



UNIVERSITY OF NAIROBI

SCHOOL OF COMPUTING AND INFORMATICS

**A Model for Design and Deployment of mHealth Solutions Fit
for Low-Resource Settings: Case of Maternal Care**

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**THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE
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UNIVERSITY OF NAIROBI**

DECLARATION

I, Stephen Ng'ang'a Mburu, do hereby declare that this PhD research is entirely my own work and where there's work or contributions of other individuals, it has been duly acknowledged. To the best of my knowledge, this dissertation has not been previously presented to any other education institution or forum.

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ADDITIONAL SUPERVISION ACKNOWLEDGED



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Prof. Alexander Schill

Dr. Elke Franz

Dr. Thomas Springer

DEDICATION

*To my **lovely wife, Esther**; You have endured the long nights and absences when research severally took me away from bed and home. Thank you for the love and support throughout this journey*

*To my **daughter, Laura and son, Collins**; Thanks for standing with me all the time despite missed days and plays. You're my treasure beyond compare*

*To the **First Lady Republic of Kenya, Margaret Kenyatta**; Thanks for sacrifices for the sake of well-being of mothers and children*

“Healthcare transformation agenda can be realized through the reduction of theories and design concepts to actual practice”

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ABSTRACT

Globally, there are concerted efforts to implement interventions that fast-track attainment of millennium development goals (MDGs 4 and 5) aimed at reversing trends in maternal and child mortality. This is the motivation behind mHealth initiatives in developing countries to exploit opportunities provided by global mobile penetration now approaching 96%. Despite these efforts, a global survey by WHO and ITU in 2013 indicates most of these initiatives are weak platforms that have failed to transit to actual practice. The survey revealed that, only 9-16% of the developing countries that have implemented eHealth projects have managed to support them for at least three years. These findings confirmed another global observatory survey conducted by WHO in 2009 that indicated over 2/3 of mHealth interventions were trial projects implemented in Africa and South Asia between 2008 and 2011. Despite generous donor-funding, it is our contention that this low uptake is due to poor designs and deployment strategies. Therefore, there is need for a holistic approach to identifying critical factors that will accelerate integration of mHealth into healthcare ecosystem. This is by aligning mHealth conceptual designs in the early stages of development to the reality in low resource settings.

This research set out to narrow the gap between design and reality in the context of use by providing a socio-technical approach to identifying key factors that influence deployment and utilization of mHealth innovations in low-resource settings. Based on a 6-month pre-study fieldwork meant to identify the factors, and in-depth review of related work, we derived a conceptual model that serves as a blueprint for development of mHealth artefacts suitable for low-resource settings. The proposed model is anchored on predictive modelling technique to help in validating conceptual designs prior to development of mHealth artefacts.

To validate the model in a practical scenario, we developed a maternal care prototype named *mamacare* using system development blueprints derived from the conceptual model. However, before designing and deploying the prototype, we conducted pilot tests on random samples of antenatal and postnatal mothers to constantly get their perceptions on use of mobile phones in maternal care. Later, the subjects who gave consent to be receiving SMS alerts such as appointment reminders, safe delivery, danger signs and nutrition were recruited to participate in a repeated measures experiment.

To analyse data from a repeated measures experiment, we used Partial Least Squares Structural Equation Modelling (PLS-SEM), repeated measures ANOVA and Bonferroni post hoc tests. Results from three datasets demonstrated high internal consistency, construct

and discriminant validity of the pretest and post-test data collection instruments. Modelling of the pretest dataset using PLS-SEM predicted 64% post-deployment utilization. This was followed by two post-tests that indicated approx. 51% utilization after one month and 53% after 3 months. Further inference on consolidated datasets using PLS-SEM and parametric tests predicted utilization of approx. 61% against actual use of 48%. This proves that evaluating factors that influence utilization can inform on design and deployment of mHealth artefacts that have high probability of utilization after deployment.

This study contributes to body of knowledge by providing a socio-technical approach to design of mHealth solutions suitable for deployment low resource settings. This is by providing a model that supports implementation of ISO/IEC/IEEE 29148:2011 standard on requirements engineering and the ISO/IEC 25010:2011 standard for evaluating systems and software quality. Furthermore, the study contributes to health informatics research by integrating technologies and behavioural models into schemas suitable for investigating factors that limit utilization of mHealth innovations in a clinical environment.

