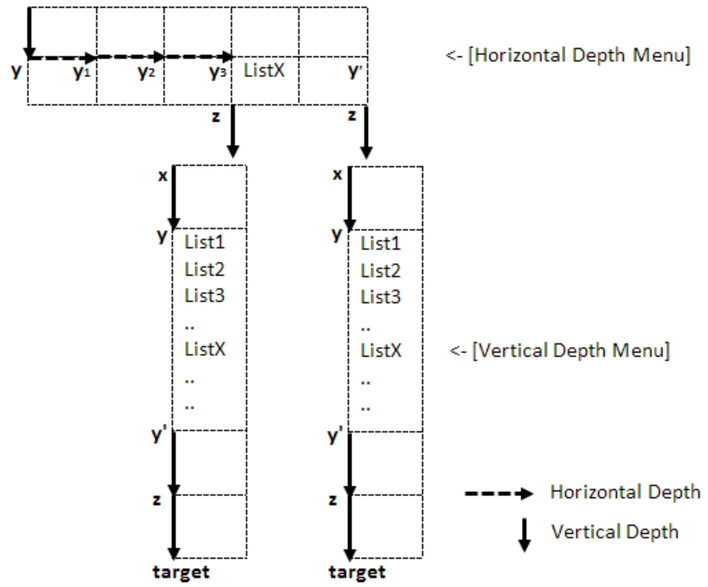


Figure 4.7: User menu system (UMS) design: Horizontal and vertical depths
Source: adopted from Chae & Kim (2004)

Due to limitation of a mobile screen size, the menu system provides a scrolling method in order to display information line by line; thus, a user is able to scroll up and down using a finger without getting to the next page. This menu-driven approach reduces the number of pages in the system. In consideration of different mobile platforms and screen sizes, the menu system displays contents as a '**Button-List**' (list acts like a button) to help a user select the desired value faster. It is actually a 'radio list' to act as a button so that it can increase ability for driving menus. The concept of using a button-list is to reduce the number of mis-presses while driving in a small screen. Sample user menu system from the M-ECG DSS as displayed on a mobile device is shown in Figure 4.8.

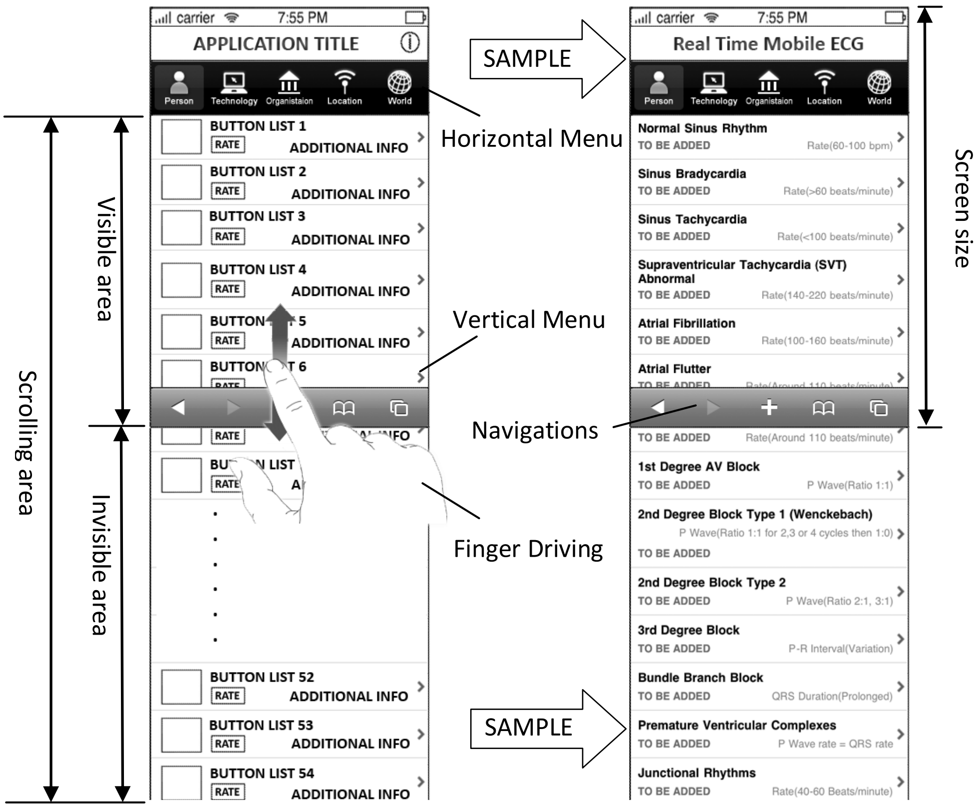


Figure 4.8: Sample button-list with menu system used in the development

The button-list menu system is called by a CSS3 programming library (button-list model). Before information is displayed on a screen, the application calls the button-list model to generate a button-list menu instead of displaying a small radio button. According to prior research (Tversky & Kahneman 1974), people always focus on a reference point when they try to access, and keep searching their current point on the basis of their reference point. Therefore, the button-list model can be accessed by an entire application and display a list driving button menu to help a user select a desired reference point. This result can be applied to navigation within a menu system through relative information changes. For example, if users access to particular information by pressing a list button, the selected information is sent to a server to call relative data and display in the next page (Horizontal depth). A section of the code for the button-list model (Figure 4.9) is shown below; it delivers a button-list structure in pages.

```
/***************   Button-List Menu Model   ********* *****/
.newsList {
   width: 100%;
   margin:0 auto;
  padding:0px;  }
.newsList li {
   background-color:#ffffff;
   margin:0;
   padding:0;
   border-bottom: 1px solid #e0e0e0;
   clear:both;
   list-style:none;
   float:left;
   width:100%;
   vertical-align:middle; }
.newsList li > a {
   background:url(../images/Arrow.png) no-repeat right center;
   padding:0px 0;
  text-decoration: none;
  color: #000000;
  margin: 0;
  display:block;
  overflow:hidden;
  -webkit-tap-highlight-color:rgba(113,135,164,0.4); }
.newsTitle {
   margin:0;
  font-size: 14px;
   font-weight:bold;
  color:#000000;
  white-space: normal;
  line-height:1.2;
  display:inline; }
```

Figure 4.9: Button-list model using Cascading Style Sheet 3(CSS3)

3. A user uses the menu system to pass each menu element in a sequential order. In this case, a user moves a finger directly to the location of where they believe the menu element is located. This also applies to the case that the user knows where to access a menu or information within the menu structure. As discussed above, it utilises a user interface (UI) based on menu driving to deliver information needs. However, there is more to include in the M-ECG DSS to develop the prototype system and evaluate operational validity. For example, basic ECG diagnosis instructions were provided by cardiologists so that the project was able to develop a prototype system - guidelines about navigation (page forward and backward) and the required ECG information

for medical diagnosis. Figure 4.10 shows a flowchart of the application design running on a mobile device.

Due to smaller displays in smart mobile devices (ranging from 3inch to 4inch), there is a limit on how much related cardiac/ECG information can be displayed at any one time. This directly impacts on a user's attitude toward an application. Also, processing time while using an application, including the time it takes to scan options displayed in the visible area and the time it takes to find the desired value, needs to be considered. Moreover, ability to provide cues or aids in navigating a system may affect the level of user acceptance while using the M-ECG DSS.

4.3.2 ECG Signal Analysis

Any DSS interface developed needs to take into account special users' perceptual or physical impairments so that it allows participants to use the M-ECG DSS more efficiently, with minimal errors and frustration to support decision-making. As literature review indicates, a mobile DSS is a useful and time-saving tool for clinicians in healthcare when obtaining profiles of patients' medical data and can detect medication errors and reduce diagnosis failures (Pauline et al. 2010). One of the major developments is to assist specialists in the decision-making process. The traditional way of ECG diagnosis and decision-making are based on a cardiologist's knowledge; however, this way of diagnosis 'does not cope well with sudden changes in the data format' (Gari et al. 2006, p. 36). The ability to seamlessly cope with changes in ECG signal gain, frequency, ECG lead configuration, data dimensionality, and arbitrary non-contiguous breaks in the waveform only happens in real-time monitoring under electronic reading devices such as computer or mobile phone, but not paper-based. Thus, the development is required to provide a **digital measuring scale tool** to allow ECG diagnosis while ECG waveform is still moving.

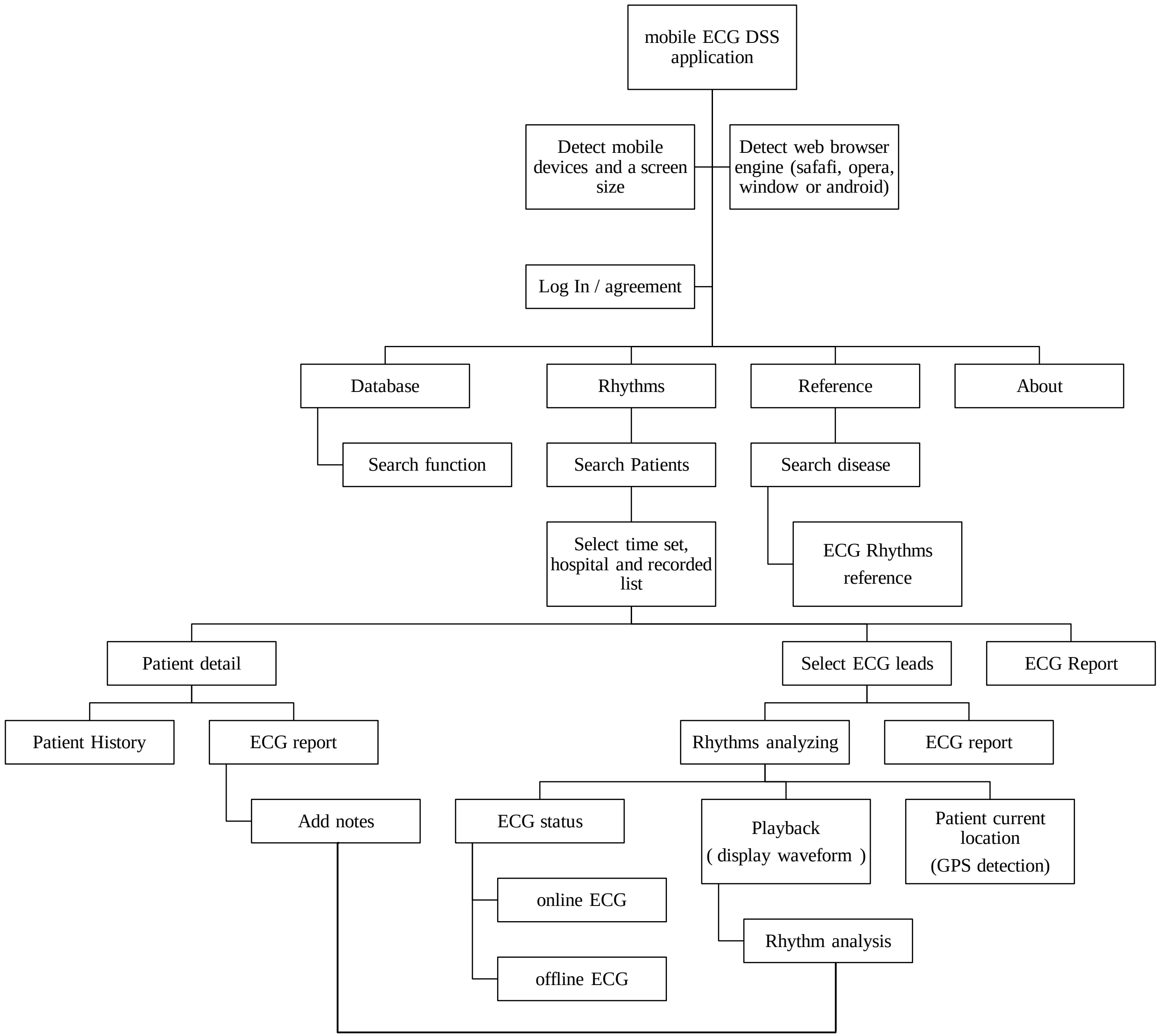


Figure 4.10: M-ECG DSS flowchart of its design and implementation

This research development only focuses on how to increase decision-making processes and support medical diagnosis. Therefore, this study does not look at how ECG data is collected from subjects or examine the devices and electrodes attached to the subject. Although patients can be attached to numerous recording devices or electrodes, there is an expectation to reduce interference in a recording situation. For example, while transforming ECG data into waveform, it is necessary to include an application of adaptive filtering to remove noise from the ECG signal (noise cancellation). According to Rahman (2009, p. 121), ‘the extraction of high-resolution ECG signals from recordings contaminated with background noise is an important issue to investigate’. In order to provide an ECG signal with a clean waveform, it is important to present a mobile filter application that facilitates easy and accurate interpretation for ECG signal analysis. Therefore, doctors and nurses are able to obtain a better signal estimation and detect shape variation in the device. Figure 4.11 shows how an adaptive mobile filter application process removes noise and reformats the ECG signal.

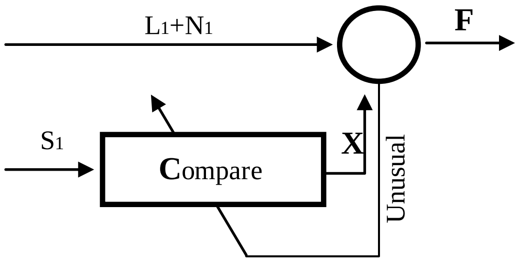


Figure 4.11: Adaptive Mobile Filter application structure.

Figure 4.11 shows an adaptive mobile filter application with a primary data input that is a signal from one of the ECG leads L_1 with additional noise N_1. ECG data were from webserver or directly from ECG mobile device. A reference signal S_1 is obtained as a noise free signal in each lead to compare with input signal L_1+N_1. This way, a reference input selects possible ECG signal wave to reduce recording of noise. If the filter output is x then the filter is looking at the input to generate final result F. Thus, the filter structure is able to obtain a noise free signal in a mobile application signal process. Figure 4.12 shows an example of how ECG lead I signal is processed in an adaptive mobile filter application.

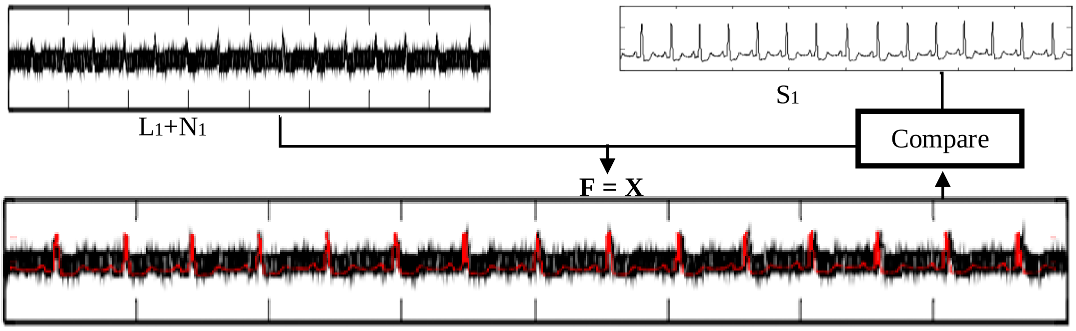


Figure 4.12: Selected ECG signal and noise cancelled signal

In order to provide a method to estimate and establish a waveform with vector in a mobile browser, this research has created The Signal Algorithm (TSA) to convert ECG data input type to line vector *x(n)* as per the JavaScript programming applied by Sparkline (Gareth 2010) plugin under the JQuery project (jQuery 2010). Sparkline is a type of information graphic characterised and 'presents trends and variations associated with some measurement in a simple and condensed way' (Gareth 2010). The jQuery project is part of the Software Freedom Conservancy; 'a fast and concise JavaScript Library that simplifies HTML document traversing, event handling, animating, and Ajax interactions for rapid web development' (jQuery 2010). TSA uses those plugins to process an input signal *x(n)* and generate the timely interval output *y(n)* with line selectors. For example, when ECG data has been sent to mobile devices, the data values will be put in place to read from the specified tag:

```
<p>Sparkline: <span class="sparkline">3,5,2,4,7,8,5,3,2,1,3,8,5</span></p>
$('.sparkline').sparkline();
```

The number between ** and ** is the noise free data calculated by JavaScript method which is imported from ECG devices and web servers. For ECG signal waveform, *x* values can also be specified:

```
<p>Sparkline: <span class="sparkline">1:1,2.7:4,3.4:6,5:6,6:8,8.7:5,9:3,10:5</span></p>
$('#sparkline1').sparkline([ [1,1], [2.7,4], [3.4,6], [5,6], [6,8], [8.7,5], [9,3], [10,5] ])
```

Sparkline Options from JavaScript additional input method can also be set by passing on the tag itself to mobile webpages. This way, the ECG lead signals will be easy to identify and be read by users. These tags can be changed by a user to be in line with user behaviour (additional information can be found in section 4.2.1 with AUI interaction).

```
$('.sparkline').sparkline([1,2,3,4],  {enableTagOptions: true} )
<p>Sparkline: <span class="sparkline" sparkType="bar" sparkBarColor="red">loading</span></p>
```

Furthermore, users can prefix all options supplied as tag attribute with *'spark'* (configurable by setting tagOptionPrefix). There are ten options to set up ECG signal selected by importing '*numbers'* option of '*graph'* (Gareth 2010).

- spotColor - Set to '' to not end each line in a circular spot
- minSpotColor - If set, colour of spot at minimum value
- maxSpotColor - If set, colour of spot at maximum value
- spotRadius - Radius in pixels
- lineWidth - Width of line in pixels
- normalRangeMin
- normalRangeMax - If set draws a filled horizontal bar between these two values marking the "normal"or expected range of values
- normalRangeColor - Colour to use for the above bar
- drawNormalOnTop - Draw the normal range above the chart fill colour if true
- defaultPixelsPerValue - Defaults to 3 pixels of width for each value in the chart

Figure 4.13 provides an example of calling JavaScript method (Figure 4.13) to display an ECG signal with real-time interaction shown in a mobile web application.

```
<script type="text/javascript">
$(function () {
//ECG  Real-time Speed
        var Amrefreshinterval = 250; // update display every 25ms.
        var Alastmousetime;
        var Ampoints = [];
        var Ax;

        Amdraw = function () {
           var Amd = new Date();
           var Atimenow = Amd.getTime();
           var Amegarray = NoiseFreeValue;  // update real-time ECG data from JavaScript library with noise
free data input.
           for (Ax in Amegarray) {
              if (Alastmousetime == Atimenow) {
                 var Apps = Amegarray[Ax];
                 Ampoints.push(Apps);
                 Ampoints.splice(30, 1, Amegarray[Ax]);
                 $('#Aecgspeed').sparkline(Ampoints, { width: '305px', lineWidth: 2, height: '70px', lineColor:
'yellow', fillColor: false });
                 if (Ampoints.length > 80) {
                    Ampoints = Amegarray;}
              }
              Alastmousetime = Atimenow;}
           Amtimer = setTimeout(Amdraw, Amrefreshinterval);
           Ampoints.splice(1, 9);
           return;
        }
        var Amtimer = setTimeout(Amdraw, Amrefreshinterval);
        $.sparkline_display_visible();
        $('#simplelink')[0].target = '_blank';
     });
  </script>
```

Figure 4.13: Calling JavaScript method to display an ECG signal

The *NoiseFreeValue* has the ability to transmit real-time ECG data to *Amegarray*. This way, the JavaScript calling method is able to present a real-time ECG waveform in a mobile web application. The TSA implementation generates inline sparkline charts from data supplied either to the method or inline in a mobile web browser and an application. This ECG signal analysis is performed to measure a cyclic occurrence of patterns with different frequency content (P wave, QRS complex, T wave). For this purpose, this analysis looks at specific sinus rhythms with unusual frequency content at different values of heart rate. For example, the result of analysis with QRS > 120 ms duration will refer to left bundle branch block, anterior myocardial infarction (normal QRS duration <=120 ms). The ECG signal analysis has followed a standard of ECG diagnosis, which is used clinically in diagnosing various abnormalities and conditions associated with the heart. The example of normal value of ECG frequency content (heart beat lies in the range of 60-100 beats/minute) is provided in Figure 4.14 (Saritha et al. 2008, p. 70),

Amplitude	P-wave — 0.25 mV
	R-wave — 1.60 mV
	Q-wave — 25% R wave
	T-wave — 0.1 to 0.5 mV
Duration	P-R interval : 0.12 to 0.20 s
	Q-T interval : 0.35 to 0.44 s
	S-T interval : 0.05 to 0.15 s
	P-wave interval : 0.11 s
	QRS interval : 0.09 to 0.12 s

Figure 4.14: A standard of ECG frequency content

The Adaptive Mobile Filter Application also looks at different values of ECG frequency content to identify a specific symptom. For example, if the P-R interval is greater than 0.2 seconds, it may suggest blockage of the AV node. Details of cardiac diagnosis can be found in section 2.5. The research was performed in light of the assessment of ECG signals from the cardiac point of view. It is interested in the decision-making process in order to increase acceptance of using a mobile device for medical diagnoses. Thus, this research will not look at how ECG frequency contents are calculated or what methods are used to identify symptoms. However, the research has used Adaptive Mobile Filter Application to generate noise free ECG signals and provide simple ECG analysis for mobile decision-making practices using TSA. By the use of the M-ECG DSS, this ECG signal analysis implementation allows users to see how potential covers and layout will look. This research further emphasises the importance of early perceptions and mobile technology acceptance by users. As advocated by Elwyn (2000, p. 892), transforming preferred data format and providing tailor-made information to find a user reactions (e.g., ideas, fears, and expectations of possible options) may increase acceptance of process and decision-making role preferences.