Keywords: ANOVA, conceptual design, Low-resource settings, mamacare, and mHealth PLS-SEM predictive modelling, repeated measures experiment.

“We have to understand that the world can only be grasped by action, not by contemplation. The hand is more important than the eye...The hand is the cutting edge of the mind - Jacob Bronowski”

LIST OF ABBREVIATIONS

AUP.....	Agile Unified Process
ANOVA.....	Analysis of Variance
CDMA.....	Code Division Multiple Access
CIR.....	Clinical Investigator Record
CoIA	Commission on Information and Accountability for Women's and Children's Health
CSE.....	Computer Self-Efficacy
DICOM.....	Digital Imaging and Communication in Medicine
iERG.....	independent Expert Review Group
GEE.....	Generalized Estimating Equation
GSM.....	Global System for Mobile Communication
HIPAA.....	Health Insurance Portability and Accountability Act
HIS.....	Health Information System
HL7.....	Health Level Seven
ICT.....	Information Communications Technology
IEC.....	International Electro-technical Commission
ISO.....	International Organization for Standardization
ICTs.....	Information and Communication Technologies
ITU.....	International Telecommunication Union
KNH/UoN-ERC	Kenyatta National Hospital/University of Nairobi Ethics Research Committee
MDGs.....	Millennium Development Goals
mHealth.....	Mobile Health
PLS.....	Partial Least Squares
TIPFit.....	Technology, Individual, Process Fit
PVT.....	Process Virtualization Theory
RMNCH.....	Reproductive, Maternal, Neonatal and Child Health
SEM.....	Structural Equation Modelling
SIM.....	Subscriber Identity Module
SMS.....	Short Message Service
SQuaRE.....	Systems and software Quality Requirements and Evaluation
TTF.....	Task-Technology Fit
UML	Unified Modelling Language
UN.....	United Nations
WHO.....	World Health Organization

TABLE OF CONTENTS

DECLARATION.....	ii
GUEST SUPERVISORS.....	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
ABSTRACT	vi
LIST OF ABBREVIATIONS	viii
TABLE OF CONTENTS	ix
List of Figures.....	xiv
LIST OF TABLES	xvii
GLOSSARY OF TERMS.....	xix
CHAPTER 1.....	1
Introduction	1
1.1. Background	1
1.2. Low-Resource Settings.....	1
1.3. Maternal care in Low-Resource Settings	3
1.4. ICT Interventions in Low-Resource Settings	3
1.5. Mobile-Health Deployment Challenges	5
1.6. Healthcare Systems Deployment Models.....	6
1.7. Problem Statement	7
1.8. Aim of the Study	8
1.9. Research Objectives	8
1.10. Research Questions	8
1.11. Research Hypothesis	9
1.12. Study Justification and Setting.....	9
1.13. Scope of the Study.....	10
1.14. Summary of Thesis Report.....	10
CHAPTER 2.....	12
Literature Review	12
2.1 Introduction	12
2.2 Fundamentals of Health.....	12
2.2.1 Public Health.....	13
2.2.2 Clinical Health.....	13
2.2.3 Ontology of Clinical Health Records	14
2.3 Socioeconomic Settings	16
2.3.1 Level of Economic Development.....	16
2.3.2 Available Resources	17

2.4	Challenges in Deploying mHealth	17
2.4.1	Infrastructure and Resources	17
2.4.2	Technical Expertise	18
2.4.3	Standards and Policy Guidelines	18
2.4.4	Financial Constraints	19
2.4.5	Needs and Priorities	19
2.4.6	Health Education and Awareness.....	20
2.4.7	Ethics and Legal Framework.....	20
2.5	Healthcare ICT Innovations	21
2.5.1	Mobile Technologies in Healthcare	22
2.5.2	Global mHealth Initiatives	24
2.6	Socio-technical Approach to Design.....	26
2.7	Systems Development Paradigms	26
2.7.1	Design Science	26
2.7.2	System Development Methodologies.....	28
2.8	Information System Models	29
2.8.1	Technology Acceptance Model.....	29
2.8.2	Information Systems Success.....	30
2.8.3	Process Virtualization Theory and Impact of IT	31
2.8.4	Task-Technology Fit	34
2.8.5	Extended TTF Model	36
2.8.6	FITT Model	37
2.8.7	Integrated TTF and PVT Model.....	38
2.9	Towards a Conceptual Model.....	38
2.10	Conceptual Model: Main Constructs.....	39
2.11	Conceptual Model: Extended Constructs	41
2.11.1	Individual Characteristics	42
2.11.2	Process Requirements.....	45
2.11.3	Technology Functionality.....	47
2.11.4	Fit	49
2.11.5	Technology Utilization.....	50
2.12	Summary of Literature Review	50
CHAPTER 3.....		51
Methodology: Model-Driven System Development		51
3.1	Introduction	51
3.2	TIPFit Operationalization Roadmap	51
3.2.1	Pre-study Fieldwork	52

3.2.2	System Development Blueprints	57
3.2.3	Prototype Development Approach	62
3.3	Inception Phase	63
3.3.1	Conceptualization: Modelling and Requirements	63
3.4	Elaboration Phase	66
3.4.1	Functional Modelling	66
3.4.2	Static Models.....	68
3.4.3	Responsive UI Design	71
3.4.4	SMS-Alerts Considerations.....	73
3.5	Construction Phase	74
3.5.1	Server-side Implementation	74
3.5.2	Client-side Implementation.....	75
3.5.3	Security and Privacy.....	77
3.6	Transition Phase	78
3.6.1	Mamacare Deployment	78
3.6.2	Prototype Testing	79
3.6.3	Training and Awareness	79
3.6.4	User Acceptance Testing.....	80
CHAPTER 4.....		82
Methodology: Design of Experiment		82
4.1	Introduction	82
4.2	Experimental Design	82
4.2.1	Within-Subjects Design.....	83
4.2.2	Experiment Procedure	85
4.2.3	Sampling Criteria	85
4.2.4	Cohort Preparation	86
4.2.5	Ethical Considerations.....	87
4.3	Data Collection Methods.....	88
4.4	Operationalizing TIPFit: Measurement Indicators.....	89
4.4.1	Individual Characteristics.....	89
4.4.2	Process Requirements.....	90
4.4.3	Technology Functionality.....	92
4.4.4	Fit and Technology Utilization.....	93
4.4.5	Operationalizing TIPFit: Hypotheses	93
4.5	Data Preparation and Processing	97
4.5.1	Predictive Modelling	97
4.5.2	Comparative Analysis	99

CHAPTER 5.....	100
Results and Discussion	100
5.1 Introduction	100
5.2 Discussion of Pretest Results	101
5.2.1 Participants' Demographic Details.....	101
5.2.2 Reliability and Validity Tests.....	103
5.2.3 Path modelling and Analysis.....	105
5.2.4 Significance of Factors and Path Coefficients	106
5.2.5 Sobel Test for Mediation Effect of Fit	108
5.2.6 Summary of Pretest Results	110
5.3 Discussion of Post-test1 Results.....	112
5.3.1 Data Preparation for Analysis	112
5.3.2 Participants' Demographic Details.....	112
5.3.3 Reliability and validity Analysis	113
5.3.4 Path modelling and Analysis.....	115
5.3.5 Significance of Factors and Path Coefficients	116
5.3.6 Summary of Post-test1 Results.....	117
5.4 Discussion of Post-test2 Results.....	118
5.4.1 Data Preparation for Analysis	118
5.4.2 Participants' Demographic Details.....	119
5.4.3 Reliability and Validity Analysis	119
5.4.4 Path modelling and Analysis.....	121
5.4.5 Significance of Factors and Path Coefficients	122
5.4.6 Summary of Post-test2 Results.....	122
5.5 Data Triangulation and Discussion of Results	124
5.5.1 Within-Subjects Effect on Treatment.....	124
5.5.2 Treatment Effect on Individual characteristics	125
5.5.3 Treatment Effect on Process requirements.....	125
5.5.4 Treatment Effect on Technology Functionality	126
5.5.5 Effect of Time on Fit and Technology Utilization	126
5.5.6 Composite Predictive Model	127
5.5.7 Composite Evaluation model	128
5.5.8 Comparison between Sample Means	129
5.5.9 Inference on Null Hypothesis.....	133
CHAPTER 6.....	135
Conclusion and Recommendations	135
6.1 Introduction	135