4.3.3 Multi-Touch Measuring Scale Tool

The empirical evidence (Elwyn et al. 2000; Rebecca & Dawn 2010; Viswanath et al. 2002; William et al. 2002) shows that patients in decision support make a significant and enduring difference to diagnosis outcomes. The development of prototype M-ECG DSS involved not only developing a real-time monitoring application, but also including a method to increase time taken for decision-making and acceptance of the process. An Action Guide for Nurses, Midwives and Health Visitors (Department of Health 2001) has stated that there is a high demand on building a highly skilled diagnostic tool within specialist areas. For cardiac patient care, this involves developing competence in the realm of ECG analysis. Joanne (2006) has highlighted that 'accurate 12-lead ECG interpretation requires thoroughness and care'. Incorrect decision-making is commonly attributed to the failure to detect subtle relevant indicators. For example, a short PR interval may be easily ignored, and this could result in a mis-diagnosis of Wolff-Parkinson-White Syndrome. Thus, it is important to provide other measuring methods, which are able to detect potentially fatal arrhythmias. The purpose of this development is essential in correct decision-making in cardiac diagnoses. Before developing an additional measuring method, it is first necessary to create a stationary background of a M-ECG illustrated graph to obtain a standard ECG reading paper tool (Figure 4.15). The colour of illustrated graph (**RED** colour) is selected to match normal paper-based ECG reading so it can provide the information in a familiar style for user recognition (Vincent 2007, p. 45).

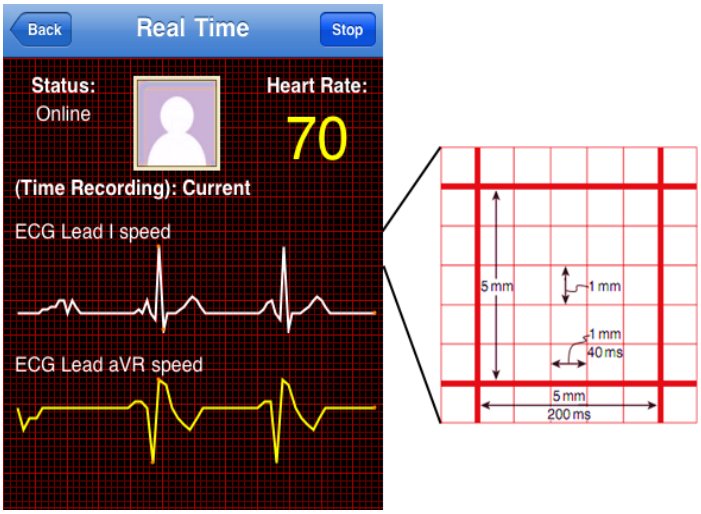


Figure 4.15: The mobile ECG illustrated graph

The graph is composed of 1 mm squares, which each represent 0.04 seconds (40 milliseconds (ms)) in time on the horizontal axis. The thicker red-lined box contains 25 small boxes and measures within 5mm squared. This thicker box represents 200 milliseconds (5mm) on the horizontal and vertical axis. The speed of ECG signals needs to be 25mm/second to contribute with this parameter (details of coding ECG speed can be found in the section 4.2.2, an example of TSA processing). After defining a M-ECG illustrated graph for ECG interface display, a measuring tool is needed to provide additional ECG interpretation (Joanne 2006, p. 216). Therefore, this research has employed a Multi-Touch Processing (MTP) technology to build a multi-touch measuring scale tool which has the ability to interpret with ECG signals. The multi-touch measuring scale tool uses fingers to control a graphical interface through smart mobile devices to replace mouse interaction. Based on traditional ECG diagnosis, ECG paper provides a fixed scale to measure time including hash marks at either the top or bottom of the graph paper to indicate intervals; however, according to the literature review, there is still no method to provide a virtual tool to replace the actual scale instrument. Although there are some statistical analyses generated by the ECG instrument itself, the additional diagnostic tool is still needed for other tasks such as measuring ST and T wave changes to detect coronary syndromes.

The multi-finger interaction is a common experience to support typing and executing key commands that are discrete serial actions (Tomer 2006). The goal of this multi-touch and multi-layer processing is to make it easy for a user to diagnose using simple 3D layers to measure a lower layer ECG waveform. The DSS process has two supporting parts. First is a multi-layer interface for graphical manipulation. These layers allow users to move the measuring tool to the top of each waveform. Second is a multi-touch cursor technique for fluid multi-parameter interaction with measuring tool objects (Figure 4.16). This function allows users to double and roll the measuring tool object for better estimation.

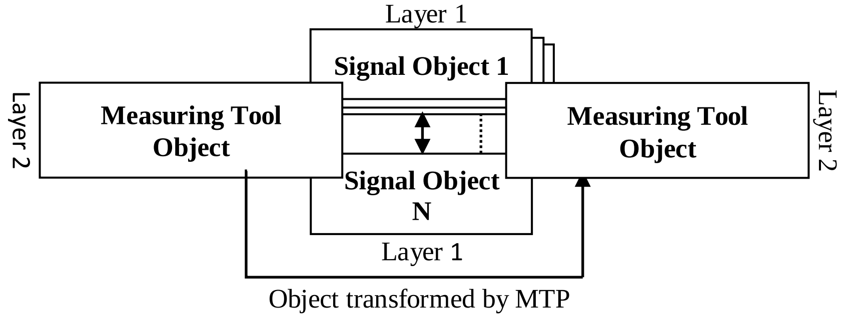


Figure 4.16: Multi-parameter interaction diagrams with measuring tool objects

The technique shown in Figure 4.17 extends the idea of area cursors by allowing a user to transform the tool object with one or two fingers. The user can scale, translate and rotate objects by moving their fingers on top of the tool object, where the relative positions of the associated contact points towards the object are preserved. The size of the activation area is proportional to the span of the fingers.

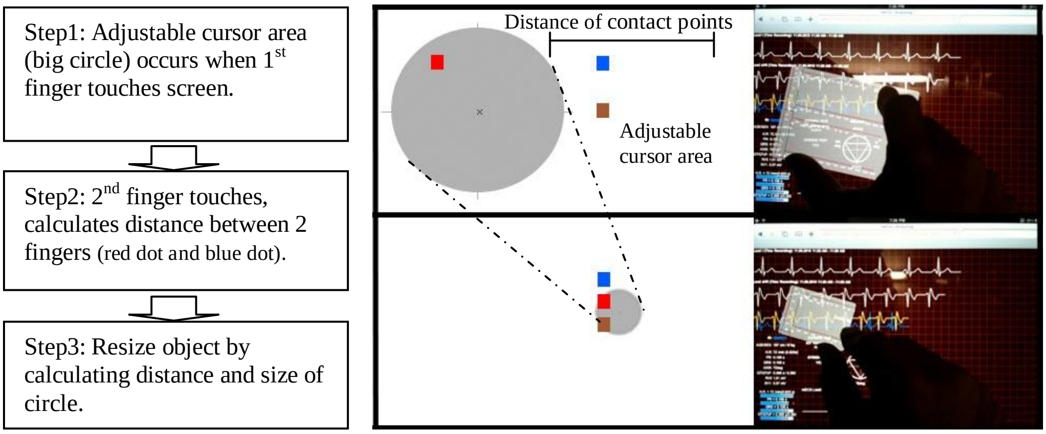


Figure 4.17: Adjustable cursor area makes it easy to select isolated targets (big circle with red dot) and calculates the distance with individual targets (blue dot) while allowing for resizing of objects.

The MTP integration is considered in two parts. When designing a user experience, it is often useful to provide a familiar style to take advantage of human recognition (Vincent 2007, p. 45). Therefore, MTP adopts this point of view as part of the development objective. The measuring scale tool should act as a normal roller tool to retain a familiar style so that the scale object can be used without any instruction. To be able to provide this method, this research has introduced MTP as a major implementation aspect in measuring scale tool integration. The research development is based on web application so that a common programming language needs to be filtered. The M-ECG DSS has developed a multi-touch class created by JavaScript with JQuery built-in to retrieve multi-touch function in order to listen to a user's finger movement for MTP integration. This can only be achieved through certain mobile devices due to type of screen surfaces and mobile web browsers. There are several features to add such as rotating, scaling, resorting and animating. This MTP also includes finger activity frames to trigger moving events such as OnTouchStart, OnTouchEnd and OnTouchMove. A section of the code to trigger multi-touch functions in decision support pages for default MTP setting is shown below in Figure 4.18.

```
/***************   MTP integration   ********* *****/

jQuery.fn.touch = function(settings) {

        // DEFINE DEFAULT TOUCH SETTINGS
        settings = jQuery.extend({
                animate: true,
                sticky: false,
                dragx: true,
                dragy: true,
                rotate: false,
                resort: true,
                scale: false
        }, settings);

        // BUILD SETTINGS OBJECT
        var opts = [];
        opts = $.extend({}, $.fn.touch.defaults, settings);

        // ADD METHODS TO OBJECT
        this.each(function(){
                this.opts = opts;
                this.ontouchstart = touchstart;
                this.ontouchend = touchend;
                this.ontouchmove = touchmove;
                this.ongesturestart = gesturestart;
                this.ongesturechange = gesturechange;
                this.ongestureend = gestureend;
        });
};
```

Figure 4.18: Default Multi-Touch Processing (MTP) setting to trigger multi-touch function

When using the measuring scale tool, it not only has the ability to move but also includes quick, easy and accurate measurements for diagnosis (reading ability). In fact, the inspiration for the measuring scale tool for the DSS interpretation was derived from a normal measuring instrument (transparent ruler), which has the ability to look through backgrounds. In this way, a user is able to more accurately diagnose using the measuring scale tool without covering the ECG wavelet. Figure 4.19 shows how the measuring scale tool is used with an ECG wavelet.

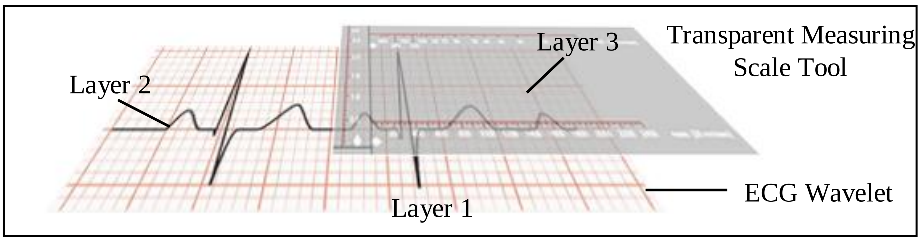


Figure 4.19: Transparent method for measuring scale tool integration

This transparent method uses HTML5 (Galpin 2010), an open standards-based operating environment which is easily integrated with third party mobile systems to describe and transport content. The HTML5 provides mobile device' users with richer web applications and improved its usability. This solution allows object changes to be made both by configuration and scripting. The multi-touch measuring scale tool is built as an additional measuring instrument as its base, with MTP, interpretation system and diagnosis on top of wavelet. Moreover, this development also allows the measuring scale tool the ability to double the size of the ruler to increase the reading area and diagnosis ground. The transparent method contains statistical tools and two ways of ruler use (move and roll) for diagnosis. It is developed to cooperate with ECG illustrated graph background, which allows ECG wavelet to display in the interval frames. A section of the code for default method under HTML5 integration is shown below to transform this measuring scale tool object (Figure 4.20) to be a transparent and double object. This is done under Cascading Style Sheets 3 (CSS3) class.

```
.largetouchbox {
        width: 465px;
        height:167px;
        background-image:url(../images/ecg_analyze.png);
        opacity: .75;
        filter: alpha(opacity = 75);
        -moz-border-radius: 10px;
        -webkit-border-radius: 10px;
        color:#FFFFFF;
        font-weight: bold;
        font-size: 14px;
        text-align:right;
        margin: 10px;
        z-index: 950; }
.largetouchbox b {
        line-height: 130px; }
.smalltouchbox {
        width: 50px;
        height:50px;
        background-color:#999;
        color: #FFF;
        opacity: .75;
        filter: alpha(opacity = 75);
        -moz-border-radius: 5px;
        -webkit-border-radius: 5px;
        text-align: center;
        font-weight: bold;
        font-size: 14px;
        margin: 10px;
        z-index: 900;
        position: absolute; }
```

Figure 4.20: HTML5 integration to transform measuring scale tool object

The core function used WebKit application in CSS3, a layout engine designed to allow web browsers to render web pages to provide a set of classes to display web content in a mobile browser (Apple 2009). This function gave measuring scale object the ability to load as a transparent layer in web pages. The above section code, *opacity = 75* gave object within 75% opacity to display on a screen and *-webkit-border-radius: 10px* gave object the ability to increase area of ruler radius. This multi-touch measuring scale tool, combined with multi-touch processing (MTP) and transparent method, is shown in Figure 4.21 (process of entire measuring object transformation).

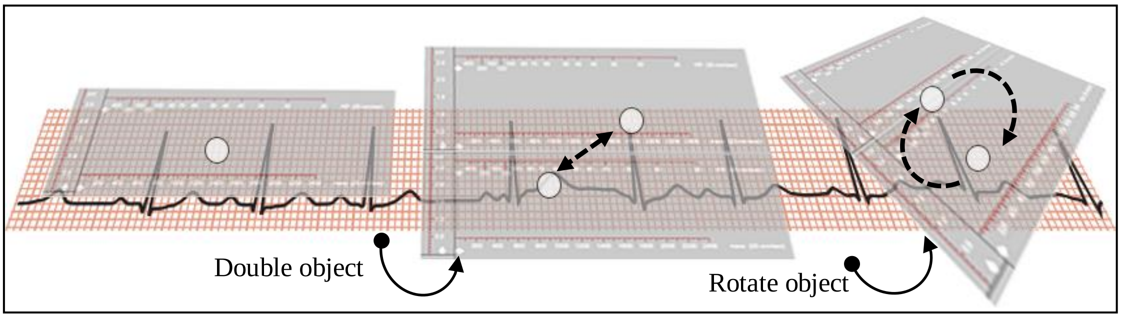


Figure 4.21: Process of measuring object transformation using multi-touch function

This web-based solution allows content to be accessed through different smart mobile platforms such as Apple iOS and Android-based devices and is able to embed an application into those platforms. This way, the M-ECG DSS not only supports real-time monitoring but also includes reference tool to help users to review ECG related knowledge. For example, without mobile Internet access, users are still able to review patients' status, which has been downloading earlier while able to access the network from a mobile app (embedded mobile application) and have the ability to provide a partial diagnosis. If syndrome is detected, any further analysis is possible to diagnose under a mobile environment. The embedded application can take advantage of less information flowing to reduce network traffic used and can prevent many dynamically configurable operating systems from being used in multiple mobile web environments (Leena & Marika 2003). By using this method, this research aims to capture user experience in order to evaluate acceptance and decision-making processes. Figure 4.22 shows an example of the idea of using embedded application with a mobile web browser included (iPhone iOS application).

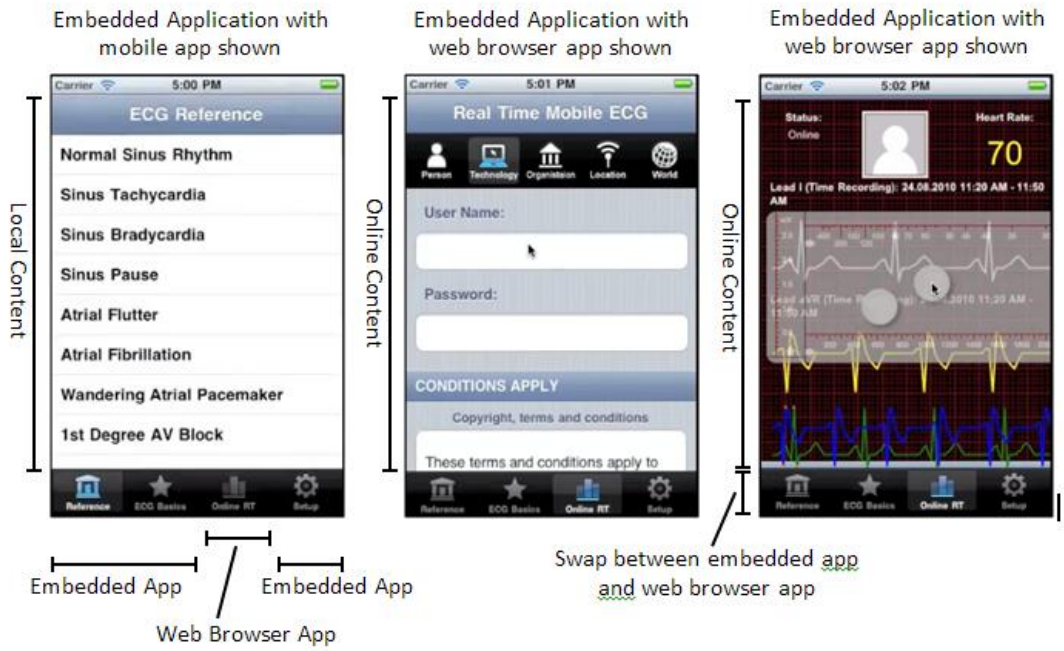


Figure 4.22: Embedded mobile application with a mobile web browser included

One of the crucial steps in the ECG diagnosis and decision-making process is to accurately detect the different waves forming the entire cardiac cycle (Saritha et al. 2008, p. 76). Since ECG diagnosis in mobile environment is a new field of research, many methodological aspects of DSS and wavelet transformation require further investigations in order to improve the clinical usefulness and acceptance of this M-ECG DSS.

4.4 Decision Support System Implementation

It is suggested that the prototype M-ECG DSS may contain the following processing to deliver information over a mobile network.

- ECG wavelet transform processing
- Web Server Processing
- Mapping Processing

These processes were useful for supporting the decision-making that needs to be met while developing an application that can be accepted and used in clinical practice. With respect to the above, the M-ECG DSS prototype was developed as a trial to evaluate user acceptance in a mobile environment. The DSS is intended for users in the actual mobile environment for medical diagnosis. These processing approaches make DSS closer to users' expectations in decision-making (feedback occurred early on in the research). The following processing describes how this DSS prototype is developed to support decision-making.

4.4.1 Web Server Processing

The M-ECG DSS web server contains mobile transmissions, web application, web services and patients' databases. It has been designed to record data via a mobile network and wireless technologies. The web server is used to detect serious heart anomalies and sending an alarm message to a physician's or doctor's mobile on time. This way, it allows the monitoring of cardiac patients remotely, to access a specific case, review data and make an on-line diagnosis through mobile communications. The web server performs multi-user real-time monitoring. This web server module efficiently manages resources in a web environment and improves diagnosis in four ways:

- notifying of emergency situations
- real-time mobile environment monitoring and transmission
- patient recording and analysing
- diagnosis support

The web server is a bridge that receives messages from ECG devices and sends them when a mobile enters a connected area. This service also offers physicians the possibility of setting, during monitoring, a set of parameters for a monitored patient. This research has chosen web server processing to expose the functionality of M-ECG DSS because 'it makes use of standard technologies that reduce the heterogeneity and facilitate an application integration' (Jimena et al. 2004, p. 105). The web server has the ability to communicate with a database and retrieve information when needed. These services provide information processing to the M-

ECG DSS application independently. This approach involves a database management system (DBMS), an ECG data package to control the creation, maintenance, and the use of a database. By using this web server processing, this DBMS provides facilities for controlling data access, enforcing data integrity, managing ECG wavelet performance and storing ECG data from ECG devices, as well as analysing arrhythmia data to obtain a prompt diagnosis. For example, if a syndrome is detected, a notifying message (Push Function) will be sent to a physician's mobile device for future diagnosis or immediate treatment through the web server processing method. The architecture of web server processing is shown in Figure. 4.23.

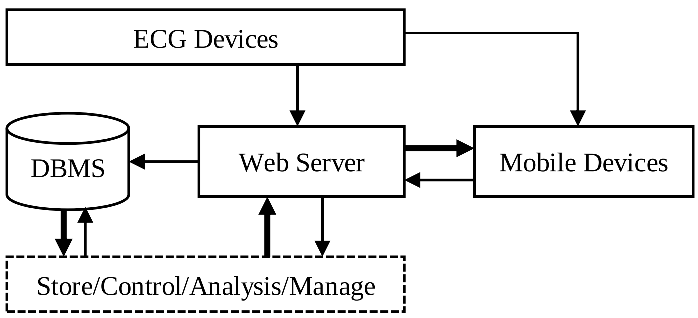


Figure 4.23: Architecture of web server processing

The web server processing not only manages all ECG data across DBMS, but also manages all DSS pages of the application (bold arrows) and traces user information. This processing allows decision-makers to have consistent assessment, complete information and accurate opinions for alternatives and assessment-criteria. In terms of web service support, 'a DSS will place health services in an advantageous position relative to accurate treatment' (Fahhad 2000).

4.4.2 Location Processing

According to the literature (Chung & Hsueh-Ming 2009; Ekström 2006; Julie et al. 2006), it has been identified that patients suffering cardiac disease or accidents require urgent diagnosis and emergency care. However, 'the medical staff, restricted by distance and space, cannot give patients the best treatment in good time and fail to save many lives' (Hsu-Yang et al. 2005). In view of this, this research has included mapping processing (latitude services) to identify a patient's location when cardiac syndrome is detected.

Location service is part of Google Latitude API (Google Code 2010), the company's mapping application programming interface for web browser. It is a tool for tracking mobile location and sharing it with others and allow for websites and programs to integrate with Google Latitude. Google latitude (Google Code 2010) uses a record of where a user was at a given time to demonstrate a user's location by GPS service and AGPS (Assisted GPS). Based on this API, this research developed a service using AJAX language to connect with the M-ECG DSS web server using shared location resources. Therefore, the M-ECG DSS is able to detect a patient's location and give the best diagnosis in an appropriate timeframe. Emergency services are also able to detect a patient's current location when cardiac disease occurs. In this way, delays are reduced in receiving treatment. A sample mapping output from the M-ECG DSS is shown in Figure 4.24.

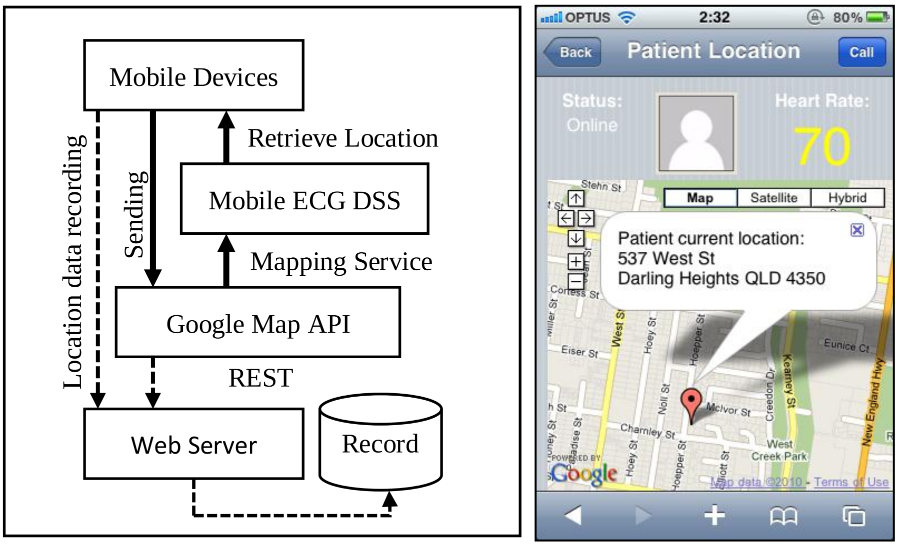


Figure 4.24: Google Latitude in decision support system (DSS)

The M-ECG DSS uses Representational State Transfer (REST) (Google Code 2010) to invoke this API. With this REST method, actions are taken on location resources using HTTP operation such as GET, POST, PUT, and DELETE to retrieve mapping service from a mobile device. Resources are accessible at a globally-unique URI. An example of obtaining current location is:

```
GET https://www.googleapis.com/latitude/v1/currentLocation?key=INSERT-YOUR-KEY&granularity=best
```

According to Google Code (2010), ‘REST enables data caching and is optimised to work with the web's distributed infrastructure’. The web server has imported this REST to allocate URI for authorising Google Latitude API. This way, physicians or emergency services are able to detect more than one patient’s current location simultaneously. Physicians are also able to update a patient’s current location by sending an HTTP POST to the current location URI:

```
POST https://www.googleapis.com/latitude/v1/currentLocation?key=INSERT-YOUR-KEY
```

While updating the current location, a representation of the new location resource needs to be included in the message body to indicate a latitude and longitude for the current location. An example of a successful request to retrieve/ locate a patient’s location is shown below:

```
/* Authorization header here */
Content-Type: application/json
{
   "data": {
   "kind":"latitude#location",
   "latitude":37.420352,
   "longitude":-122.083389,
   "accuracy":130,
   "altitude":35
   }
}
```

This Google Latitude API gives the M-ECG DSS an opportunity to reduce time taken to find a patient’s location, a new deployment for ECG diagnosis. With the ability to use mobile technology, location processing is one of the tools to assist physicians in monitoring patients and saving lives.

4.5 Chapter Summary

The aim of the M-ECG DSS development is to test the rules of the mobile implementation base of the medical diagnosis against normal ECG devices (paper and computer based). The results of this implementation could be used to decide the utility of mobile technology in evaluating acceptance of processes in medical diagnosis. The field prototype of this mobile application was deployed to meet a user requirement in order to deliver better decision-making and improve ECG diagnosis. The idea behind a new system of managing cardiac patient care in conjunction with modern telecommunication applications using mobile devices is to improve the quality of cardiac care.

The M-ECG DSS application uses structured information to form a patient's history and ECG recordings, which are processed to generate statistical distributions of diseases based on demographics. It consists of compositions of information in different ways to form larger structures. Named groups, lists, trees, graphs and spatial embedding objects will impact on how a user navigates that structure to find a particular piece of information on patients. Furthermore, the information is also used to address users' profiles, location and any activity related to cardiac disease.

This first-ever M-ECG DSS not only involves innovation of a multi-touch measuring scale tool, but also gives specialists the ability to make diagnosis decisions easily. It performs both online (web app) and offline (native app) uses. Specialists are still able to interact and diagnose data when network is not available. Key innovations involved in this prototype mobile application are as follows:

- An adopted native and web apps together to involve the process of decision-making for health service and give them a non-delay access and fast interpretation;
- A new creation of Adaptive Mobile Filter Application and The Signal Algorithm (TSA) to convert ECG data input type to line vector with noise cancellation;
- A first-ever multi-touch measuring scale tool for ECG wavelet analysis;

- An innovation of M-ECG location service (detecting patient current location while ECG devices been attached); and
- First time specialists have the ability to interpret amplitude of signal on a mobile device.

It is important to evaluate this M-ECG DSS to ensure it does its task satisfactorily and physicians will accept it. In this research, the knowledge base on a mobile DSS was evaluated using an acceptance model to identify the ability of mobile technology and to improve the quality of cardiac diagnosis based on decision-making processes. The following chapter outlines the qualitative and quantitative data analysis to evaluate the level of acceptance in delivering the M-ECG DSS. It aims to answer the research questions by validating the propositions.

Chapter 5 Data Analysis and Results

5.1 Introduction

This chapter presents the results of qualitative and quantitative data analysis. It reports results of the interviews and surveys surrounding ECG functional / DSS system characteristics and mobile technology acceptance for a mobile ECG decision support system (M-ECG DSS). The results of an investigation into mobile health technology acceptance under ECG diagnosis are expected to support the development of a conceptual model. The data analysis begins with participants' responses and descriptive statistics. There are two major results for this data analysis. The study aims to identify the ECG functional characteristic needs and test whether M-ECG DSS can be accepted for ECG diagnosis while adopting identified ECG functional characteristics. The interview and survey questions explore the role of mobile health technology and perceived acceptance value from participants who tested M-ECG DSS practices. The study used quantitative data analysis to triangulate results from qualitative method. This method entails collecting data from multiple sources and provides an additional means for ensuring data accuracy (Yin 2008). This approach enables detailed interpretation to help understanding of the research results.

As proposed in the previous chapter, the study first evaluated the needs of ECG functional and DSS system characteristics, then applied the results to the M-ECG DSS technology acceptance. The initial aim was to collect data from 18 specialists. There are three statuses and major departments required for acquiring the cardiac diagnosis. Three different departments, statuses and two different countries were surveyed followed by in-depth interviews and descriptive statistics to briefly review the idea of significance testing from interviews and surveys. The individual acceptance factor was classified into departments, statuses and countries and produced substantial biases in the aggregate proportion of each factor within each category (Chapter 3). Specialists' responses to the needs of ECG functional and DSS system characteristics of a M-ECG DSS are answered via open interview questions and a survey. The results of data analysis are classified into each factor within constructs in the following sections. Qualitative and quantitative analyses were employed to examine significant requirement of system characteristics in mobile environment and testing values of acceptance in M-ECG DSS. The results indicate values of mobile technologies adoption in cardiac disease. The structure of this chapter is shown in Figure 5.1 below,

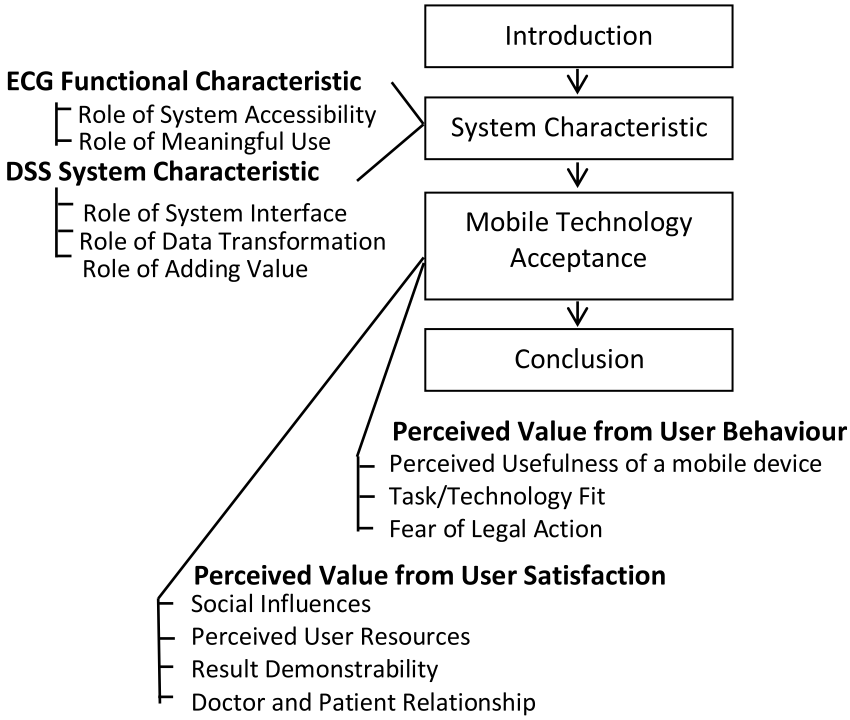


Figure 5.1: Structure of Chapter 5

5.2 Demographics

The sampling group (18 specialists) was selected from hospitals in Australia (A) and Taiwan (T). These health professionals are doctors (D), nurses (N) and cardiologists (C) who have experience with ECG monitoring and pre-hospital ECG analysis. Respondents' work experience distribution ranged from 1 to 25 years, 38.9 per cent having 1-5 years of experience and 22.2 per cent having over 16 year experience. In terms of status (job title), the sample is composed of cardiologists (n=4, 22.2 per cent), doctors (n=9, 50.0 per cent) and nurses (n=4, 22.2 per cent). In terms of departments where they provide cardiac services, four participants worked in the cardiology department (22.2 per cent), eight in intensive care unit (ICU) (44.4 per cent) and six worked in emergency and other departments (22.2 per cent). Descriptive statistics of the data are presented in Table 5.1.

Table 5.1: Country, work experiences, job title and department of respondents

Country	Frequency	Per cent	Cumulative Per cent
Taiwan (T)	12	66.7	66.7
Australia (A)	6	33.3	100.0
Total	18	100.0	
Work Experiences	**Frequency**	**Per cent**	**Cumulative Per cent**
1-5 years	7	38.9	38.9
6-10 years	3	17.7	56.6
11-15 years	4	22.2	78.8
Over 16 years	4	22.2	100.0
Total	18	100.0	
Status	**Frequency**	**Per cent**	**Cumulative Per cent**
Cardiologist (C)	4	22.2	22.2
Doctor (D)	9	50.0	75.2
Nurse (N)	5	27.8	100.0
Total	18	100.0	
Department	**Frequency**	**Per cent**	**Cumulative Per cent**
Cardiology (C)	4	22.2	22.2
ICU (I)	8	44.4	66.7
Emergency and others (E)	6	33.3	100.0
Total	18	100.0	

In terms of providing pre-hospital ECG monitoring and analysis, sixteen participants (88.9 per cent) have provided this form of medical diagnosis. Fourteen participants routinely used ECG monitoring (83.3 per cent) for patients with non-traumatic chest pain (77.8 per cent) or traumatic chest pain (88.9 per cent). In term of situations dealing with cardiac patients, all participants are used to providing treatment for general illnesses. Moreover, eleven participants (61.1 per cent) have experience in telemedicine concepts or devices that involved patient care and seven participants (38.9 per cent) had no experience with any telemedicine diagnosis. Respondents have provided diagnosis for cardiac patient remotely with recording only (n=11, 61.1 per cent) and with real-time transmission and recording (n=7, 38.9 per cent). Descriptive statistics of the data are presented in Table 5.2.

Table 5.2: Respondents' work experiences in detail

Use ECG Routinely with non-traumatic or with traumatic			
	Frequency	Per cent	Cumulative Per cent
No	4	22.2	22.2
with non-traumatic	16	88.9	88.9
with traumatic	2	11.1	100.0
Total	18	100.0	
Yes	14	77.8	100.0
with non-traumatic	14	77.8	77.8
with traumatic	4	22.2	100.0
Total	18	100.0	
Total	18	100.0	
Experienced in telemedicine			
	Frequency	Per cent	Cumulative Per cent
No	7	38.9	38.9
Yes	11	61.1	100.0
Total	18	100.0	
Provided remotely diagnosis			
	Frequency	Per cent	Cumulative Per cent
Recording only	7	38.9	38.9
Real-time transmission	0	0.0	0.0
Recording with real-time transmission	11	61.1	100.0
Total	18	100.0	

Participants were also asked about their involvement in medical instrument conferences in relation to new healthcare service and responses ranged from medium (n=8, 44.4 per cent) to high attendance (n=10, 55.5 per cent), new mobile medical technology acceptance as 'low' (n=2, 11.1 per cent) to 'high interest' (n=9, 50 per cent) and attitude toward mobile adoption as 'after tested and proven' (n=13, 72.2 per cent) to 'use immediately' (n=3, 16.7 per cent). The majority of participants (n=15) had used Far-End (wireless medical system) devices in health recording (a systematic collection of electronic health information about individual patients), whereas only six participants had experienced remote diagnosis for cardiac patients. Descriptive statistics of the data are presented in Table 5.3.

Table 5.3: Attitude toward mobile medical technology acceptance

Involvement in medical instrument conferences			
	Frequency	Per cent	Cumulative Per cent
Medium	8	44.4	44.4
Medium-high	2	11.1	55.5
High	8	44.4	100.0
Total	18	100.0	
New mobile medical technology acceptance			
	Frequency	Per cent	Cumulative Per cent
Low	2	11.1	11.1
Medium	2	11.1	22.2
Medium-high	5	27.8	50.0
High	9	50.0	100.0
Total	18	100.0	
Attitude forward mobile adoption			
	Frequency	Per cent	Cumulative Per cent
After tested and proven	13	72.2	72.2
Medium	1	5.0	77.2
As soon as available	1	5.0	82.2
Use immediately	3	16.7	100.0
Total	16	100.0	

According to the above descriptive statistics, participants are well selected to encompass a diverse range of responsibilities and experiences, and provide multiple perspectives in this research. The frequency distribution shows the different groups of observation from the data set that fall into each category describing the ECG functional characteristics and M-ECG DSS acceptance. In terms of participants' previous experience, they are very positive towards adopting new medical instruments. However, to enhance the quality of healthcare using mobile technology, it is important to look at all acceptance factors (Nesaar & Jean-Paul 2009). The following sections analyse individual responses with a single context that share certain characteristics as a result of being conditioned to study research propositions in the roles of ECG functional and DSS system characteristics, as well as user acceptance of the M-ECG DSS. At the end of each section, the research employs quantitative data analysis to triangulate the data collection to establish finding results, and to observe the effect of a phenomenon over different variables.

5.3 Functional and System Characteristics of M-ECG DSS

This section describes the interview results of qualitative responses relating to ECG functional and DSS system characteristics in a M-ECG DSS, including role of 12-lead ECG, meaningful use, system interface, data transformation and adding value. Results are derived based on interview responses. Participants' responses are anonymous as no information can be associated with an individual, as shown in Appendix A.

5.3.1 ECG Functional Characteristics

Role of 12-lead ECG

Several participants responded that 12-lead ECG in mobile ECG systems should have the ability to detect disease, rhythms and symptoms as well as filter the ECG signal to show charts in a clear waveform. A cardiologist in a Taiwan hospital (TCC01) explains:

> *'A 12-lead ECG device should provide rhythms and symptoms detection. These allow us to examine patient's condition and do some basic diagnosis without having any interpretation.'*

Similarly, a Taiwanese doctor from a ICU department (TDI04) points out that an ECG system needs to have the ability to measure basic human body activities for diagnostic purposes. TDI04 adds:

> *'By bringing mobile technology for cardiac diagnosis, there is a need to perform basic physiological activities related to heart conditions such as heart rate, PR interval, QRS duration, QT interval and QRS axis. This way, we will be able to provide accurate diagnosis from those physiological sign to doctors, cardiologists and patients.'*

An Australian doctor from an emergency department (ADE15) also comments similarly, describing the wide scope of ECG uses has on cardiac service performance as:

'In the case of ECG diagnosis, naked eye observing by health professions still plays important role in measuring ECG charts…. If we can provide advanced interpretation tool, it will maximise ECG services.'

A cardiologist (TCC11) highlights the importance of 12-lead ECG system accessibility in mobile performance for doctors to have on-demand access to information:

'There is a need to record rhythms changes and charts…so that if a patient got a sudden case or need immediacy treatment, we will can have resources available and help them to increase the chance of survival.'

Correspondingly, a Taiwanese cardiologist (TCC02) has experienced that a 12-lead ECG enhances evaluation of cardiac disease and diagnosis. A doctor from an emergency department (TDE12) points out that the ability of a 12-lead ECG system in mobile environment should increase the data performance.

An ICU nurse (TNI03) further adds:

'It is important that rhythms changes on patient's heart condition may affect a diagnosis process in terms of monitoring results.'

Similarly, a nurse from a hematoma department (TNE07) points to the importance of system accessibility in the adoption of mobile technology for ECG services,

'The ability to provide patient's condition and medication correlated with rhythms/symptoms will ensure that patient is getting a right treatment… ensure doctors understand how to deal with wide range of normal variability in the 12-lead ECG.'

According to one Australian doctor (ADE14), the 12-lead ECG and mobile technologies together create an opportunity to present data and information in real-time. Thus, any new 12-lead ECG system needs to be able to detect disease and measure heart conditions, as well as interpret each lead and provide information on a patient’s condition. This could be accomplished by using mobile technology.

Role of meaningful use

Participants strongly agree on the need for ECG functional characteristics in a new mobile service to bring advanced care to cardiac patients. A doctor from a ICU department (TDI08) believes that the timing for implementing mobile technologies into 12-lead ECG has broad implications for monitoring a patient in order to provide cardiac diagnosis. A ICU doctor in Taiwan (TDI06), in emphasising the need for 12-lead ECG system characteristics to be aligned to hospitals, believed major changes to medical diagnosis should include ECG charts and diagnostic intervals of rhythms. This health innovation needs medical specialists involved so that they will benefit. A doctor from one ICU department (TDI05) also adds that mobile implementation must be justified by health organisations to create additional value for diagnosis processes. A cardiologist (TCC02) also stresses another key characteristic in 12-lead ECG for remote diagnosis with the following statement:

> *‘It is critical that you have to integrate waveform description in place to make message more useful. The 12-lead ECG should provide information professionally…incorporate complex processes and workflow that involve all doctors and nurses, other healthcare practitioners, and settings.’*

A doctor from ICU (TDI10) also alludes to the importance of ECG functional characteristics in mobile adoption, highlighting that ECG data to support and improve diagnosis practices, education and research, are established prior to implementation of useful 12-lead ECG resources.