6.2	Research Objectives Achievement.....	135
6.2.1	Research Objective #1.....	136
6.2.2	Research Objective #2.....	136
6.2.3	Research Objective #3.....	137
6.3	Benchmarking the Study	138
6.4	Implication for Practice	139
6.5	Research Contributions	140
6.6	Conclusion.....	141
6.7	Future Research.....	141
	REFERENCES	142
	APPENDICES	149
	Appendix 1: TIPFit Operationalization Definitions	149
	Appendix 2: Sample Pretest Questionnaires	151
	Appendix 3: Sample Post-test Questionnaire	155
	Appendix 4: Informed Consent	159
	Appendix 5: Cover Letter.....	162
	Appendix 6: KNH/UoN-ERC Research Approval.....	163
	Appendix 7: Ministry of Health Research Approval.....	164
	Appendix 8: Mamacare Prototype Development	164
	Appendix 8A: Sample Pre-Study Questionnaire	166
	Appendix 8B: Sample Pre-prototyping Questionnaire.....	166
	Appendix 8B: Sample Pre-prototyping Questionnaire.....	171
	Appendix 8C: Sample Prototyping Questionnaires.....	171
	Appendix 8C: Sample Prototyping Questionnaires.....	174
	Appendix 8D: Sample Mamacare UI Screenshots	176
8D. 1	Dashboard on Computer and Mobile	176
8D. 2	Login and Cascading Menu on Mobile	176
8D. 3	Mamacare Reports on Desktop PC	177
8D. 4	Mamacare Reports on Mobile	177
8D. 4	Dynamic Charts	177
	Appendix 8E: Mamacare Database Schema.....	179
	Appendix 8F: Sample Mamacare Program Codes	180

LIST OF FIGURES

Figure 2.1: Clinical Health Processes	14
Figure 2.2: Clinical Investigator Record ontology (Beal & Heard 2007).....	15
Figure 2.3: ICT innovations in healthcare (Omachonu & Einspruch 2010)	22
Figure 2.4: Technology Acceptance Model (Davis 1989)	29
Figure 2.5: Information System Success (DeLone & McLean 2003).....	30
Figure 2.6: Process virtualization Theory (Overby 2008).....	31
Figure 2.7(a): Task-Technology Fit (Goodhue & Thompson 1995)	35
Figure 2.7 (b): Basic TTF model (Goodhue 1998).....	35
Figure 2.8: Extended TTF model (Strong, Dishaw & Bandy 2006).....	36
Figure 2.9: FITT model (Ammenwerth, Iller & Mahler 2006)	37
Figure 2.10: Integrated TTF-PVT model (Overby & Konsynski 2010).....	38
Figure 2.11: TIPFit Conceptual model: A predictive approach	39
Figure 2.12: Decomposed conceptual model.....	41
Figure 3.1: Roadmap to TIPFit model operationalization.....	52
Figure 3.2: Pre-study session with caregivers	53
Figure 3.3: Pre-study responses from health practitioners	54
Figure 3.4 (b): Mobile use in maternal care	56
Figure 3.4 (a): Voice calls and sms services	56
Figure 3.5: Typical Software development process.....	57
Figure 3.6: Rational Unified Process (Booch et al. 2007).....	62
Figure 3.7: Conceptualization session with caregivers	63
Figure 3.8: Requirements discovery model.....	64
Figure 3.9: Mamacare Admin use case diagram.....	66
Figure 3.10: Mamacare Caregiver use case diagram	67
Figure 3.11: Mamacare Patient use case diagram.....	67
Figure 3.12: Patient appointment sequence diagram	68
Figure 3.13: Mamacare class and data modelling.....	69
Figure 3.14: Mamacare entity relationship diagram	70
Figure 3.15: Mamacare navigation model.....	71
Figure 3.16: Mamacare view on mobile.....	71
Figure 3.17: Mamacare view on desktop computer and tablets	72
Figure 3.18 (a): Desktop and tablet form	72
Figure 3.18 (b): Mobile form.....	72