> *‘An ECG system should have information to interpret ECG chart by individual physicians and also consider “complete” EMRs that already contain all the needed functionality.’*

A cardiologist in Taiwan (TCC11) emphasises the need for a 12-lead ECG functional characteristics to have a strategic approach to mobile implementation:

> *'Their use by doctors and nurses to achieve significant improvements in cardiac care will lead us to adopt new system regarding the objectives that allow practices and hospitals to qualify for use of mobile ECG.'*

A cardiologist in Australia (ACC16) reiterates this view:

> *'Don't need to think what the missing value in normal ECG uses because it has been identified for a long time. Extending the benefits of EHRs should be a key point to bring what we need in 12-lead ECG…this includes providing patients with electronic versions of their health information and identifying major transitions in the ECG charts.'*

Similarly, one of the Taiwanese doctors from ICU (TDI05) highlights a major and widespread reality that a mobile ECG should have resources available for meaningful use:

> *'The core element is to improve basic diagnosis of cardiac disease and knowledge-based prompting… This may perform a better solution in EMS conditions or remote diagnostics.'*

A doctor from ICU (TDI08) perceives that a 12-lead mobile ECG creates a meaningful use in supporting office- or home-based access by providers via use of mobile technologies. TDE09 also suggests that ECG services should emanate from and be aligned to the requirement of its user.

> *'Create additional feature to help ECG diagnosis and data transformations for diagnosis process are the most important for ECG monitoring nowadays. But once you move to that mobile environment, it increases simple things to be complicated.'*

A doctor from ICU (TDI06) adds:

'How to balance new implementation and provide positive effect to user could be aligned to process of diagnosis. ECG diagnosis has existed for a while, it is important to adjust new value and element of that change and that necessary information to mobile ECG services.'

A doctor from an emergency department (ADE14) also concurs:

'The use of information to assist ECG diagnosis needs to be considered in a different scenario to any possible cardiac treatment.'

One other cardiologist (TCC02) shares this view:

'In most of case, patients need to be intensively monitored as much as we can and this aligns on balance between receiving useful data recording and recognising the disease in a clear waveform.'

However, according to TDE09, hospitals face difficulty in standardising on technologies used,

'The challenge we face is getting it integrated and getting a uniform approach to ECG needs, and when to use, and what do we use it for.'

According to one Taiwanese cardiologist (TDC01), the diagnosis process using mobile devices for 12-lead ECG has proved to be an urgent need. An Australian cardiologist (ACC16) also believes that adopting mobile technologies in ECG has a positive impact on diagnosis settings through a multitude of time and resource-based benefits. Thus, any new implementation to be included in ECG functional characteristics needs to consider usefulness and be meaningful to users. This could be accomplished by adopting a decision support system concept in the ECG system.

The findings of this study **lend support** for **proposition (P1)** that adopting mobile technology into an ECG system requires specific ECG functional characteristics to be included in order to deliver useful data to users. ECG functional characteristics identified as being needed are: provide measurements, provide advice on patient's condition, waveform description and disease detection, particularly through the use of mobile communication technologies. Moreover, the findings suggest that the M-ECG DSS should consider 'complete' EMRs (Electronic medical records) or EHRs (Electronic health records) functionality in order to develop a system that results in an accelerated diagnosis process. Consequently, increased meaningful use in supporting clinical- or hospital-based access via use of mobile technologies leads to accelerated acceptance momentum. The delivery of ECG charts in a digital form through enhanced mobile technologies connotes that non-delay and two-way communications have the potential to improve diagnosis interactions between specialists. In this respect, adapting necessary ECG data followed by ECG functional characteristics for obtaining high asymptotic performance creates an environment in which clinicians are able to deliver high quality, patient-specific information. Evaluating system accessibility and meaningful use for mobile health technology are identified to have a profound impact on diagnosis delivery. This includes data performance and receiving better ECG information (image and chart). The study indicates that the prototype M-ECG DSS should include necessary ECG functional characteristics in order to support health professionals and to enhance the performance of the diagnosis process in day-to-day interactions.

5.3.2 DSS System Characteristics

Role of system interface

Some of the most effective mobile system interfaces have been those that interoperate with human interactions. A doctor from Taiwan (TDI04) identifies the importance of user interface in mobile DSS for ECG diagnosis.

> *'An interface should provide an ability to speed up decision-making and simplify diagnosis process when operating systems.'*

Similarly, an Australian nurse from emergency department (ANE13) adds:

> *'The user interface in mobile device should take into account special perceptual or users' normal behaviour so that we can use DSS more efficiently, with minimal errors and frustration.'*

A cardiologist from Taiwan (TCC11) also adds:

> *'I have to say that the key for developing user interface should reduce unnecessary surfing.'*

User interface provides **content adaptation** by adaptive selection and prioritisation of the most relevant items when 'a user searches for relevant information and includes the adaptation of visible components layout' (Ekaterina et al. 2005). TCC02 also highlights an important layout characteristic for a user interface towards DSS adoption:

> *'User is able to interpret a menu and locate a particular patient that they wish to view. Easy of navigation and fast responses may affect level of user acceptance when using a mobile system… A different ECG data format is required for small screen to assist ECG diagnosis in mobile device.'*

A doctor from ICU (TDI05) summarises:

> *'System user interface in mobile DSS should provide ability in that being able to distribute information for decision-making and have interoperation with natural human interaction.'*

Thus, the user interface in DSS should rely on a user being able to quickly transition from novice to expert. The role of DSS system characteristics for M-ECG also needs to give a user the feeling that they are instantly and continuously successful in providing diagnoses. This could be accomplished by adopting a more natural and intuitive user interface in a DSS.

Role of data transformation

Health services through mobile technologies are a useful and time-saving tool for clinicians in healthcare when obtaining profiles of patients' medical data and to enable detection of medication errors to reduce diagnosis failures (Pauline et al. 2010). This is clearly evident in the following statement by one of the cardiologists in Taiwan (TCC01).

> *'The new generation of mobile health technology should have reliable data transformation for medical diagnosis.'*

The need for a decision support tool to deliver high quality, patient-specific information just when it is most useful continues to grow (Peter et al. 2010, p. 772). An Australian cardiologist (ACC16) supports this view that the availability and accessibility of data transformation is a key characteristic in a mobile DSS.

> *'Dealing with all kinds of cardiac symptom, it is a critical thing to provide non data loss and readable ECG charts. This helps us to identify rhythms easily and correctly.'*

The same cardiologist (ACC16) emphasises that DSS in a mobile environment should deliver 'real-time' transmission and transformation of data and have the ability to 'process ECG information' faster for medical practices. A doctor from ICU (TDI10) also shares the consensus view that data transformation should provide individuals with a sense of being up-to-date, regardless of the presence of uncertainty. There is general agreement that most doctors and nurses would be grateful to see a measurement tool on screen. A doctor from ICU (TDI06) reiterates the view of many participants that a DSS in ECG diagnosis creates the possibility to reduce time taken for diagnosis.

> *'Meaning of DSS in medical service should refer to time-saving tool to deliver healthcare services.'*

A doctor from ICU (TDI10) also shares the consensus view that data should provide individuals with a sense of being up-to-date, regardless of the presence of uncertainty. ACC16 adds:

> *'Through mobile technologies, "real-time" access to ECG charts is beyond anything that we ever used to have. This is a big thing happens in medical diagnosis field for health delivery.'*

Thus, DSS system characteristics should involve not only communication but also an environment (**structure and presentation adaptation**) that can provide a highly scalable interface for users. This may include real-time mobile communication and the efficient conversion of ECG real-time data. Moreover, allowing clinicians to interpret ECG charts in a digital form (measurement tool) without using any additional physical tools creates an opportunity to speed up the diagnosis process.

Role of adding value

There is wide consensus amongst the participants that a DSS needs to improve doctors' quality of care and increase their effectiveness. A cardiologist from Taiwan (TCC02) states:

> *'DSS should create channels for different type of symptoms… What DSS does, it should allow you to identify cardiac rhythms easily. For example, specific sinus rhythm with unusual frequency content at different values of heart rate. This may increase the quality of cardiac treatment based on our decision-making.'*

There is also general agreement amongst participants that an ECG DSS should involve the process of decision-making and enrich ECG content. A doctor from an emergency department (TDE12) also points out the underlying intention of DSS in ECG diagnosis.

> *'The whole point of DSS for mobile ECG monitoring is to be able to reach patient's detail in a remote location.'*

ICU nurse from Taiwan (TNI13) also adds:

> *'This creates value for health service as mobile access provides remote diagnosis. I would like to see a DSS which enhances the quality of a physician's decision-making.'*

Correspondingly, DSS in healthcare has been identified to assist medical practitioners primarily in two areas: data interpretation and diagnosis (Chung & Hsueh-Ming 2009). A nurse from an emergency department (ANE13) states:

> *'The key value to be included [in] a DSS should be: interpretation, time taken to retrieve patient's medical records, automatic analysis and examination of outcomes and… access to the latest medication formulary, disease description.'*

There is also a general agreement that most doctors and nurses would grateful to have patient detail available online. A cardiologist from Taiwan (TCC11) highlights this view by stating:

> *'There is a need to have records on patient's condition, medical history and medication… we will have resources available to help them to increase the chance of survival.'*

Thus, DSS system characteristics should include reference material to assist clinicians. This can be incorporated in a mobile system to support CVD care in diagnosis settings.

The findings of this study **lend support** the **proposition (P2)** that DSS system characteristics can be integrated in a M-ECG to support CVD patients in diagnostic settings. The study also finds that the user interfaces is often the key to acceptance of new mobile health technology. DSS system characteristics were identified to consist of content adaptation (real-time ECG data, patient history and reference), structure adaptation (communication, device environment) and presentation adaptation (measurement tool) in a mobile environment. A DSS is required to interact with a user on practical experience, receive ‘usefulness’ and ‘ease to use’. The findings suggest that an ECG system on a mobile platform is required to integrate a user friendly interface to offer decision support to users. There is consensus amongst participants that a mobile tool to assist doctors and nurses in their clinical diagnosis is needed in situations where patients are not nearby or where faster assessment is required. The findings clearly establish that DSS builds confidence in using the M-ECG. This helps researchers to develop effectiveness in the use and performance of a system. The identified ECG functional characteristics through collaboration with DSS system characteristics are found to significantly influence both perceived diagnosis quality and effectiveness of diagnosis outcomes. A mobile DSS often requires the ability to speed up decision-making and simplify the diagnosis process. The results of the study indicate that the UI in a mobile DSS requires interaction to fit a user’s normal use of behaviour and create meaningful use from the system. However, participants claim that a small screen to assist ECG diagnosis in a mobile device might have an impact on decision support. Clinicians require a mobile DSS to present information in four categories: communication (processing quality of pre-diagnosis and providing full ECG charts and images); device management (type of device used in the M-ECG), measuring tool (diagnosis methods and tools) and reference (patient management and knowledge sharing). This study finds that adopting identified DSS system characteristics to the prototype M-ECG DSS could meet clinicians’ expectations and create more channels for different diagnoses.

Nevertheless, adopting a DSS should be established in an environment where it can be integrated into usual workflow processes. Using a mobile service and DSS for CVD diagnosis is still in the early stage of development, thus, clinicians may be uninformed or have concerns regarding its scope and usability. The selection of a mobile device operating system (OS) is also identified as having an influence on perceived ‘usefulness’ and ‘ease to use’. To deal with this matter, the M-ECG DSS needs to incorporate user-friendly smart mobile devices and diagnosis processes for more accurate treatment by adopting ECG functional/DSS system characteristics together. This would help reduce the possibility of incorrect diagnosis by clinicians and perhaps create better patient outcomes.

5.4 Mobile Technology Acceptance in M-ECG DSS

This section describes the results from data analysis regarding mobile health adoption to deliver healthcare (Table 2.3 and Figure 3.3), perceived usefulness, task/technology fit, legal action, social influences, user resources, result demonstrability and doctor-patient relationship. The results are drawn based on interviews and surveys' responses after using the M-ECG DSS.

In terms of overall mobile technology acceptance in M-ECG DSS, Table 5.4 shows that the average of overall perceived usefulness is 4.08 (out of 5) with standard deviation 0.575, overall task/technology fit (3.99 out of 5, SD = 0.611), overall fear of legal action (3.31 out of 5, SD = 0.99), overall social influences (3.5 out of 5, SD = 0.94), overall perceived user resources (3.25 out of 5, SD = 1.07), overall result demonstrability (4.12 out of 5, SD = 0.49), and overall doctor-patient relationship (3.2 out of 5, SD = 1.63).

Table 5.4: Descriptive statistics: mobile technology acceptance

Factor	N	Min	Max	Mean	Std. Deviation
Perceived Usefulness	18	3.00	5.00	4.08	0.575
Task/Technology Fit	18	3.00	5.00	3.99	0.611
Fear of Legal Action	18	1.67	5.00	3.31	0.993
Social Influences	18	1.50	4.50	3.50	0.947
Perceived User Resources	18	1.00	5.00	3.25	1.074
Result Demonstrability	18	3.11	4.89	4.12	0.493
Doctor-Patient Relationship	18	1.00	5.00	3.22	1.629

5.4.1 Perceived Value from User Behaviour

Perceived usefulness

Perceived usefulness factor is comprised of content and benefits of the support system, as well as barriers to and facilitators for implementation of the system (Davis et al. 1989). A doctor from ICU (TDI06) reveals that mobile technologies are leveraged to advance ideas in the decision-making stage. There is general agreement that ECG DSS using mobile transmission enables individuals to achieve an instant diagnosis and prescribe treatment. This is particularly evident in the response of a doctor in an emergency department in Australia (ADE15).

> *'Our future medical service and healthcare is going to move from traditional printout to all digital. A smart phone just enables collaborative-based decision-making in healthcare. This application will be able to accelerate the specialist's process of discussion, debate and decision. '*

An Australian cardiologist (ACC16) continues:

> *'Faster to make an assessment and avoid unnecessary suffering can be gained in this mobile adoption but it is probably a matter of getting used to it.'*

A nurse from ICU (TNI03) also reiterates this view:

> *'Mobile control of DSS for real-time monitoring when we are in situations that needs us to communicate with the patient immediately.'*

One doctor (TDE09) highlights that mobile technologies enable support for patients at all levels within cardiac care to contribute:

> *'Diagnosis opportunities for a hospital or clinic that lack sufficient ECG diagnosis equipment… and is more likely now to be useful in cardiac care environment.'*

Participants perceive that the M-ECG DSS promotes realistic expectations of real-time monitoring and higher levels of cardiac care to patients. With easy access to ECG information from the hand-held device, it could contribute to increasing confidence towards acceptance. A doctor from ICU (TDI10) states:

> *'If carried out properly, it can increase confidence.'*

A nurse (TNE07) also adds:

> *'It provides confidence to me because there is so much information …also includes the reference for reviewing ECG knowledge.'*

A nurse from Taiwan (TNE07) continues with this view:

> *'Different departments may have different requirements… the ambulance may have different needs than a hospital or home care group. This application comes with so much potential for me.'*

A cardiologist from Taiwan (TCC11) perceives that M-ECG DSS needs to be used more extensively to collaborate with cardiologists affected by technology change. A doctor from ICU (TDI08) states:

> *'It won't be an issue to accept new mobile technology for doctors… from my point of view, we love trying new things to speed up all diagnoses.'*

The discussion around ECG data transmission and transformation has been identified to provide 'real-time' diagnostic capabilities using wireless as a way to reduce time taken for a diagnosis. One doctor from Taiwan (TDI10) summarises the majority view that ECG with mobile communication capability should initially involve establishing a decision support process, developing doctors' skills and ultimately creating efficiency. However, there is little a word of caution to be considered. A cardiologist from Australia (ACC16) states:

> *'Do not think it is time saving...almost all patients need to have a careful diagnosis and analysis.'*

Another Taiwanese cardiologist (TCC02) also adds:

> *'This ECG DSS application… that's going to only give us 50 precent of what cardiac patients need and what current ECG lacks, so there is no need to*

consider transmission latency or data communication…. should be more focus on decision support on mobile devices.'

During interviews, participants were asked to answer a questionnaire about usefulness of this M-ECG DSS. The questionnaire also included a general ranking of overall perceived usefulness of the M-ECG DSS. Thus, responses from these participants were analysed. Descriptive statistical analysis is used to examine responses. The results of perceived usefulness factor are provided in Table 5.5.

Table 5.5: Descriptive statistics: perceived usefulness of the M-ECG DSS

	N	Range	Min	Max	Mean	Std. Deviation
It is easy to analyse a patient's data using the M-ECG application (using multi-touch measuring scale tool)	18	1	4	5	4.28	0.461
M-ECG application provides legible information and reliable output	18	3	2	5	4.22	0.878
This 12-lead M-ECG device has more flexibility for me to provide patient support than other ECG devices I use	18	3	2	5	4.00	0.970
Paramedics within EMS system could utilise the M-ECG technology routinely	18	3	2	5	4.33	1.138
Overall perceived usefulness of a mobile devices	18	4	1	5	4.22	1.215

Based on perceived usefulness of M-ECG DSS, the results show that there are variances between area of practice, and within positions. Table 5.4 shows that the average for perceived usefulness is 4.08 (out of 5) with standard deviation 0.575 (Table 5.4). There was no difference between usefulness and their work positions ($F(2,15) = 1.151$, $p > 0.05$) on perceived value from user behaviour (Appendix B1). It appears that cardiologists, doctors and nurses support the proposition of perceived usefulness of the M-ECG DSS.

For different department in hospitals, there is no main effect on overall perceived usefulness ($F(2,15)=1.224$, $p>0.05$) which is part of user behaviour (Appendix B2). In addition, no interaction effect is observed. This result is in line with the comments made by participants: the mobile technology appeared to be the most useful decision support tool to help specialists provide far-end (remote) diagnosis.

However, for the impact on patient support from other ECG devices and the M-ECG DSS, the interaction effect between different countries and usefulness ($F(1,16)=10.256$, $p<0.05$) was significant (Appendix B3). For Taiwan, users perceived the highest level of usefulness while reading M-ECG DSS output to their daily cardiac practices.

According to the above analysis, mobile technologies and ECG DSS together create not only an opportunity to speed up diagnoses, but also usefulness in decision-making. What follows is an analysis of how the M-ECG DSS also needs to be more precise regarding specialists' expectations of a DSS for different departments in order to increase the level of usefulness.

Task/Technology fit

An ICU nurse (TNI03) revealed that mobile technologies are enabling health services to develop a proactive approach. An Australian nurse from an emergency department (ANE13) also supports this notion:

> *'When I started using mobile technologies to get information, I found that what can be done is to increase the ability of health services and we can be proactive in remote services.'*

An Australian doctor from an emergency department (ADE15) also refers to a specific need for this ability to change, referring to remote health diagnosis:

> *'The current health services have worked under an environment where mobile services can be accessed anytime, anywhere... there is a chance to add value on how to bring remote health service to people successfully… more and more medical diagnosis become available and come online in rural area…. This application did meet the smart future technologies.'*

An Australia nurse from clinical cluster education unit (ANE17) also provides a similar point of view:

> *'We need this because this could actually save patient in-bed uses which will save us money as well.'*

Some participants identify that M-ECG DSS is enabling cardiology to replicate success. This is particularly evident in the response of TDE09:

> *'Remote diagnosis of cardiac disease is a necessary treatment to ensure that the cardiac patient can be taken care of by us or by one particular team all the time. I can see that this system just brings an idea to health service and provides an example of real-time remote monitoring… This technology has potential to fit into cardiologists' daily activities.'*

A cardiologist from Taiwan (TCC01) also strongly emphasises that hospitals and clinics have a responsibility to provide these mobile technologies as it has a positive impact:

> *'Mobile technologies that we currently use as a communication tool… should lead us to develop health service through mobile and create better healthcare outcomes.'*

Mobile health services are also enhancing collaboration at the medical scale, according to TDE09:

> *'Health services with mobile technology have changed the way we run our medical diagnosis nowadays and I think that we are far more effective in the process of diagnosis… This device creates frequent interactions with mobile communications to narrate patient's condition than before.'*

Under the use of the M-ECG DSS, participants also report that this is their first experience using a multi-touch function as a measuring tool in ECG diagnosis. One

ICU doctor from Taiwan (TDI5) also finds that it is aligned closely with current work practices:

> *'While I can use it in its entirety I think it is a very useful tool that can benefit much of our everyday work.'*

An Australian doctor from emergency department (TDE12) also adds:

> *'It has not been easy, but it's a beginning, before you have learnt the functions…. then I would have indeed used it, I would change to a better smart phone and use in my daily work.'*

Participants acknowledge that this device would be able to help them keep abreast of the latest information through mobile adoption. One of the cardiologists (TCC02) points out that whilst mobile technology is intended to enhance time taken for diagnosis, there is also the possibility of applying this concept to more complex environments for remote health services. However, most participants believe that hospitals would obtain support for the use of mobile technology from within the public healthcare sector. The response of a ICU doctor (TDI08) points out that one aspect of the lack of support related to the level of skills.

> *'I believe that the hospital IT department may not highly skilled and would take some time to adjust to support a more innovative device like this M-ECG DSS.'*

A doctor from an emergency department (ADE14) adds:

> *'There are resources required to support the use of such devices and that still will need to be incorporated with general practices. I wish to see this service in action as soon as possible.'*

Participants reveal that whilst mobile technology is enabling collaboration at a medical level, there are implications for other health services. One of the doctors

(ADC15) also emphasises that hospitals are facing new innovation of mobile health services:

> *'There is always going to be a need to discuss patient information through telecommunication in term of medical diagnoses and you have to hand off to mobile communication. These services are getting sort of attention and support that you want from your professional status.'*

During interviews, participants were asked to answer a questionnaire on how new mobile technology fits to medical service needs. The questionnaire also included a general ranking of overall technology/fit of the M-ECG DSS. Descriptive statistical analysis was used to examine responses, and the results of task/technology fit factor are provided in Table 5.6.

Table 5.6: Descriptive statistics: task/technology fit

	N	Range	Min	Max	Mean	Std. Deviation
M-ECG mobile application prints better ECG wave graphs	18	2	3	5	4.33	0.767
It is a good idea to use M-ECG application as a reading instrument in comparison to using the original ECG on paper read-out	18	3	2	5	3.72	1.074
To what extent do you perceive that there are realistic expectations for the use of mobile technology in an ECG monitoring device for treatment and diagnosis in hospital, home care and clinic?	18	2	3	5	3.94	0.725
To what extent do you believe there are benefits to be gained by the application of a mobile ECG for the production and delivery of patient care?	18	2	3	5	4.17	0.618
To what extent have you tested/trailed or experimented with M-ECG (hardware/software) for its potential use?	18	4	1	5	3.78	1.263
Overall Task/technology fit	18	4	1	5	4.00	1.188

One-way ANOVA also shows that there was no interaction effect between task/technology fit and department ($F(2,15) = 0.945, p > 0.05$) (Appendix B4), status

($F(2,15) = 0.369, p > 0.05$) (Appendix B5), and country ($F(1,16) = 2.27, p > 0.05$) (Appendix B6). The average of task/technology fit is 3.99 (out of 5) with standard deviation 0.611 (Table 5.4). Therefore, mobile technology implementation has support in the case of healthcare services.

However, in a case of comparative tested/trialled or experimented use of M-ECG DSS for its potential use in hospital, there was a interaction effect between task/technology fit and country ($F(1,16) = 6.731, p < 0.05$) (Appendix B7). Taiwan has a perceived higher level of mobile technology interest in the use of M-ECG DSS.

According to the above empirical analysis, participants would consider using mobile technology services in a healthcare environment. They expect that mobile technologies would provide doctors and nurses who do most of their work at the point of care with the ability to diagnose remotely. Cardiologists, doctors and nurses in Taiwan have a high interest in mobile technology adoption in health services. Thus, the mobile technologies and ECG DSS together have the ability to accomplish ECG diagnosis and create better healthcare outcomes.

Fear of legal action

Another influence identified by doctors who want to use mobile technology as an information and decision support system is, 'reflecting the growing unease amongst the doctors of the increasing trend of malpractice legal suits being brought against doctors' (Nesaar & Jean-Paul 2009). One ICU doctor from Taiwan (TDI04) highlights a major and widespread reality that hospitals take lower responsibility than doctors:

> *'This M-ECG DSS might help in action that could assist doctors for incorrect cardiac diagnosis and management.'*

A nurse from a hematoma department (TDE07) believes that reducing fear in decision-making could increase the level of M-ECG DSS use. The fear of legal action is a concern for nurses in their work and, as they see it, is the only way by which doctors have their instructions carried out. TDE07 states:

> *'We are supposed to be simply an assistant for the purpose of carrying out doctor's orders but what if doctor makes a mistake.... welling to see this device keeping a history of patient data and all decisions made regarding diagnosis; it could help defend the doctor's decisions.'*

ICU nurse from Taiwan (TDI03) adds:

> *'An audit of patient information and history, a patient's diagnosis prescribed could be kept.'*

One of the Australian cardiologists (ACC16) explains that cardiac diagnosis depends to a substantial degree on a good understanding between doctors, cardiologists and nurses. When cooperative communication is lacking, diagnosis is under threat and healthcare is impaired. A doctor who specialises in surgery (TDE12) states:

> *'I can see a demand for building a highly skilled DSS tool for cardiac diagnosis. The mobile communication and DSS together is just what we need to reduce mistaken treatment… the actual diagnosis should involve not only voice-to-voice but also with evidence supported… this is the perfect solution to reduce my trepidation of cardiac diagnosis.'*

The fear of legal action being brought against a doctor or nurse was also identified during the discussion on patient influence. They are aware that once the M-ECG DSS becomes a major mode of diagnosis delivery for cardiac patients, a doctor needs to make 100% certain that the correct decision and diagnosis of the patient takes place.

> *'I have confidence that this could help reduce the possibility of incorrect diagnosis and perhaps legal action against doctors.'(TD6)*

An Australian doctor from emergency department (ADE15) adds:

'Generally… I can see the potential capability of this DSS, once you move to that mobile technology environment, it could enhance diagnosis skills but….This is just a tool to increase decision-making and decision support for a patient's diagnosis. There is no need to fear legal action from using it.'

An Australian nurse from a clinical cluster education unit also supports this view as long as the process is very transparent as to who receives data, where to put data and where it data is recorded and what is done with it. However, there is a conflicting statement to rebut the fear of legal action:

'The worst case scenario is someone being sent to hospital and not having access to case, then patient die... This has happened anyway by using Holter ECG… if patient is well doesn't mean patient is not sick… so M-ECG only achieves a 50% success rate in diagnosis to support treatment.'(TDE07)

A nurse from nursing support unit (ANE18) adds:

'If the protocols of use for M-ECG DSS are very clearly defined then there is no problem with fear of legal action… because the protocols will identify the risk.'

During interviews, participants were also asked to answer questions about fear of legal action from use of new mobile technology in dealing with their patients. These questions are based on participants' attitude towards accepting mobile implementation that could reflect to fear of or manifest into legal action. The questionnaire included a general ranking of overall fear of legal action to users. The following descriptive statistical analysis examines responses relating to fear of legal action factor, the results of which are provided in Table 5.7.

Table 5.7: Descriptive statistics: fear of legal action

	N	Range	Min	Max	Mean	Std. Deviation
To what extent do you accept new mobile medical technology in treatment of patients?	18	3	2	5	3.89	1.231
In your opinion should new medical technology with mobile technology be implemented?	18	3	2	5	2.78	1.166
Overall perception of fear of legal action	18	4	1	5	3.28	1.526

One-way ANOVA also shows that there is no interaction effect between fear of legal action and department ($F(2,15) = 1.461, p > 0.05$) (Appendix B8)., status ($F(2,15) = 1.262, p > 0.05$) (Appendix B9), or country ($F(1,16) = 1.271, p > 0.05$) (Appendix B10). The average for fear of legal action is 3.31(out of 5) with standard deviation 0.993 (Table 5.4). This result is in line with the above analysis. Doctors and nurses have strong acceptance that M-ECG DSS increase the ability of diagnosis and reduces the fear of legal action.

According to the above analysis, most participants strongly agree this M-ECG DSS solution reduces trepidation in cardiac diagnosis. The majority of participants also concur that the M-ECG DSS itself can only achieve a 50% success rate in the diagnosis process. Thus, the influence of mobile technology towards ECG decision support system is not limited to fear of legal action. This also could improve usability and acceptance of mobile health to ameliorate this factor.

The M-ECG DSS is perceived to make an impact on organisational and individual aspects of acceptance. The results show acceptance of M-ECG DSS from users' behaviour (and **lend support** the **proposition P3**). This is supported by findings that the ECG functional and DSS system characteristics identified in P1 and P2 respectively are acceptable to users. Mobile diagnosis still requires training and practise, particularly where technology change impacts on the role of diagnosis. Based on observed user behaviour, the findings identify that cardiologists are accelerating their discussion and decision-making process more than other users. Doctors accept the system to be an effective way of diagnosis and to facilitate mobile implementation in healthcare in order to receive better quality diagnosis, faster assessment and avoid unnecessary suffering as key features of the M-ECG DSS.

Providing real-time monitoring is also a necessary characteristic to satisfy users' needs in a mobile health setting. The real-time monitoring encountered by individuals in their day-to-day workflow processes and through collaboration with EMS is found to be important and of perceived value to deliver ECG data.

This research also finds that cardiologists perceive a high level of usefulness in the use of M-ECG DSS. The findings also identify that perceived usefulness of mobile health technology could depend on environments wherein clinicians are familiar with extensive use of smart mobiles. In this respect, clinicians are not afraid to use mobile technologies as their diagnosis method in their daily practices.

In relation to perceive 'task and technology fit', the findings identify that advanced mobile communications could affect the use of mobile health technology in delivering health services. The speed of data transmission and transformation is also essential in driving successful adoption of mobile health technology in order to enhance the quality of a physician's decision-making, and influences capabilities in which data are transferred. Clinicians are looking forward to using mobile technology to assist their daily practice. The availability and effective utilisation of the M-ECG DSS creates opportunities to deliver ubiquitous care sustainably. In this respect, the M-ECG DSS can now be seen as a model for remote health service to establish a mobile health environment for successful implementation.

5.4.2 Perceived Value from User Satisfaction

To check the experimental M-ECG DSS and operational validity in order to gauge user expectation, the study conducted pilot testing with 4 subjects, after which some revisions were made to the prototype. This provided some development guidance to help ensure the prototype met user needs and to gain further evidence of user satisfaction. Participants were asked survey questions during an interview session after using the system. The research used four different acceptance factors ('social influences', 'perceiving user resource', 'result demonstrability' and 'doctor-patient relationship') (Table 3.2) to measure perceived acceptance value from user satisfaction.

According to one-way ANOVA results, there are no interaction effect between user satisfaction and independent values (status ($F(2,15) = 1.02, p > 0.05$) (Appendix B11), department ($F(2,15) = 2.073, p > 0.05$) (Appendix B12) and country ($F(1,16) = 1.819, p > 0.05$) (Appendix B13).

Social influences

Participants hold the consensus that mobile technology has the potential to influence social relationships between doctors and patients, as well as clinical management. Inherently, the implementation of mobile health technology is a diagnosis process and the effective utilisation of mobile technology requires doctors' input and involvement throughout medical processes. A strong statement in connection with the effect of social influences leading to doctors' decisions to use a mobile technology was made by an ICU doctor from Taiwan (TDI05) who states:

> *'If I see one of my colleagues using such devices and have performed better outcome of diagnosis to their patients, I would most definitely be influenced to get one as well.'*

A nurse from a hematoma department (TDE07) concurs:

> *'... as more doctors start using new device, you will definitely want to see how this device works in action and how it provides better treatment… otherwise, you will become the odd one out for not using such new tools.'*

One of the Australian doctors from an emergency department (ADE15) adds:

> *'Most of the doctors in the hospital that are in-line with the change… therefore adopt change quicker than others, and everyone else will follow.'*

Similarly, a ICU doctor from Taiwan (TDI06) states:

'When certain doctors that you work with see positive values, then you are a lot more likely to adopt this, and actively search for and implement this technology into your daily work.'

An Australian nurse from a clinical cluster education unit (ANE17) amplifies the social influences by commenting:

'The influences could be hospital follows hospital… there is something that successful will result in good patient outcomes.'

But, there is a conflicting statement from an ICU doctor (TDI08):

'I would not be influenced to use this device by my peers nor would I think of it as increasing my status just based on peer influence. I would prefer to test the device by myself and see how it can cooperate with my medical specialty rather than listen to others.'

A doctor from ICU (TDI10) also shares this view:

'It is hard to totally avoid from others… I did agree that status or peer influence could change their decision to use the device… but we still always need to use human intervention in term of providing right treatments.'

According to TDI10, decisions on using this device to provide real-time communication and decision-making have proven the most challenging. A DSS during the development process is likely to increase the interaction between a clinician and mobile communication and lead to a successful diagnosis. Everyone has different preferences in making a medical diagnosis and according to a doctor (ADE15):

'All medical staff could have reason to use it but getting it integrated and getting a closer approach to what we need and when we use it and what do we use it for…will be another story. At this point, we are already influenced by new ways of communication through mobile technologies… what we need to focus on is how to use this technology to enhance our skill of diagnosis.'

An ICU doctor (TDI08) also emphasises that doctors could influence each other by their opinions of the usefulness of a device. One cardiologists (TCC02) points out the important role of influence in adopting new M-ECG DSS:

> *'DSS is a tool to support diagnosis…allow doctors to start using it well and with confidence and without frustration, will increase the chance to introduce to others.'*

An Australian nurse from an emergency department (ANE13) raises the issue that the ability of influencing people in order to deliver different medical diagnoses bears critical influence on the success of diagnosis delivery. ADE14 outlines that the fundamental element of social influences in medical diagnosis depends on a doctor's thoughts, feelings or actions in diagnosis delivery, the ability to lead others to change and instil the right type of diagnosis behaviours. Another cardiologists (TCC02) concurs:

> *'I can see that this M-ECG DSS implementation can be affected by the ability of diagnosis method... The mobile technology has existed for a while, but if it's not aligned to what we need, then it's probably not going to work… however it influences us to build all those diagnosis needs and accept information from another as evidence of treatments.'*

During interviews, participants were asked to answer questions about the potential to influence social relationships between doctors and patients as well as clinical management. The question is based on how well doctors use new communication methods and how they share knowledge with each other. The questionnaire also included a general ranking of overall social influence as discussed in chapter 2 (Table 2.3). The following descriptive statistical analysis examines responses on social influence (Table 5.8).

One-way ANOVA shows no interaction effect between specialists' status and social influences (Appendix B14) on perceived usefulness ($F(2,15) = 0.671, p>0.05$), and perceived higher levels of confidence by doctors in taking advantage of mobile adoption in healthcare system. The average for social influences is 3.5 (out of 5) with standard deviation 0.947 (Table 5.4). However, there is an interaction effect between social influences and departments (Appendix B15) on perceived useful value to deliver new methods of technology ($F(2,15) = 9.276, p<0.05$). Cardiology and ICU departments perceive higher levels of interest in mobile technology adoption from user satisfaction. This is an interesting outcome from doctors and nurses who come across with different opinions when working in different departments.

Table 5.8: Descriptive statistics: social influences

	N	Range	Min	Max	Mean	Std. Deviation
To what extent do you connect/communicate with a medical provider outside your discipline/section on medical and treatment matters?	18	4	1	5	3.56	1.381
To what extent do you connect/communicate with a cardiac specialist at other organisation / department on medical and treatment matters?	18	4	1	5	3.28	1.274
How frequently have you attended some form of healthcare / medical instrument conference in the last year?	18	3	2	5	3.94	1.056
Overall social influences	18	4	1	5	3.22	1.478

In addition, there is no main effect between Australia and Taiwan (Appendix B16) on perceived social influences ($F(1,16) = 0.0, p >0.05$). Therefore, both Australia and Taiwan appear to be similar in their perceptions about mobile technology adoption in a healthcare environment.

According to the above analysis, most participants agree that status or peer influence could change their decision to use the device. Influences could be made by successful results via good patient outcomes. Moreover, different departments may find different value from ECG delivery to cardiac patients. This could influence their intention to use M-ECG DSS.

Perceived user resources

How clinicians perceive the availability of resources they can use in practice has been discussed in the healthcare literature (Table 2.3). Resources to support use of devices did not negatively influence a doctor's intention to use them. Doctors may learn to cope with limited resources on a daily basis, despite their extremely pressurised work environments. Benefits of using mobile technology were identified to include rhythm guideline (TNI03, TNE07, ANE13, ANE17, ANE18) from nurses, patient's history (TDI04, TDI05, TDI06, TDI08, TDI10) from doctors in ICU, time taken for diagnosis (TCC01, TCC02, TCC11, ACC16) from cardiologists, and vision for capability (ADE14, ADE15) from doctors in emergency departments. An ICU doctor (TDI10) also perceives that the M-ECG demonstrates the benefits of cardiac diagnosis skills and is particularly useful when the diagnosis is needed and where the workplaces fail to provide additional instruction on a patient's condition:

> *'To the point where the benefits may not readily realised be because it take time to get affected from diagnosis changes but this DSS may have chance to take us out of the daily routine on diagnosis and give us the opportunity to practice and learn the benefits… then we will be able to see the big picture of a powerful device and DSS.'*

An ICU doctor from Taiwan (TDI08) adds:

> *'Adding useful information is always necessary for decision support system. This is not only perceived usefulness of system but also gives us ability to see through the benefit of new implementation.'*

However, there are a few conflicting statements to rebut the benefits of mobile technology in healthcare. A cardiologist from Australia (ACC16) believes that the use of a mobile technology device within the healthcare environment may not obtain support from health providers. There is a feeling of hopelessness when taking new technology to a hospital's IT support team. One aspect regarding the lack of support related to the level of skills is expressed as:

'I believe that hospital's IT support team may not be highly skilled and would take some time to adjust to support a more innovative device like this M-ECG DSS.' (TDI08)

A nurse from an emergency department (ANE13) adds:

'I feel that the hospital's IT support team was under-resourced and would not be able to cope with addition support required for a mobile technology device.'

A nurse from Australia (ANE17) also highlights this aspect:

'There may be issues using smart phones on nurses. Doctors are easy to follow up with new mobile technologies but not nurses.'

An ICU doctor (TDI10) believes that cooperation required between a hospital's IT support team and doctors is necessary to establish mobile implementations. This is clearly evident from the interview with a nurse (TNE07) who stated:

'The hospital might not support this new innovation of mobile diagnosis in the short term, but that still will not stop us from looking for a new method of mobile medical diagnosis.'

One of the cardiologists (TCC01) highlights numerous other benefits of successful mobile health technology:

'Based on what I see in this system, it has done well to provide all the need of diagnosis information and it's fit for purpose. It accelerates ability of cardiac diagnosis in my work...because this device has got the useful measurement tool that can help me move into next generation of diagnosis environment and perceived more valuable in medical care.'

There was general agreement that effective mobile health technology allows doctors to access a patient's information that is aligned with their diagnosis needs. An

Australian doctor from an emergency department (ADE14) also holds the view that during the new device adoption, whilst support in all aspects is vital to inspiring confidence, it has a minimal effect on the level of acceptance in utilising M-ECG DSS. A cardiologist (TCC02) also highlights that perceived user resources should be established not only in hospital but also in the training stage:

> *'There is a need to perceive personal resources and skill to use the device for doctors and nurses…to adopt mobile technology in healthcare. Doctors and nurses have to be trained to learn very basic infrastructure on decision-making through this mobile environment.'*

Similarly, an ICU doctor (TDI04) highlights the contrasting views of mobile adoption and a decision support system towards user resources:

> *'Lack of resources to support doctors' use of device may influence their intention in this mobile adoption… This could be attributed to the doctors who find themselves in, where they have learnt to contribute with limited resources on the diagnosis.'*

During interviews, participants were asked to answer questions about perceived user resources to benefit cardiac diagnosis skill and particularly usefulness. Based on the literature review, it appears that cardiologists are still using recorded data to evaluate a patient's condition and there is still no mobile monitoring with real-time data transmission. Therefore, the questions can only look at their agreement on currently used devices and perceived availability of user resources for ECG monitoring. The following descriptive statistical analysis examines responses of perceived user resources factor (Table 5.9).

Table 5.9: Descriptive statistics: perceived user resources

	N	Range	Min	Max	Mean	Std. Deviation
To what extent do you perceive that you have sufficient resource for ECG monitoring?	18	4	1	5	3.22	1.700

Based on responses, no interaction effects were observed on perceived user resource issue between two independent variables and status (*F(2,15) = 0.031, p >0.05*) (Appendix B17) or department (*F(2,15) = 0.036, p >0.05*) (Appendix B18). The average for perceived user resources is 3.25 (out of 5) with standard deviation 1.074 (Table 5.4). This result is in line with the above analysis. Cardiologists, doctors and nurses have strong dependency on DSS in order to increase diagnosis resources and show confidence in using mobile technology as their diagnosis instrument. The main user satisfaction levels of different countries on perceived user resources (Appendix B19) while using M-ECG DSS as their decision-making tool also appears to be not statistically significant (*F(1,16) = 0.051, p >0.05*).

According to the above analysis, there is no doubt that mobile technology is a key feature for future health services. ICT in hospitals may lack resources to support innovative mobile health services, but this is the way of the future in healthcare. All participants perceive not only the benefit of mobile adoption, but also the innovation of a multi-touch measuring tool for diagnosis. This could influence functionality and usability of a DSS in M-ECG and influence acceptance of mobile health technology services.