Figure 3.19: Mobile SMS design using preferred languages	73
Figure 3.20 (a): Form on computer	75
Figure 3.20 (b): Form on mobile.....	75
Figure 3.21: Sample sms-alerts from mamacare server	76
Figure 3.22: Mamacare deployment diagram	78
Figure 3.23: Mamacare physical deployment architecture.....	79
Figure 3.24: User training in maternity section	80
Figure 3.25: User acceptance testing on caregivers	80
Figure 3.26: User acceptance testing on patients	81
Figure 4.1: Repeated measures experimental design	84
Figure 4.2: Study cohort in Kimbimbi Hospital	86
Figure 4.3: TIPFit predictive modelling.....	94
Figure 4.4: Predictive modelling using PLS-SEM	99
Figure 5.1: Participants' age distribution	101
Figure 5.2: Participants' education level	102
Figure 5.3: Pretest instrument reliability analysis.....	103
Figure 5.4: Pretest AVE coefficients	104
Figure 5.5: Predictive model from pretest dataset	105
Figure 5.6: Bootstrapped predictive model	107
Figure 5.7: Direct effect of Attitude on Technology utilization	108
Figure 5.8: Mediated effect of fit on technology utilization.....	108
Figure 5.9: Sobel test on mediating effect of fit	109
Figure 5.10: Post-test1 reliability analysis	113
Figure 5.11: Post-test1 AVE coefficients.....	114
Figure 5.13: Post-test1 bootstrapped model	116
Figure 5.14: Post-test2 reliability analysis	119
Figure 5.15: Post-test2 AVE coefficients.....	120
Figure 5.17: Post-test2 PLS Visual Model.....	121
Figure 5.16: Post-test2 indicators and path coefficients	121
Figure 5.17: Composite TIPFit predictive model	127
Figure 5.18: Composite utilization model	128
Figure 5.19: Boxplot inspection for outliers.....	130
Figure A7: Copy of Ministry of Health Research Approval	164
Figure A8D (b): OPD on Mobile	176
Figure A8D (a): OPD Dashboard on PC	176
Figure A8D (d): Mobile dashboard.....	176

Figure A8D (c): Maternity dashboard on PC	176
Figure 8D (f): Menu on mobile.....	176
Figure 8D (e): Login screen.....	176
Figure 8D (g): OPD Clinic follow-up schedule on PC	177
Figure 8D (h): Deliver Records in Maternity on PC.....	177
Figure 8D (i):ANC appointment.....	177
Figure 8D (j): Deliveries report	177
8D (k): Dynamic Charts client-server interaction.....	178
8D (l): Patient’s weight trend after 3 clinic follow-ups	178
Figure A8E: Mamacare database schema.....	179
A8F: Bash script for extracting parameters from received sms	181

LIST OF TABLES

Table 2.1: Healthcare stakeholders and their expectations	21
Table 3.1: Summary of pre-study discussions with caregivers	54
Table 3.2: Summary of pre-study interview with clients/patients	56
Table 3.3: System development matrix for individual characteristics	58
Table 3.4: System development matrix for process requirements	59
Table 3.5: System development matrix for technology functionality	60
Table 3.6: System development matrix for fit and technology utilization	61
Table 3.7: Summary of the four workflow outcomes	61
Table 4.1: Repeated measures design	84
Table 4.2: Dimensions and indicators of individual characteristics	90
Table 4.3: Dimensions and indicators of process requirements	91
Table 4.4: Dimensions and indicators of technology functionality	92
Table 4.5: Dimensions and indicators of fit and technology utilization	93
Table 4.6: Hypothesized cause-and-effect relationships Propositions	96
Table 4.7: Codebook for representing responses	97
Table 5.1: Participants' age distribution	101
Table 5.2(c): Owns mobile	102
Table 5.2(b): No. of children	102
Table 5.2(a): Pregnancies	102
Table 5.3: PLS Reliability and validity tests	104
Table 5.4: Pretest Instrument discriminant validity	105
Table 5.5: Pretest factor loadings	106
Table 5.6: Pretest path coefficients	106
Table 5.7: Path coefficients t-test values	107
Table 5.8: Significance of Fit as mediating variable	109
Table 5.9: Test outcome of hypothesized relationships	111
Table 5.10(a): Subjects' age	112
Table 5.10(b): Subjects' education	112
Table 5.11(b): Participants' no. of children	113
Table 5.11(a): Participants' gravida	113
Table 5.12: Post-test1 reliability and validity tests	114
Table 5.13: Post-test1 discriminant validity	115
Figure 5.12: Post-test1 indicators and path coefficients	115
Table 5.14: Post-test1 indicators loadings	116