Result Demonstrability

One of the cardiologists (TCC02) believes that M-ECG DSS would be able to help doctors deliver better quality care to their cardiac patients. A doctor from ICU (TDI08) concurs with this view, in terms of the mobile adoption:

> *'At least the M-ECG DSS made those happened… real-time diagnosis… quick decision-making…useful resources…mobile health implementation is an increasingly important component to quality care.'*

An ICU doctor (TDI06) highlights that the effectiveness of mobile technology in a cardiac diagnosis requires an even level of resources. Correspondingly, another doctor from ICU (TDI08) emphasises the need for real-time cardiac diagnosis.

'A real-time monitoring of cardiac patient by which doctors are able to control patient remotely is definitely a necessary element for mobile adoption… and it proves that this system has ability to provide this concept and service… however, there is still a need to evaluate all of resources and realign the DSS, so as the diagnosis method changes, as the new technology adopts, we need to be realigning to not only diagnosis method, but also to be comprehensive as to what is happening within the medical and mobile environment changes.'

Similarly, a doctor from one emergency department (TDE12) agreed that changes in diagnosis methods normally emanate from successful treatment:

'This DSS did provide what I need to remote monitoring my cardiac patients. I don't even need to spend much time on travelling and waiting for ECG data result….I can diagnose those data straightway…it may not only meet doctors' satisfaction but also enhance the success of treatment in patient terms.'

However, one cardiologist (TCC02) is of the view that benefits from changes in diagnosis methods are not easy to measure in the delivery of health services:

'We are experimenting with a new way of delivering medical treatment to patient. This is somehow new to us and I haven't seen the full potential of this implementation even though there are some existing mobile medication methods currently used.'

Involving doctors' skill and judgment, and convincing them to change diagnosis methods which involve decision-making processes, is not easy. A doctor from one emergency department (TDI12) explains:

'It is a lot harder for doctors to change their way of diagnosis to remote monitoring. They are likely to adopt new method to increase their ability for diagnosis but not everything can rely on technologies. A digital measurement tool still can't replace the foundational knowledge of cardiac treatment.'

Where major change is implemented for cardiac diagnosis using M-ECG DSS, doctors must be familiar across the entire process of decision-making. One doctor (TDE09) states:

> *'To have a better quality diagnosis and successful change of diagnosis method, you need to see every individual as doctors need…make it as a useful tool... I can see the potential of mobile technologies in health setting and those changes create an opportunity to allow time, and space for real-time remote diagnosis.'*

A nurse from ICU (TDI04) concludes that this M-ECG DSS results in the ability to make decisions and is necessary for better diagnoses. Another nurse (TNE07) states:

> *'Ideally doctors and nurses… have to learn new ways of diagnosis and everyone needs to have ability to provide earlier diagnosis so that we will effectively manage our patients. This M-ECG just provides all levels of cardiac knowledge, at all functions … that help us rise up the level of right prescription.'*

A doctor from an emergency department (ADE15) also outlines the results of implementation:

> *'The major change not only provides real-time monitoring but also increases decision support process to us…… It is also a good idea to reduce paper use because there are just so many areas where it is better to have digital charts or charts to be use anywhere to provide remote diagnosis. This technique by mobile communication may greatly result in increasing the chance of survival for cardiac patients.'*

The multi-touch measuring tool was also identified by some participants to be the most powerful virtual measuring instrument to assist cardiac diagnosis. The need for this tool with scaling to drive decision-making is clearly evident in the following statement by a doctor from an emergency department (ADE14):

> *'Normally, it is hard to make a final decision or measure ECG charts if there is no physical ruler and may spend more time looking at graph. With this multi-touch scale, I am able to give the right diagnosis in just few second. This ruler is just what is missing for simple diagnosis needs… not only carries a lot of influence in helping cardiac diseases, in the real-time communication and time taken for diagnosis, but also provides more way of examination.'*

There was general agreement that the multi-touch measuring tool is able to reduce the number of incorrect diagnoses. A cardiologist from Taiwan (TCC02) states:

> *'It is hard to make a decision if there is too much interference or with abnormal appearance…especially when we can't see our patient face-to-face. We need a DSS to support our decision-making and speed up diagnosis… This tool did provide the ability to evaluate our patient's condition.'*

Another cardiologist (TCC11) also highlights that when mobile adopted technologies occur in healthcare, doctors more readily accept new diagnosis techniques.

> *'If I hear about the new coming technique to assist our daily diagnosis needs, I would definitely want to know what it is and hope that it makes it a lot easier for us to work with our patients'*

Similarly, an ICU doctor (TDI04) states:

> *'This M-ECG DSS will lead the change of diagnosis method in healthcare, but doctors might get more ideas from those changes. This is a good start to demonstrate the possibility of real-time monitoring and remote diagnosis in healthcare settings.'*

Participants answered survey questions about the value of a new implementation to deliver better quality care to their cardiac patients. Descriptive statistical analysis examines responses - the results for the demonstrability factor are provided in Table 5.10.

For demonstrability, neither of the two independent variables showed statistically main effects with M-ECG DSS nor any interaction effects on M-ECG DSS (department ($F(2,15) = 0.53$, $p > 0.05$) (Appendix B20); status ($F(2,15) = 0.425$, $p > 0.05$) (Appendix B21); or country ($F(2,15) = 0.53$, $p > 0.05$) (Appendix B22). The average result for demonstrability is 4.12 (out of 5) with standard deviation 0.493 (Table 5.4). Therefore, there is no perceived difference between demonstrated M-ECG DSS output for diagnosis and paper-based presentation of the same output.

Table 5.10: Descriptive Statistics: result demonstrability

	N	Range	Min	Max	Mean	Std. Deviation
M-ECG application increases the level of quality in comparison to a 12-lead ECG paper printout	18	3	2	5	3.67	1.138
Diagnosis time has been reduced by using the M-ECG application in comparison to other 12-lead ECG devices	18	3	2	5	4.00	0.970
M-ECG provides data completeness in presenting and recording	18	2	3	5	4.33	0.686
To what extent do you perceive that M-ECG can enhance the **quality** of your treatment and diagnosis for patients?	18	2	3	5	3.89	0.583
To what extent do you perceive that mobile ECG can enhance the **delivery** of treatment and diagnosis to patients?	18	2	3	5	4.17	0.618
M-ECG system will improve the overall referral processes and treatment of cardio vascular patients	18	2	3	5	4.33	0.686
M-ECG can be particularly helpful to doctors, to assist them in initiating appropriate early action while also making more accurate assessments and focused treatments	18	2	3	5	4.28	0.669
This M-ECG can support patients because it has capabilities for long distance communication through a high-level interactive M-ECG interface for notification	18	3	2	5	4.39	0.916

However, there is a interaction effect for data completeness in presenting and recording section ($F(2,15) = 8.152$, $p < 0.05$) (Appendix B23) from different departments. ICU departments perceive higher value in detailed data presentation and recoding from the M-ECG DSS. This could be because of different types of job requirements and diagnosis needs.

According to the above analysis, all participants agree that the M-ECG DSS could provide ‘real-time’ monitoring, remote diagnosis and decision support. The M-ECG DSS may lead to changes in diagnosis methods for cardiac disease. Thus, any new mobile health DSS needs to be time saving, enhance effectiveness, have competitive advantage, promote learning and increase decision maker satisfaction. This could be accomplished by the M-ECG DSS and thus add value.

Doctor and patient relationship

Participants perceive that doctors are the main drivers of diagnosis change, and that change is driven from the acceptance of new method implementation. One of the nurses from Australia (ANE18) emphasises that the doctor-patient relationship is central to diagnosis practice and is essential for delivering quality of care. The doctor-patient relationship forms one of the foundations of medical ethics and is referred to as rapport between doctors and patients, upholding patients’ dignity and respecting their privacy. A nurse from Taiwan (TNE07) states:

> *‘We must have confidence in the competence of our diagnosis and must get our patient to feel that they can depend on us… so we can be able to maintain good relationship to our patients. To maintain a professional relationship with our patients is important in some cases, such as cardiology and family medical treatment.’*

There is general agreement that the quality of the doctor-patient relationship is important to both parties. A better relationship in terms of mutual respect, trust, shared values and perspective about disease and life, or even time available, will improve the amount and quality of information about the patient’s disease. It can enhance accuracy of diagnosis and increase the patient's knowledge about the disease. The view resonates clearly in the response of an ICU nurse (TNI03):

> *'Doctors should at least be aware of disparities in order to establish relationship and optimise communication with their patients. This M-ECG DSS implementation seems create a channel to increase communication skills to both of us… It may future benefit for us having a form of diagnosis method in healthcare system.'*

However, one cardiologist (TCC02) advocates the importance of the doctor-patient relationship being connected with the degree of responsibility for healthcare:

> *'New adoption is considered in situations where determining the most efficient diagnosis, or encountering avoidance of diagnosis, creating a disagreement between the doctor and the patient… In such cases, we need to minimise unfavourable treatment options to strain doctor-patient relationship. This DSS just creates a way to whole new level of cardiac diagnosis for ECG use and best interests.'*

An ICU doctor from Taiwan (TDI06) also perceives that the relationship between patients and healthcare practitioners may decrease the quality of care in the time taken to re-establish proper doctor-patient relationships. An Australian nurse (ADE13) also states:

> *'Generally, the doctor-patient relationship is facilitated by continuity of care in regard to attending personal… the mobile technology in cardiac care creates an opportunity to continuity diagnosis by single healthcare providers using remotely method… so that this may increase the quality of care in some cases.'*

The approach of mobile technology towards change in 'doctor-patient relationship' defines the approach of mobile health acceptance. A doctor from an emergency department (TDI12) highlights the pivotal role of the 'doctor-patient relationship' in real-time communication and the need for a decision support system in a mobile device when doctors present the diagnosis to patients:

‘There is no need to worry about the change of diagnosis method…the final decision still made by person who drives this patient… so this device just increase the ability of decision-making and process.’

An Australian nurse from a clinical cluster education unit (ANE17) supports this view:

‘This DSS just increase 50% of diagnosis ability to assist decision-making. Doctors do need to interact with patients all the time even using mobile communications.’

This research only focuses on doctors’ perspective to patients and how well the device distributes to patients. Therefore, there is no separate question to distinguish between doctor and patient relationship. Table 5.4 shows that the average for doctor and patient relationship is 3.22 (out of 5) with standard deviation 1.629 (Table 5.4). With the doctor and patient relationship issue, there is a main effect by different departments on perceived user satisfaction ($F(2,15) = 5.168$, $p < 0.05$) (Appendix B24), but there was no main effect of different status ($F(2,15) = 1.722$, $p > 0.05$) (Appendix B25) and country ($F(1,16) = 0.01, p > 0.05$) (Appendix B26).

According to the above description, the medical instrument is a tool that is used for diagnosis and therapy purposes in patient care. The M-ECG DSS attempts to achieve ECG’s principal action by adding value to assist doctors’ needs. All participants have provided positive impact to *‘doctor-patient relationship’*. The doctor-patient relationship may experience variation for specific diagnosis from different departments. Thus, this could be evaluated by perceived value of users.

The research **lends support** the **proposition (P4)** that the M-ECG DSS meets clinicians’ expectations (perceived value and user satisfaction) and enhances ECG diagnostic capabilities through the introduction of ubiquitous mobile technologies. This study finds that the successful adoption in an ECG system requires the evaluation of user acceptance and clinicians who are able to effectively operate the system to prevent unnecessary suffering. There is consensus amongst participants that healthcare through mobile technologies is suitable in situations where clinicians are not able to reach patients face-to-face and require ‘far-end’ diagnosis. An ECG with DSS collaboration tools is also perceived to be highly influential in gaining acceptance. This is because the decision support system can provide capabilities to help clinicians in diagnostic settings. The findings clearly establish that a M-ECG DSS builds confidence and is perceived to be of more value in CVD care, thus highlighting a link to proposition P4.

The findings also clearly establish that different departments within hospitals exhibit varying levels of individual confidence in the use of M-ECG DSS. ICUs require the M-ECG DSS to perform sustainably and provide accessibility in presenting ECG data (charts and images). On the other side, participants who work in emergency departments indicate that the M-ECG DSS should have decision support to carry out initial diagnosis of patients. There is a consensus amongst participants that this prototype M-ECG DSS has perceived quality of care, acceptability and satisfies users’ needs in CVD delivery. Correspondingly, doctors believe that the M-ECG DSS is able to obtain a closer connection with patients by using mobile communications in the role of perceived value from the doctor-patient relationship. The use of mobile communications in ECG decision support is identified as having a positive impact in terms of degree and progress towards CVD delivery.

The major findings also show that the integration of an ECG service, a DSS and mobile services not only enhances diagnostic capabilities, but also adds perceived value and user satisfaction. These results are significant for future medical practice.

5.5 Conclusion

The findings clearly draw a link between ECG functional characteristics, DSS system characteristic and acceptance of the prototype M-ECG DSS. These are indicative of characteristics exhibited by doctors and nurses with respect to the implementation and utilisation of M-ECG DSS. The findings also approach the acceptance of mobile health technology and decision-making processes together for CVD care. The findings in answering **four propositions are completed**. The successful adoption of mobile technology in healthcare involves understanding the capabilities of individuals and creating a better diagnosis environment within their medical capacity.

Interviewees highlighted a number of challenges in accepting new medical technology. These include usefulness, social influences, user resources, technology fit, result demonstrability, legal action and doctor-patient relationship. The study finds that a DSS in a mobile device as a reading instrument has the potential to deliver CVD care to clinicians. It provides the opportunity for improved and accurate diagnosis to a cardiologist, doctor or nurse in real-time monitoring. Compared to doctors' and nurses' previous experiences, participants were very positive towards using the multi-touch measuring scale object as their primary ECG decision-making tool. However, to enhance the quality of healthcare using technology it is important to look at all acceptance factors (Nesaar & Jean-Paul 2009). Participants believe that the M-ECG DSS might increase the quality of diagnosis. This study shows an alternative way to think about using a mobile based decision support system to improve cardiac care by applying technology acceptance factors. In the process of carrying out this prototype development and study, the study determines not only what technology acceptance factors might occur in mobile healthcare, but also the reasons for those assessments.

Fundamentally, the multi-touch function on the smart phone was found to be useful and acceptable to doctors, nurses and cardiologists in real-time (simulated) monitoring of cardiac patients when obtaining a patient's ECG signal from a mobile transmission. The multi-touch measuring tool may support doctors in reaching accurate diagnoses. Based on feedback, the M-ECG DSS has been modified to arrive at a better solution to users. However, to optimise the use and acceptability of this M-ECG DSS, it is important to evaluate the system in doctors' everyday clinical practices. With the addition of more functions and content, the mobile ECG decision support system will become more acceptable and user-friendly for doctors and nurses for long distance real-time monitoring. The following chapter discusses and ties the results of this study to the research problem. The theoretical and practical implications of these findings and discussions are also explored in the final chapter.

Chapter 6 Discussion, Limitations and Future Research

6.1 Introduction

The research is concerned with the evaluation of the knowledge base of a cardiovascular disease (CVD) diagnosis expert system called the M-ECG DSS. This final chapter examines the findings of propositions that were developed at the outset of the study. It addresses the research problem and details the specific implications for theory and practice. The DSS for diagnosis consists of CVD rules that were provided by medical experts. The research findings are consistent with the current literature embodying studies of mobile health implementations acceptance and new development of the M-ECG DSS delivery. The perceived limitations of this research are discussed to explore the subject area in greater depth, with a particular focus on the ECG and DSS aspects of collaboration through mobile communications.

The motivation to develop the mobile ECG and build a DSS was that research might establish a way for doctors and nurses to have the tools to speed up decision-making and simplify the diagnosis process in healthcare settings as well as be more accepting of new health technology in a mobile environment. With respect to the problem of CVD diagnosis, by adopting the M-ECG DSS as a major mode of diagnosis delivery, patients may be able to obtain treatment earlier and specialists can better manage their patients. The objectives of this research are: (a) identifying the ECG functional / DSS system characteristic requirements for mobile adoption; (b) bridging the gap in mobile health practice; and (c) testing the acceptance of M-ECG DSS.

It is clear that using Technology Acceptance Model (TAM) and Information System Success Model (ISSM) as primary underpinning theories to evaluate the acceptance of the developed M-ECG DSS is critical. The TAM provides this research an informative representation of the mechanisms by which design choices influence user acceptance (Lidia et al. 2007) and the ISSM explains the relationships of mobile implementations with user-related constructs (DeLone & McLean 2002). The use of both models captures the necessary theory that underpins the study's conceptual model. This combination provides a new contribution to research on mobile technology based DSS. The chapter begins with major findings from qualitative and quantitative analysis undertaken to answer the proposed research questions. The research then describes the contribution from those findings to theories and implications for management practice in health delivery by health professionals and IT professionals. Finally, the chapter concludes with limitations and directions for future research.

6.2 M-ECG DSS Characteristics Finding and Discussion

Mobile health technology integration has played a critical role in data communication and system performance. The findings relating to mobile communications in healthcare show the importance of mobile adoption in a diagnostic setting. It was determined by cardiologists, doctors and nurses that any M-ECG DSS development should involve clinicians who specialise in CVD patients or require diagnostic assistance. The M-ECG DSS provides accurate and timely ECG data and ensures that all activities achieve a high degree of *'satisfaction'* and *'behaviour'* modification. The discussions and findings below highlight the importance of characteristics in order to develop a M-ECG DSS and how this impacts healthcare services.

6.2.1 ECG Functional Characteristics

An ECG instrument is used to measure the rate and regularity of heartbeats as well as size and position of chambers or the presence of any damage to the heart. Most ECGs are performed as in-bed diagnostics or EMS conditions. The study finds that a basic ECG device should contain several characteristics for use in a diagnosis setting. There are four main characteristics which should be included to provide basic ECG diagnosis (Table 6.1).

It is important to contain a wide range of normal variability in a 12-lead ECG. The ECG functional characteristics, therefore, need to consider ECG reading experience to discover all the normal variants. Correlating to various ECG findings with a particular patient's clinical status has led to the ECG instrument becoming a valuable clinical tool. Based on the findings, a basic ECG device should not only interpret a patient's condition but also have the necessary technical capabilities to assist clinicians' in their daily practice. The study also finds that clinicians would prefer to retrieve patients' details, medical history, rhythm changes and medication while reading a ECG. This is a **NEW** finding (patient's condition) and necessary for M-ECG DSS adoption. Thus, it is important to note that the use of a ECG instrument without consideration of ECG functional characteristics requirements may lead to the lower satisfaction levels in users' attitudes towards using a device. The study also finds that it is necessary to include a 'waveform description' to increase clinicians' diagnosis skills. This is another **NEW** contribution to ECG system characteristics.

Table 6.1: Identified ECG functional characteristics

ECG functional characteristics	**Description**
Rhythms / Symptoms	An ECG device should have ability to detect disease, rhythms and symptoms as well as filter the ECG signal to show charts in a clear waveform.
Measurements	An ECG device should be able to measure heart rate, PR interval, QRS duration, QT interval and QRS axis as well as interpret each lead for diagnosis purpose. In the case of ECG analysis, naked eye observing by human expects still plays an import ant role in measuring ECG charts.
Patient's condition **(NEW)**	Clinicians are able to record patients' details, medical history, rhythm changes and medication. This is a missing part in the current ECG instrument.
Waveform description **(NEW)**	An important feature to analyse ECG charts. Identifying major transitions in the ECG chart and diagnostic intervals of normal rhythm and intervals of ventricular arrhythmias by a clinician's knowledge of ECG could be extremely difficult. Therefore, waveform description to for ECG interpretation becomes necessary in use of an ECG device.

To understand the relationships between the study's findings and previous research, the identified ECG functional characteristics and the relevant ideas in the literature are listed in Table 6.2.

Table 6.2: Identified ECG functional characteristics and the relationship with literature

DSS system characteristics	Previous studies to the characteristics
Rhythms / Symptoms	- show charts with type of rhythms/symptoms in a clear waveform (Afsar & Arif 2007; Dean & Stephen 2009; Joanne 2006; Saritha et al. 2008). - **Lend supported by this study as important.**
Measurements	- analysis basic symptoms and measure patient's physiological condition (Doll & Torkzadeh 1988; Engin et al. 2005). - **Lend supported by this study as important.**
Patient's condition	Finding from this study **(NEW)**
Waveform description	Finding from this study **(NEW)**

6.2.2 DSS System Characteristics

The ECG decision support system (DSS) is a knowledge-based system that supports clinicians' or hospitals' decision-making activities for CVD. An ECG DSS should serve the management, operation and diagnosis levels of the process and help in decision-making which, in turn, may increase CVD diagnostic capabilities. Delivering ECG data through a mobile environment is a useful and time saving tool for clinicians which is particularly evident from interviews. The study finds that a M-ECG device together with DSS should contain ECG functional characteristics in order to monitor a CVD patient remotely. In addition, clinicians also indicate that M-ECG DSS should add additional value (real-time communication and DSS) for ECG monitoring remotely and require DSS system characteristics on top of the ECG system to increase capacities for diagnoses (Table 6.3).