Table 6.16: Post-test1 Path coefficients	116
Table 5.15: Post-test1 path coefficients	116
Table 5.16: Post-test1 path coefficients significance test.....	117
Table 5.17: Pretest and post-test1 sub-hypothesis	118
Table 5.18(a): Subjects' age	119
Table 5.18(b): Subjects' education	119
Table 5.19(b): No. of children	119
Table 5.19(a): Subjects' gravida	119
Table 5.20: PLS Post-test2 reliability and validity tests	120
Table 5.21: Post-test2 discriminant validity.....	120
Table 5.22: Post-test2 factor loadings	121
Table 5.23: Post-test2 path coefficients	122
Table 5.24: Post-test2 inner model t-test values	122
Table 5.25: Post-test2 sub-hypothesis test outcome	123
Table 5.26: Comparison of pretest and post-tests path coefficients	124
Table 5.27: Significance of pretest and post-tests path coefficients.....	124
Table 5.28: Summary of Pretest and Post-tests sub-hypotheses testing	126
Table 5.29: Summary of composite predictive model coefficients	128
Table 5.30: Summary of composite post-test model coefficients.....	129
Table 5.31 (a): Pretest subsample means for attitude	130
Table 5.31 (b): Significance of difference between means	131
Table 5.32: Mauchly's test of sphericity.....	131
Table 5.33: Tests of Within-subjects effects	132
Table 5.34: Summary of Repeated Measures ANOVA	132
Table 5.35: Bonferroni differences between sample means.....	133
Table 5.36: Summary of pretest and post-test statistical inference.....	134
Table 6.1: Summary of research objectives and questions.....	135

GLOSSARY OF TERMS

1. **Clinical Investigator Record:** An ontology that describes clinical information created in the process of healthcare delivery; suitable for design of Electronic Medical Records.
2. **Deployment:** Process of installation, configuration, running, testing, and user training on a new software artefact ready for use in its environment.
3. **Design Science:** Application of the principles of science in design to help make the world's finite resources meet needs of all humanity, without disrupting the ecological processes.
4. **eHealth:** Use of ICTs such as computers, mobile phones and radios to provide healthcare services and information.
5. **ICTs:** Information and Communications Technologies (ICTs) refers to a full range of devices that facilitate electronic means of processing and transmission of information. These include but not limited to computers, mobile phones, TVs, radios and fax.
6. **Low-Resource settings:** Underserved rural and urban areas characterized by poor infrastructure, inferior technologies, limited access to basic needs and poor lifestyle.
7. **mHealth:** New form of electronic health that makes use of mobile technologies such as mobile phones and tablets to provide healthcare services and information.
8. **Predictive model:** A model made up of variables or factors that are likely to influence future behaviour or results. Such models employ linear equations or artificial neural networks
9. **Process Virtualization:** Completing a process in a virtual or remote environment where physical interaction between the participants has been removed.
10. **Responsive Design:** System design in which the same application dynamically adapts into different execution platforms to provide optimal viewing experience.
11. **Technology Fit:** capability of technology to accomplish individual's task and enhance performance.
12. **User-Centred Design:** Design paradigm in which needs, expectations and limitations of users of a product or service are given extensive attention at each stage of the design process.
13. **Vital Signs:** Body parameters such as temperature, respiratory rate, pulse, blood pressure and haemoglobin that provide information about one's state of health.
14. **Repeated Measures:** Taking multiple observations on the same experimental subject at different time points or treatment conditions.

CHAPTER 1

Introduction

1.1. Background

To exploit opportunities provided by the unprecedented mobile penetration, case studies and ICTs initiatives seeking to fast-track attainment of Millennium Development Goals (MDGs) have gained traction globally. Latest statistics by International Telecommunication Union (ITU) indicates that by the end of 2014, mobile penetration rate is expected to reach 96% globally (ITU 2014). In developing countries, penetration rate is expected to reach 90% demonstrating that mobile connectivity is approaching global population. The report also indicates that, mobile-broadband penetration is approaching 32% with developing countries registering the fastest growth rate of 26% against 11.5% in developed countries. In Kenya where the study was conducted, a national ICT survey conducted in 2010 revealed that about 84% of Kenyans have access to mobile telephony (KNBS & CCK 2010). Latest quarterly report released in July 2014 by Communications Authority of Kenya indicates that the current mobile penetration rate in Kenya stands at 78.2% (CA 2014).

Despite this technological growth and interventions aimed at exploiting this opportunity, access to healthcare remains a big challenge in most developing countries. Findings from a global observatory survey on mHealth conducted by World Health Organization (WHO) in 2009 indicated that over two-third of mHealth initiatives were trial projects most of which never matured to pervasive use (WHO 2011). Recently, a survey conducted jointly by WHO and ITU in 2013 indicates that most eHealth initiatives are weak platforms that requires a holistic approach (WHO & ITU 2014). The survey findings revealed that, only 9-16% of developing countries have managed to continue implementing and funding eHealth initiatives for at least three years. This low uptake is also evident in reviewed case studies conducted by Mechael et al. (2011), Vital Waves Consulting (2009) and UN (2010). Therefore, the motivation behind this study is to investigate why current mHealth artefacts have failed to address realistic health challenges in low-resource settings.

1.2. Low-Resource Settings

The term low-resource setting refers to areas characterized by poor infrastructure, limited access to basic needs and poor living standard (Aggarwal et al. 2005; OECD 2011). Though the term is mostly used in reference to developing countries, it is also applicable to developed countries where people have inadequate access to resources due to demographics

and geopolitical disparities. In this study context, we limit the scope of the low-resource settings to underserved rural and urban areas in developing countries.

Globally, there are concerted efforts to implement socioeconomic and technological interventions focusing on Millennium Development Goals (MDGs) relating to poverty reduction, maternal deaths, child mortality, HIV/Aids and malaria (Mechael et al. 2010; WHO 2011; ITU 2010). In developing countries, the following challenges are attributed to poor access to healthcare:

- Poor infrastructure: Poor transport network, unreliable power supply, and lack of medical facilities and equipment results to high cost of accessing distant health centre which contributes to loss of lives in cases that could have been avoided.
- Health professionals: In most developing countries, only few tertiary institutions offer professional training in health sciences. This leaves the lives of many to unqualified people like “traditional or herbal doctors” because the few qualified personnel like doctors and nurses are reluctant to work in harsh environments.
- Funding: Due to poor economic ability, governments in developing countries allocate insufficient funds to healthcare that can hardly maintain healthcare demands such as medical devices and instruments, drugs and expendables.
- Poor management: In most developing countries, there is shortage of trained health personnel in healthcare sector and the few available lack commitment due to low motivation attributed to limited resources, poor remuneration and political interference.
- Poor living standards and lifestyle: Due to poverty, most communities in low-resource settings lack access to basic needs such as food, housing and clothing. This is compounded by poor lifestyle such as drug abuse, alcoholism and careless sexual engagements.

Despite these socioeconomic and technical challenges, developing countries are eager to use available resources and technologies to fast-track attainment of MDGs 4, 5 and 6 (UN, 2010) that states:

- MDG-4: Between 1990 and 2015*, reduce the under-fives child mortality rate by two-thirds. This is yet to be realized!
- MDG-5: Between 1990 and 2015*, reduce maternal deaths by three-quarters. Though there is notable improvement, the set target is yet to be realized!
- MDG-6: By 2015, combat HIV/AIDS, malaria, and other diseases and begin to reverse the spread of HIV/AIDS, incidence of malaria and other major diseases.