Table 6.3: Identified DSS system characteristics

DSS system characteristics (In M-ECG DSS)	Description
Communication	Enable two way communication and collaboration as well as real-time service to perform better ECG diagnosis through doctor-patient interaction. Create a channel for earlier diagnosis before patient arrival at hospital.
Device environment	A mobile OS environment that it can provide a highly scalable interface and increase the ability to customise interface by individual users. Has a potential to increase speed of diagnosis and reduce time taken in surfing system itself as well as the ability to perform full capabilities of ECG data.
Measurement tool **(NEW)**	Allows clinicians to interpret ECG charts without using any additional physical tool. A scale tool for more accurate diagnosis and treatment. Provides the ability to provide a correct diagnosis in few seconds and simplify the diagnosis process.
Reference **(NEW)**	Access to the latest medication formulation, disease description, symptoms and treatment as well as access to clinical procedures provided on a mobile device. The device is able to provide reference material to easily assist clinicians' reviewing.
Medical history	Provides full history useful in formulating a diagnosis and providing medical care to a patient in the palm of a carer's hand.

A smart mobile device provides the capability for clinicians to carry and have available vast amounts information with them at all times. The study suggests that a DSS should not only provide decision-making data but also increase system resources availability. For example, the research finds that it is necessary to include a 'reference' (ECG knowledge-base) and 'medical history' in the M-ECG DSS in order to improve knowledge sharing and access to a patient's complete history when making a diagnosis. This is a **NEW** finding of a DSS system characteristics required in a mobile adoption.

This study finds that successful adoption for the M-ECG DSS requires not only basic ECG functional characteristics but also mobile capability (DSS) system characteristics. From the DSS, clinicians are looking for a system which provides the ability to speed up decision-making and simplify diagnoses in CVD care settings. Looking at how the M-ECG DSS is going to change the diagnosis process is critical to CVD care. From a doctor's view, employing this approach may enhance their skill of treatment from a diagnostic perspective, and provide a chance to influence other diagnoses while instilling the right type of diagnostic behaviours.

Table 6.4: Identified DSS system characteristics and the relationship with literature

DSS system characteristics	Previous studies to the characteristics
Communication	- Communication is a key efficient emergency function for mobile technologies adoption (Chung & Hsueh-Ming 2009; Ekström 2006; Julie et al. 2006) - **Lend supported by this study as important**.
Device environment	- Mobile OS choice could produce different levels of user satisfaction and affect implementation of mobile applications in healthcare (Mobile Health News 2009). - **Lend supported by this study as important**.
Measurement tool	Finding from this study **(NEW)**
Reference	Finding from this study **(NEW)**
Medical history	-Medical resources provide healthcare using M-Health to reduce time taken of diagnosis (David et al. 2011; Department of Foreign Affairs and Trade 2008; Hanley 1976). - **Lend supported by this study as important**.

The role of DSS system characteristics in a M-ECG is to clearly define how they are going to affect the diagnosis process in CVD care and how it will improve the quality of care. The key to successful mobile health implementation in a DSS is to determine performance expectancy and facilitate conditions such as selection of OS in terms of operating efficiency as well as adoption of a measurement tool in terms of perceived usefulness. The study also finds that it is necessary to include a 'digital measurement scale tool' to replace actual (physical ruler) scale instrument in order to increase clinicians' diagnosis skills. This is a **NEW** contribution to DSS concepts applied to M-ECG. To understand the relationships between these findings and previous research, the identified DSS system characteristics and the relevant ideas in literature are listed in Table 6.4.

6.2.3 M-ECG DSS Characteristics

Internally, a M-ECG should consider the accessibility of mobile communications. The performance of a user interface is now also important in order to gain more use of a device. The study finds that M-ECG DSS characteristics should include the role of system accessibility, meaningful use, system interface, data transformation and adding value (Table 6.5). Clinicians indicate that the M-ECG DSS needs to present data in a format that is able to provide 'easy to use' and 'usefulness' to users. In order to develop a M-ECG DSS, it requires identification of DSS system characteristics on top of identified ECG functional characteristics in addition to those found in the literature in order to increase diagnostic capabilities of users.

Table 6.5: Identified M-ECG DSS system characteristics

M-ECG characteristics	Description
Accessibility	Provide a CVD service at anytime, anywhere and change management process of patients in day-to-day interactions.
User interface	Provide content adaptation and prioritisation of the most relevant information to users as well as create better solution for a user-friendly interface for clinicians. The user interface should be considered as part of DSS in order to improve quality of decision-making.
Data transformation	Improve clinical decision-making at the point of care through visual ECG data transformation and interactivity. Using graphing, trending, colours, visual cues, etc… to provide easy interpretation.
Added value	Bring ECG data to a user in a meaningful way, easy to incorporate with clinician daily practice. Have the ability to save time, cost, delay in delivery of service for remote diagnosis.
Meaningful use	Provide an alternative way to achieve treatment and demonstrate high performance of ECG quality diagnosis (eg., can either satisfy utilisation measures for ECG charts, conducting symptoms, interaction checking or demonstrate past events, etc.)

It is important to identify M-ECG DSS characteristics not only in diagnosis settings, but also in the decision process. As such, the M-ECG DSS needs to determine what level of value it will provide in influencing acceptance and uptake of this application, either through mobile communications or DSS. This will ensure that clinicians take advantage of its use in their daily diagnostic practices. From the viewpoint of doctors, they are looking for higher levels of confidence in order to use mobile devices for CVD care while nurses focus more on their experience from ECG DSS display and data transformation in the mobile environment. As such, the M-ECG DSS should consider the level of a clinician's involvement; this will have an impact on acceptance of a mobile adoption in ECG context. Participants also indicated that the DSS itself can only achieve a 50% success rate in diagnosis for clinicians aiming for better healthcare outcomes. On the contrary, mobile communications will be highly beneficial to users and keep patients at a reachable distance. As Hsu-Yang et al. (2005) aptly indicated, medical staff, restricted by distance and space, cannot give patients the best treatment and fail to save many lives. However, a DSS can create advantages for the health sector and have positive benefits for professionals (Daniel 2011). Therefore, the potential ECG functional characteristics may need to be identified well in advance and, thus, reduced to some extent. The completed model of M-ECG DSS is shown in Figure 6.6.

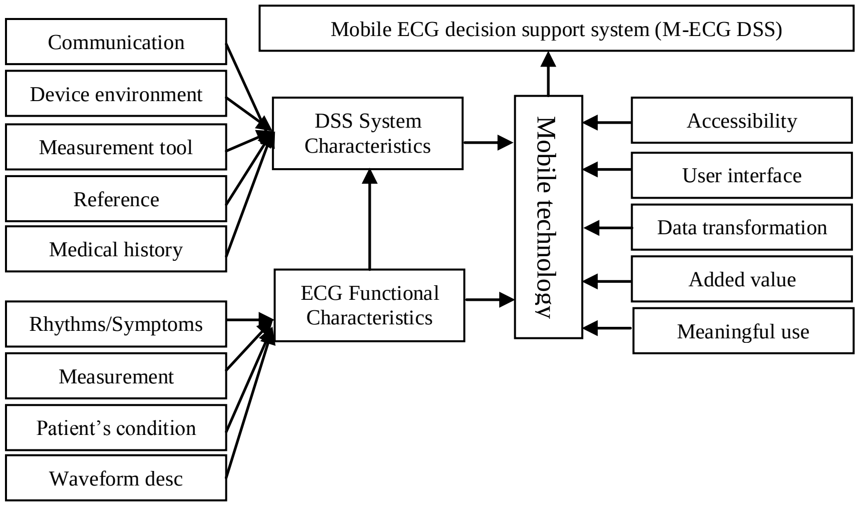


Figure 6.6: Completed model of mobile ECG decision support system

6.2.4 Mobile Technologies in Diagnostic Capabilities

Delivering ECG signals to other mobile devices by using mobile technology provides the capability to not only transmit ECG data but also enable communication between GPs and CVD patients remotely. One of the factors which affect the level of this capability in the M-ECG DSS application is 'information quality'. This refers to the accuracy and efficiency of ECG data shown in a mobile device and affects the level of perceived 'usefulness' and 'ease to use'. Another factor, 'service quality', represents the diagnosis process in a mobile device in order to measure perceived 'intention to use' and 'user satisfaction'. The study finds that more than 70% of participants perceive that mobile applications adoption with advanced smart mobile OSs has the potential to offer mobility and ubiquitous service to help clinicians monitor patients remotely.

The findings also identify that 'availability' and 'accessibility' are keys to acceptance of mobile health delivery. The M-ECG DSS is enabled by the fundamental characteristics of mobile networks and devices. It has provided the ability to ubiquitously locate and connect users, delivering diagnosis services, thus supporting mobility. The capabilities of mobile networks, particularly in terms of data delivery, are extending the scope of applications that can be supported to include large data exchange and data transformation for some medical diagnoses. There is a consensus amongst participants that a mobile adoption in an ECG service is only suitable in situations where CVD patients are far-away from their personal clinicians or where the shortage of primary care services in rural area is most acute.

The results of the study show that if functionality and usability of a mobile health application are perceived to be good, it will enhance a clinician’s satisfaction by decreasing workloads and making mobile diagnosis possible. It has benefits for effective reach. Some participants indicate the diagnosis interpretation can enhance communication status for treatment purposes. The involvement of a mobile DSS simplifies decision-making for clinicians where face-to-face diagnosis is not possible. It becomes evident that the use of M-ECG DSS for data transmission and transformation has significant potential, particularly when focused on capabilities of data delivery.

6.3 Contributions to the Literature

The findings of this research provide new insights into the relationship between mobile adoption and ECG decision support services. This development highlights the diversity of concepts that exert an influence on acceptance while developing the M-ECG DSS. The necessary ‘ECG functional characteristics’ are illustrated in Table 6.1 as being influential as a foundational diagnosis requirement to perceive ‘*result demonstrability’*. This study has made it clear that the structure of data presented (such as ECG charts, images, signal transformation, initial diagnosis) and participation (from cardiologists, doctors, specialists and nurses) are essential in CVD care settings.

The quality of information, system and service affect the acceptance of using devices and applications. To achieve those qualities, this research developed a DSS to support diagnosis for cardiologists, doctors and nurses, meet their expectations, and ensure that *'user resources'* and *'result demonstrability'* are adequate for the diagnostic task to improve quality of care by mobile technology delivery.

The above discussion describes the role that perceived value from '*user behaviour'* and '*user satisfaction'* plays in overriding technology acceptance in a mobile health service. The role of '*user behaviour'* in healthcare depends on users who perceived '*usefulness'*, met their *task* requirement and reduced '*fear of legal action'*. This changes clinicians' attitudes towards 'intention to use' in the clinical management. The role of '*user satisfaction'* in a mobile adoption has also been addressed through this study. It is evident from this research that user satisfaction in clinical settings is a subjective construct which can be influenced by system effectiveness, system characteristics and user expectations. The challenge will be to discover how to use mobile health technologies to transform healthcare into a seamless part of daily practice where health services are needed.

'Social influences' on acceptance of mobile health technology adoption from clinicians have an impact on the relationship between human intervention and clinical management. It has been made clear that decision-making for CVD needs to be established within the realm of good patient outcomes. For example, clinicians may change their thoughts, attitudes or behaviours of accepting new health technologies from interaction with other successful health professionals. In the health sector, level of investment in terms of mobile adoption, introduction of new services and integration as diagnosis components will help clinicians to accept new services.

This study also finds that there are several foundational requirements to be included to perceive '*user resources'*. Clinicians need to be confident they have organisational and individual support to use this device. Interestingly, in approaching this mobile adoption concept, clinicians were decisive and certain to accept this new method of service in their daily practice. Decision support in all aspects is key to inspiring confidence; it has an extensive effect on the level of acceptance in utilising the M-ECG DSS.

Research in the acceptance of mobile health adoption also indicates that clinicians should improve quality of care to patients and increase their treatment effectiveness so that clinicians are able to '*demonstrate results'* while operating new services. The influence of the internal result for a mobile adoption can be attributed to system demonstration, decision support, diagnosis process, doctor retention, communications and operating performance. The external result, in its influence on a mobile adoption, can be attributed to different categories of clinicians such as cardiologists, doctors and nurses. This results will enhance the level of acceptance and '*user satisfaction'*. It also appears to be a significant matter for successful mobile health adoption.

The study also finds that mobile technologies are becoming more embedded, ubiquitous and networked, with enhanced capabilities for rich social interactions and context awareness. This includes the ability to interpret information, supports a patient in understanding their condition, defines circumstances, advises on appropriate diagnosis or preventive options, and explains and discusses the risks, benefits and uncertainties of various tests. The '*doctor-patient relationship'* forms the foundation of medical ethics and refers to rapport between doctors and patients, upholding patients' dignity and respecting their privacy. However, the research finds that this is of less concern to clinicians in new mobile health adoptions.

This study contributes to the literature addressing technology acceptance of mobile health adoption. Adoption depends on the degree of confidence that clinicians have in their clinical findings from using the M-ECG DSS as well as a clinician's satisfaction with the encounter in the absence of face-to-face interaction with a patient. The contributions have been to the various concepts affecting '*user behaviour'* in conjunction with concepts that influence '*user satisfaction'* in order to achieve enhanced benefits to a physician's decision-making process.

6.4 Implications for Policy and Practice

Managing CVD patients with mobile technologies could save lives and reduce health costs. This study builds on research work that allows remote diagnosis by using a M-ECG DSS. It provides real-time data on a mobile device or tablet for specialists, GPs, hospitals and emergency services without the need for hospital admission or travel to see a health professional. Initial ideas for connecting an ECG system to a mobile phone with an application for graphical presentation of data were found to be most difficult to develop as a standard solution (Georgios & Ivan 2008). However, it is clearly evident in the responses from clinicians that mobile technology in a clinical setting is becoming necessary to healthcare in order to improve diagnostic outcomes. Some implications are identified for best practice.

6.4.1 Implications for Health Delivery by Governments

Preliminary research has developed a prototype mobile ECG application which has gained positive feedback from cardiologists in Australia and Taiwan regarding the acceptance of the proposed system of remote ECG monitoring. The research development allows the research team to demonstrate system efficiency to Queensland Health and allied health organisations. The significance of the project has found that it addresses the need for rapid and straight forward clinical monitoring in remote and regional areas. This is particularly relevant to the demographics of Queensland. For the first time, clinicians will have real-time data delivered to their mobile/smart device that carry every day.

The study believes that the successful use of mobile technology in a health environment should lie in the adaptation of the system to the available network infrastructure. For example, the system should be able to detect and utilise full National Broadband Network (NBN) services where available, but fall-back to a reduced functionality otherwise. This is important, as governments not only need to consider the global side of health services but also need to focus on availability of mobile services. Correspondingly, it is evident that clinicians are most likely to deal with their patient themselves in order to deliver treatment outcomes. As part of this, healthcare delivery is somehow requiring enhanced interaction between information and communications technologies in order to ensure that diagnostic support is well-established when a mobile technology is implemented.

The government has an overall responsibility to ensure that patients are protected and receive value from the health services provided. As such, the government needs to consider how to establish better quality of national health services through innovation and cooperation to other parties. Consideration also needs to be given to encouraging partnerships between the health provider and government in order to deliver quality services and contribute to national health goals. Australia has ‘a relatively well organised healthcare system but there are always pressures for the system to achieve greater efficiencies’ (Liza & Chris 2003, p. 165). Health technology development and resultant confidence in using mobile communications in health services is pivotal for successful implementation, particularly in federal and state-run government health units.

6.4.2 Implications for Health Professionals

The planning of a mobile technology implementation requires coordination between cardiologists, doctors and nurses to facilitate successful adoption at varying levels of healthcare (i.e. the different roles in nursing and different specialisations of doctors). Concurrently, new mobile health services require adequate levels of resources to assist health professionals in mobile technology implementations and enable them to acquire heightened diagnostic skills. Clinics and hospitals also face the issue of the extent to which health professionals may require additional training, particularly when health technology adoption is new and unique. The evaluation of acceptance in a mobile health service prior to training is therefore critical in catering to individual expectations.

Current mobile technology with advanced smart devices has the potential to offer better mobility and ubiquity of service to health professionals and in healthcare settings; implementations can create an opportunity to allow time and space for health professionals to achieve real-time remote diagnoses. This not only applies to CVD care but also to other health services. Moreover, with smart mobile devices, the technology has the ability to offer additional functional characteristics which is not available previously to provide better diagnosis processes. For example, the project’s innovation lies in development of a multi-touch measuring scale tool, a first-ever instrument that gives specialists the ability to measure ECG signal waves on a mobile or tablet. In situations where health professionals may require a physical tool to interpret ECG data, a smart mobile device has the ability to provide this digital virtual tool to assist in their diagnosis. This ability is vital to health professionals in the absence of face-to-face interaction with patients.

For effective implementation in healthcare, DSS also plays an important role in acceptance by health professionals. Implementing a DSS in a mobile health service enables health professionals to accept adoption quickly and easily because DSS is able to maintain their knowledge and support their decision-making. The successful adoption of mobile health technology for health professionals involves understanding the capabilities of individuals and creating a better diagnosis environment.

6.4.3 Implications for IT Professionals

The literature and the definition of IT implementation suggest that the most proximal antecedent of IT use is ‘intention to use’ and this is commonly taken to be what is meant when one refers to ‘acceptance’, although another common conceptualisation of acceptance is ‘end-user satisfaction’ (Richard & Ben-Tzion 2010). Acceptance and utilisation of IT in the healthcare environment has also been the central theme in the information systems literature (Gururajan 2009). Therefore, having IT professionals work within the healthcare environment becomes a necessity for clinicians as doctors, nurses and allied health professionals are supported in their use of medical instruments developed and delivered by IT professionals. Therefore, it is critical that IT professionals possess specific medical knowledge in order to deliver the health instrument and the instrument itself should increase the capacity for detection, diagnosis, and decision-making.

The study finds that additional teaching and training are important for clinicians in the delivery of a new health technology. With innovations in mobile technology, IT professionals in hospitals need to adopt more and more services and technologies in health activities. Together, IT and health professionals should be able to modify mobile technologies for general practitioners, nurses and specialists in areas such as physiotherapy, mental health, exercise therapy, occupation therapy, nutritional advice and drug and alcohol counselling. Under health technology development, IT professionals should have long been expected to:

1. have relevant medical knowledge;
2. meet health service standards;
3. require self-learning to increase the capacity of health services;
4. have the ability to meet a clinician's *'satisfaction'* ;
5. preform better system *' behaviour' to clinicians*;
6. be able to expect cooperation from health professionals.

6.5 Limitations

Despite the contributions that the research has made, some caution is necessary in interpreting the results. At this stage of system development, it did not involve real patients as the focus was only to demonstrate how well the device distributes a patient's detail to clinicians (with only synthetic ECG data). Moreover, due to the constraints of time, accessibility and cost, all the health professionals were chosen from Australian and Taiwan hospitals. The sample size was limited but mobile health technology development usually involves a small number of participants due to the need to instruct and provide support to participants (Lindquist et al. 2008, p. 31). The use of purposive sampling and research methods adopted make the conclusions analytical rather than statistical generalizable to a population.

The research development not only considers the need of mobile infrastructure and communication (data transmission and information exchange), but also concern of popularity in smart phone industries. This increases the influence of evaluating acceptance of new mobile health adoption and limits the selection of cases to adopt a mobile technology. Moreover, the unfamiliarity of the respondents with this emerging topic and development may have impacted on the response rate of the research.

The relationship between health departments and status were not included in the set of independent variables while evaluating technology acceptance. This has because the M-ECG DSS development's attempt to integrate health professionals' diagnosis needs and requirements together to build a DSS for more robust application. Therefore, by using a developed DSS, it will be easy to adjust the findings of this research to improve the level of *'user satisfaction'* and observe the level of *'user behaviour'*.

The research uses mobile application adoption considered as best practice by clinicians and CVD care. Ideally, M-ECG DSS adoption is trying to improve the decision process and connect all clinicians from wherever they are, using whatever mobile device they happen to be using. The idea behind this new system to be used in conjunction with modern telecommunication applications is to deliver quality of CVD care. However, there is no evidence to test the system effectively itself because no real patients or cases were involved. Therefore, the patient aspect was beyond the scope of this research, but should be considered in future efforts involving the establishment of mobile communication performance measurements. This will create more effective implementation for a mobile health service.

6.6 Future Research

The objective of this research was to provide greater understanding of a mobile health adoption and to evaluate its acceptance. A key research opportunity that has been reiterated and discussed throughout this study is the potential of mobile implementation in healthcare. Future research may be conducted for constructing a more complete mobile health system and DSS for decision-making. Moreover, the continuous development of the M-ECG DSS is necessary because it has reached the first step in real-time diagnostic, prognostic and follow-up processes of heart disease. It is therefore envisages that future research may focus on the performance between the system itself and health professionals' expectations.

This research involved a small number of participants due to the need to instruct. Studies in different countries may also result in various aspects of motivations and challenges in mobile health development. The researcher encourages future research to extend the results of this study, improve the results by minimising the limitations of study and/or confirm the results in different settings. A level of system performance and its relationship with clinicians may change the acceptance of mobile technology adoption in healthcare support. Specifically, the researcher suggests future research on the following areas.

1. Replicating this research in other settings helps to evaluate the possibility of a mobile adoption in other medical fields.
2. Examining the relationship between clinicians and patients in the context of mutual respect, trust, shared values and perspective about disease and life would help understanding of the utility of mobile communications in healthcare. This will help deepen the understanding of mobile health technology acceptance by health professionals.
3. Giving this research even more impact and ultimately, recognition by applying stakeholder network analysis to better understand interaction dynamics between clinicians and patients.
4. The security aspect of mobile development could be another fruitful area of research for technology acceptance. As this study only evaluated the functional and system characteristics in an M-ECG and cardiac decision support related issue, future research would be a useful extension to new mobile services.
5. Mobile health adoption is in the early stages of development; therefore, the researcher also encourages future studies to examine the relationship of specific diagnoses variables with the individual dimensions of care quality.
6. In this research, compliance with cardiologists expectations are considered as identified functional characteristics for ECG DSS and those system characteristics established on the necessary factors of technology acceptance for healthcare. Thus, studies to examine how technology acceptance factors can balance system performance (mobile health adoption) and user satisfaction (clinicians' expectations) could be another promising avenue for future research.
7. A multi-touch function in a smart phone environment could apply to other medical fields for diagnosis purpose. This would not only allow easy viewing

of therapeutic records, but also saving time in providing treatment and increasing the quality of healthcare.

8. An additional aspect that needs to be mentioned is that a number of efficient emergency rescue systems should be implemented quickly for better detection of CVD and disease prevention. Diagnostic practices and mobile system performance are extremely difficult to measure in first aid, despite being the first priority in emergency services. Therefore, the setting of objectives and establishment of performance could be a useful direction for future studies.

6.7 Conclusions

The primary research aim was to test the acceptance of remote decision support systems in CVD care. The scientific merit of the research lies in the innovative development of a system which displays the relevant information graphically and in real-time. This is a challenge, given the variety of mobile devices available to health professionals. Studies have shown that unless such a system is reliable and intuitive to use, its uptake will be limited.

Fundamentally, the multi-touch function on the smart phone was found to be useful and acceptable to cardiologists and clinicians in real-time monitoring of CVD patients when obtaining a patient's ECG signal from a mobile transmission. The multi-touch measuring tool supports the reduction of diagnoses by doctors. Based on the feedback gathered during testing sessions, the M-ECG DSS has been modified to provide solutions acceptable to users. However, to optimise the use and acceptability of this M-ECG DSS, it is important to evaluate the system in doctors' everyday clinical practices. With the addition of more functions and contents, the multi-touch M-ECG diagnostic DSS is believed to be acceptable and user-friendly for doctors and cardiologists for long distance real-time monitoring. Therefore, it is incumbent upon each participant to accept change, work towards implementing best practices and continually innovate for better health services.

This thesis has identified the need for combined ECG functional characteristics and DSS system characteristics for M-ECG adoption. Moreover, the study attempts to define a configuration for a DSS in a mobile device with the ability to successfully deliver medical services. Based on the acceptance concepts, it is recommended that a new mobile health adoption should focus on several important directions. These directions include data delivery, decision-making, system performance, quality care improvement, the role of different clinicians' task, and medical instrument characteristics. These acceptance concepts are essential for consideration in implementing new technology to health services.

To conclude, this research combined qualitative and quantitative methods to explore the acceptance of the M-ECG DSS in a clinical setting. It investigates the possible solutions in the process of arriving at a diagnosis, as well as adopting a DSS. A successful mobile health adoption requires comprehensive planning and deliberative processes from both health and IT professionals to integrate their knowledge for successful system development. It is expected that health sectors and hospitals can benefit from M-ECG DSS adoption by being able to perform their telemedicine services more efficiently and successfully.

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Appendix A: List of Research Participant

Participant	Country	Department	Status
TCC01	**Taiwan**	Cardiology	Cardiologist
TCC02	**Taiwan**	Cardiology	Cardiologist
TNI03	**Taiwan**	ICU /GI	Nurse
TDI04	**Taiwan**	ICU	Doctor
TDI05	**Taiwan**	ICU	Doctor
TDI06	**Taiwan**	ICU	Doctor
TNE07	**Taiwan**	Hematoma	Nurse
TDI08	**Taiwan**	ICU	Doctor
TDE09	**Taiwan**	Nephrology	Doctor
TDI10	**Taiwan**	ICU	Doctor
TCC11	**Taiwan**	Cardiology	Cardiologist
TDE12	**Australia**	Emergency	Doctor
ANE13	**Australia**	Emergency	Nurse
ADE14	**Australia**	Emergency	Doctor
ADE15	**Australia**	Emergency	Doctor
ACC16	**Australia**	Cardiology	Cardiologist
ANE17	**Australia**	Clinical Cluster Education	Nurse
ANE18	**Australia**	Nursing Support Unit	Nurse

Appendix B: Mobile Technology Acceptance by Factors

1. Perceived usefulness by status

Perceived Usefulness and Status

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.749	2	.374	1.151	.343
Within Groups	4.878	15	.325		
Total	5.626	17			

2. Perceived usefulness by department

Perceived Usefulness and Department

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.789	2	.395	1.224	.322
Within Groups	4.837	15	.322		
Total	5.626	17			

3. Perceived usefulness by department for Legible Information and Reliable Output

Perceived Usefulness and Department for Legible Information and Reliable Output

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.688	2	1.344	5.375	.020
Within Groups	3.250	13	.250		
Total	5.938	15			

4. Task/Technology fit by department

Task/Technology Fit and Department

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.711	2	.356	.945	.411
Within Groups	5.648	15	.377		
Total	6.360	17			

5. Task/Technology fit by status

Task/Technology Fit and Status

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.298	2	.149	.369	.697
Within Groups	6.061	15	.404		
Total	6.360	17			

6. Task/Technology fit by country

Task/Technology Fit and Country

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.790	1	.790	2.270	.151
Within Groups	5.569	16	.348		
Total	6.360	17			

7. Task/Technology fit by country for comparative tested/trailed or experimented with M-ECG DSS for potential use

Task/Technology Fit and Country for comparative tested/trailed or experimented with M-ECG DSS for potential use

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.028	1	8.028	6.731	.020
Within Groups	19.083	16	1.193		
Total	27.111	17			

8. Fear of legal action by department

Fear of Legal Action and Department

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.735	2	1.367	1.461	.263
Within Groups	14.037	15	.936		
Total	16.772	17			

9. Fear of legal action by status

Fear of Legal Action and Status

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.416	2	1.208	1.262	.311
Within Groups	14.356	15	.957		
Total	16.772	17			

10. Fear of legal action by country

Fear of Legal Action and Country

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.235	1	1.235	1.271	.276
Within Groups	15.537	16	.971		
Total	16.772	17			

11. User satisfaction by status

User Satisfaction and status

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	208.506	2	104.253	1.020	.384
Within Groups	1533.106	15	102.207		
Total	1741.611	17			

12. User satisfaction by department

User Satisfaction and Department

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	377.153	2	188.576	2.073	.160
Within Groups	1364.458	15	90.964		
Total	1741.611	17			

13. User satisfaction by country

User Satisfaction and Country

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	177.778	1	177.778	1.819	.196
Within Groups	1563.833	16	97.740		
Total	1741.611	17			

14. Social influences by status

Social Influences and Status

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.253	2	.627	.671	.526
Within Groups	13.997	15	.933		
Total	15.250	17			

15. Social influences by department

Social Influences and Department

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.432	2	4.216	9.276	.002
Within Groups	6.818	15	.455		
Total	15.250	17			

16. Social influences by country

Social Influences and Country

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	1	.000	.000	1.000
Within Groups	15.250	16	.953		
Total	15.250	17			

17. Perceived user resources by status

Perceived User Resources and Status

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.082	2	.041	.031	.969
Within Groups	19.543	15	1.303		
Total	19.625	17			

18. Perceived user resources by department

Perceived User Resources and Department

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.094	2	.047	.036	.965
Within Groups	19.531	15	1.302		
Total	19.625	17			

19. Perceived user resources by country

Perceived User Resources and Country

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.063	1	.063	.051	.824
Within Groups	19.563	16	1.223		
Total	19.625	17			

20. Result demonstrability by department

Result Demonstrability and Department

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.273	2	.137	.530	.599
Within Groups	3.872	15	.258		
Total	4.145	17			

21. Result demonstrability by status

Result Demonstrability and Status

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.222	2	.111	.425	.661
Within Groups	3.923	15	.262		
Total	4.145	17			

22. Result demonstrability by country

Result Demonstrability and Country

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.273	2	.137	.530	.599
Within Groups	3.872	15	.258		
Total	4.145	17			

23. Result demonstrability by department for Data Completeness in Presenting and Recording

Result Demonstrability From Data Completeness in Presenting and Recording

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.167	2	2.083	8.152	.004
Within Groups	3.833	15	.256		
Total	8.000	17			

24. Doctor-Patient relationship by department

Doctor-Patient Relationship and Department

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	18.403	2	9.201	5.168	.020
Within Groups	26.708	15	1.781		
Total	45.111	17			

25. Doctor-Patient relationship by status

Doctor-Patient Relationship and Status

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.422	2	4.211	1.722	.212
Within Groups	36.689	15	2.446		
Total	45.111	17			

26. Doctor-Patient relationship by country

Doctor-Patient Relationship and Country

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.028	1	.028	.010	.922
Within Groups	45.083	16	2.818		
Total	45.111	17			

Appendix C: Interview Protocol

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Tuesday, 28 September 2010

Mr Meng Kuan (Adam) Lin
Unit 42
104 Dornoch Terrace
Highgate Hill, Qld 4101

Dear Mr Lin

The Chair of the USQ Fast Track Human Research Ethics Committee (FTHREC) recently reviewed your responses to the FTHREC's conditions placed upon the ethical approval for the below project. Your proposal now meets the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* and full ethics approval has been granted.

Project Title	Evaluating the efficacy, feasibility and acceptance of a mobile network-based ECG system: development and application of mobile technology to monitoring cardiac patients remotely.
Approval no.	H10REA113
Expiry date	31/03/2012
FTHREC Decision	**Approved**

The standard conditions of this approval are:

(a) conduct the project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments made to the proposal required by the HREC
(b) advise (email: ethics@usq.edu.au) immediately of any complaints or other issues in relation to the project which may warrant review of the ethical approval of the project
(c) make submission for approval of amendments to the approved project before implementing such changes
(d) provide a 'progress report' for every year of approval
(e) provide a 'final report' when the project is complete
(f) advise in writing if the project has been discontinued.

For (c) to (e) forms are available on the USQ ethics website: http://www.usq.edu.au/research/ethicsbio/human

Please note that failure to comply with the conditions of approval and the *National Statement (2007)* may result in withdrawal of approval for the project.

You may now commence your project. I wish you all the best for the conduct of the project.

Helen Phillips
Ethics Officer
Office of Research and Higher Degrees

General information:

1. Please outline your experience with ECG diagnosis and cardiac treatment.
2. Please describe the cardiac technology that you have available. How often it is used? How useful is it to you in diagnosis and support of patients?
3. Please tell me what ECG functions you may need for monitoring cardiac patients at remote locations? What feature would you like to see in mobile decision support systems (DSSs)?
4. Tell me a little about the mobile device(s) that you currently use and/or are interested in using. Is the device(s) your own or supplied? What kind of mobile device would you like to use in the next 1 to 2 years? Do you believe that mobile devices are useful in doing your job in the hospital?
5. What suggestions can you offer to those who are trying to learn how to use outputs of ECGs? What are some important findings you have learned from this prototype?
6. What services do you think could be studied by telemedicine research of ECG devices?
7. If you have access to a 12-lead ECG, would it help you in your diagnosis? In what way do you see that you could use a mobile ECG?
8. (See this diagram of M-ECG DSS and images) Can you diagnose a patient's condition using this application? What advantages and disadvantages do you see from this?
9. In what/where direction would you like to see the mobile ECG DSS interface go in the future?

Mobile ECG decision support system (M-ECG DSS)

The enclosed questionnaire is aimed at exploring the acceptance of the mobile ECG DSS. Please answer all questions. Your answer will be very useful in improving 12-lead m-ECG application and increase the chances of M-ECG implementations in hospitals. Please set aside 20-30 minutes to provide thoughtful responses. **Do not identify yourself on this questionnaire**. Thank you very much for your co-operation.

A[1] The following questions are related to **ACCEPTANCE** of 12-lead mobile ECG systems. Please answer all questions by ticking (√) or crossing (X) in the box which represents the degree of your agreement or disagreement with the statements.

	Not at all	Slightly	Moderately	Quite a bit	Almost totally
To what extent do you perceive that mobile ECG DSS can enhance the **quality** of your treatment and diagnosis for patients?	☐	☐	☐	☐	☐
To what extent do you perceive that mobile ECG DSS can enhance the **delivery** of treatment and diagnosis to patients?	☐	☐	☐	☐	☐
To what extent do you perceive that there are realistic expectations for the use of mobile technology in an ECG monitoring device for treatment and diagnosis in hospital, home care and clinic?	☐	☐	☐	☐	☐
To what extent do you believe there are benefits to be gained by the application of a mobile ECG DSS for the production and delivery of patient care?	☐	☐	☐	☐	☐
To what extent have you tested/trialled or experimented with mobile ECG DSS (hardware/software) for its potential use?	☐	☐	☐	☐	☐
To what extent do you connect/communicate with a medical provider **outside your discipline/section** on medical and treatment matters?	☐	☐	☐	☐	☐
To what extent do you connect/communicate with a cardiac specialist **at other organisation / department** on medical and treatment matters?	☐	☐	☐	☐	☐
To what extent do you perceive a **remote ECG device** as lacking or as a barrier against your expectation of what remote ECG is?	☐	☐	☐	☐	☐
To what extent do you perceive that you have sufficient resource for ECG monitoring?	☐	☐	☐	☐	☐

A² The following questions are related to **Overall use of 12-lead mobile ECG system**. Please answer all questions by ticking (V) or crossing (X) in the box which represents the degree of your agreement or disagreement with the statements.

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
M-ECG DSS will improve the overall referral processes and treatment of cardio vascular patients	☐	☐	☐	☐	☐
M-ECG DSS can be particularly helpful to doctors, to assist them in initiating appropriate early action while also making more accurate assessments and focused treatments	☐	☐	☐	☐	☐
This M-ECG DSS can support patients because it has capabilities for long distance communication through a high-level interactive m-ECG interface for notification	☐	☐	☐	☐	☐

A³ The following questions are related to **ACCEPTANCE** of mobile technology. Please answer all questions by ticking (√) or crossing (X) in the box which represents the degree of your agreement or disagreement with the statements.

1. How frequently have you attended some form of healthcare / medical instrument conference in the last year?

Description

- Healthcare workshop
- Health research conference
- Medical instrument and equipment exhibition

Please rate your ***decision modelling competency*** based on the above descriptions

Never ☐	Once ☐	3-2 times ☐	5-4 times ☐	At least 6 times ☐

2. To what extent do you accept **new mobile medical technology** in treatment on patients?

Description

- perceive **training** for new medical device
- perceive **time to learn/practice** for new medical device
- assistance with teaching for new medical device
- perceive **discipline-based mentoring in Dept/Section** for new medical device

Please rate your ***decision modelling competency*** based on the above descriptions

Not at all ☐	Minor barrier ☐	Somewhat a barrier ☐	Major barrier ☐	Significant barrier ☐

3. In your opinion should new medical technology with mobile technology be implemented:

Please rate your ***decision modelling competency*** based on the above descriptions

Incrementally ☐	After tested & proven ☐	Barrier ☐	as soon as available ☐	Immediately ☐

B

Demographic Information. Please answer all the questions by filling the gap or ticking the options.

Department: ____

1. Participant Position: Cardiologist ☐ Doctor ☐ Nurse ☐ Specialist ☐
2. Do you provide pre-hospital 12-lead ECG monitoring/analysis? Yes ☐ No ☐
3. Work experience with cardiac patient: ____________________ years
4. Do you routinely use 12-lead ECG monitoring? Yes ☐ No ☐
5. If so, what situations do you use it in? Check all that apply

Non traumatic chest pain: All Patients ☐ Over 45 years of age patients ☐

Traumatic chest pain: All Patients ☐ Over 45 years of age patients ☐

Syncope ☐ Weakness ☐ General Illness ☐

Other____

6. Have you ever experienced any telemedicine concept or devices which involved patient care?

   Yes ☐ No ☐

If Yes, please indicate what type of device or what kind of treatment you have come across.

____

____

7. Has your department provided any remotely treatment for cardiac patient?
   Yes ☐ No ☐

If Yes, please indicate type of device:

____

What is the function of the Far-End device?

Recording only ☐ Real time transmission ☐ Recording with read time transmission ☐

C1 The following questions are related to **ECG Needs** of using the 12-lead mobile ECG system. Please answer all questions by ticking (√) or crossing (X) in the box which represents the degree of your agreement or disagreement with the statements.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
M-ECG DSS mobile application prints better ECG wave graphs	☐	☐	☐	☐	☐
It is a good idea to use M-ECG application as a reading instrument in comparison to using the original ECG on paper read-out	☐	☐	☐	☐	☐
It is easy to analyse a patient's data using the M-ECG DSS application (using multi-touch measuring scale tool)	☐	☐	☐	☐	☐
M-ECG application provides legible information and reliable output	☐	☐	☐	☐	☐
M-ECG DSS application increases the level of quality in comparison to a 12-lead ECG paper printout	☐	☐	☐	☐	☐
Diagnosis time has been reduced by using the M-ECG DSS application in comparison to other 12-lead ECG devices	☐	☐	☐	☐	☐
M-ECG DSS provides data completeness in presenting and recording	☐	☐	☐	☐	☐
This 12-lead M-ECG DSS has more flexibility for me to provide patient support than other ECG devices I use	☐	☐	☐	☐	☐
Paramedics within EMS system could utilise the M-ECG DSS technology routinely	☐	☐	☐	☐	☐

C2 The following questions are related to **Overall of Mobile DSS**. Please answer all questions by ticking (√) or crossing (X) in the box.

1. Perceived usefulness of a mobile devices				
Description				
Doctors perceived the device that is being able to provide them with relevant information either via the internet or software for the device. They perceived the device as a reference tool, patient information tool and even contemplated its use as a decision support tool that could help in diagnosis and medication prescription.				
Please rate your ***decision modelling competency*** based on the above descriptions				
Not at all ☐	Minor barrier ☐	Somewhat a barrier ☐	Major barrier ☐	Significant barrier ☐
2. Social influences				
Description				
Doctors display a professional maturity that does not allow factors like image or subjective norm to influence them.				
Please rate your ***decision modelling competency*** based on the above descriptions				
Not at all ☐	Minor barrier ☐	Somewhat a barrier ☐	Major barrier ☐	Significant barrier ☐
3. Perceived user resources				

Description				
Lack of resources to support their use of devices by the hospitals did not negatively influence their intention to adapt. This could be attributed to the social circumstances where doctors have leant to cope with limited resources on a daily basis, despite their extremely pressurised work environments.				
Please rate your ***decision modelling competency*** based on the above descriptions				
Not at all ☐	Minor barrier ☐	Somewhat a barrier ☐	Major barrier ☐	Significant barrier ☐
4. Task/technology fit				
Description				
The medical profession is very information intensive one and doctors realised that the mobile health device would be able to help and keep abreast of the latest medical knowledge.				
Please rate your ***decision modelling competency*** based on the above descriptions				
Not at all ☐	Minor barrier ☐	Somewhat a barrier ☐	Major barrier ☐	Significant barrier ☐
5. Result demonstrability				
Description				
Doctors believed that the technology would be able to help them deliver better quality care to their patients.				
Please rate your ***decision modelling competency*** based on the above descriptions				
Not at all ☐	Minor barrier ☐	Somewhat a barrier ☐	Major barrier ☐	Significant barrier ☐
6. Fear of legal action				
Description				
Underlying doctors' perceptions of the device as an information tool was an unease in respect of malpractice legal suits. It was thought that the technology could aid the decision support. This could help reduce the possibility of incorrect diagnosis and treatment, perhaps legal action against the doctor.				
Please rate your ***decision modelling competency*** based on the above descriptions				
Not at all ☐	Minor barrier ☐	Somewhat a barrier ☐	Major barrier ☐	Significant barrier ☐
7. Doctor-patient relationship				
Description				
Where doctors do not interact with patients, a number of the above factors are not applicable. Thus this can be seen as a moderating variable or factor on the other factors.				
Please rate your ***decision modelling competency*** based on the above descriptions				
Not at all ☐	Minor barrier ☐	Somewhat a barrier ☐	Major barrier ☐	Significant barrier ☐