Though most developing countries are far from realization of the set MDGs targets by 2015, combined efforts towards dealing with health challenges in low-resources settings is still a matter of priority. Therefore, there is need for the international community to set new health agenda to the realization of MDGs' targets. This will help in motivating socioeconomic and ICT interventions aimed at providing equitable access to healthcare for the advancement of wellbeing and standard of living for all.

1.3. Maternal care in Low-Resource Settings

Health and well-being of mothers and children are of critical importance, both as reflections of the current health status of individuals, communities, and the nation. In every society, the well-being of women and children is considered as the predictor of the health of the next generation. Unfortunately, poor health status and poverty in low-resource settings are closely interrelated. These challenges are attributed to poor living standards, high cost of care, limited health facilities, illiteracy, and cultural practices. In our preliminary study conducted between June and November 2012, we noted that due to poverty and illiteracy, most women are subjected to prejudice, stereotype, and disrespect. In fact one woman commented: *"I'm a poor uneducated squatter. I believe that has a lot to do with the poor quality of care, and shouting I receive from nurses... They judge me for being down there... They judged me for how many children I have... It's like I'm a waste of their time!"*

Such an experience makes many women particularly in the rural areas fear going to hospitals to receive adequate care during their pregnancies. This results in high maternal deaths due to haemorrhage, sepsis, hypertensive disorders of pregnancy, complications of unsafe abortion, and obstructed and/or prolonged labour. Fortunately, with the high penetration of ICTs even in underserved areas, it is possible to reduce the number of hospital visits to optimize usage of overstretched healthcare resources. Furthermore, it's possible to enhance interaction between the caregivers and patients to detect high-risk pregnancies for immediate action. Therefore, success of ICT interventions has the potential to increase the quantity and quality of maternal care, many cases of child and maternal deaths could be avoided.

1.4. ICT Interventions in Low-Resource Settings

Information and Communications Technologies (ICTs) refers to tools that facilitate processing and transmission of information by electronic devices such as mobile phones, computers, television, fax and radios. The rapid penetration of ICTs globally has enhanced

access and delivery of services. In particular, mobile technologies are becoming increasingly capable of handling advanced applications in education, agriculture, health, banking and other domains. It is now possible to use even the most basic phone to access banking services. For example in Kenya, *Safaricom's mPesa*¹ service has made it possible to send money locally and abroad, pay for products and services, and settle bills by the touch of a button. In fact, use of mobile applications such as m-banking has revolutionized the banking sector with over 76% of Kenya population having access to mobile money services compared to 21% bank account (InterMedia 2014). The success of mobile money has motivated deployment of mHealth artefacts in healthcare system. Deployment refers to the processes involved in getting a new software artefact ready for use in its environment, including installation, configuration, running, testing and user training.

In recent times, there has been considerable discussion on the promises of ICTs to increase access to healthcare services and foster sustainable development (InfoDev 2006; Breen, Wan & Ortiz 2010). This has motivated the global community to target developing countries particularly in Africa and South Asia as test-beds for their ICTs ideas focusing on:

- Telemedicine: Facilitates essential remote consultation, diagnosis and treatment through telemedicine
- Patient monitoring: Investigate how point-of-care devices can be used to remotely monitor patients and manage incidences of public health threats. The aim is to find out how such technologies respond in a constrained environment.
- Management: Improve efficiency in administration, recording and reporting procedures. These procedures take a lot of time which would have been used to attend to patients.
- Decision making: Facilitate health data collection, aggregation and dissemination to help in public health awareness, management of ambulatory care and emergency cases.
- Training: Facilitate collaboration among healthcare workers through sharing of knowledge, experiences and care interventions.

To deploy these services on mobile platform, there was a surge in mHealth projects in Sub-Saharan Africa between 2008 and 2011 (WHO & ITU 2014). However, investigations by UN's *independent Expert Review Group* (iERG) revealed that most of the initiatives in developing countries are weak information technology platforms that require a holistic approach. We argue that this requires a socio-technical approach to identify factors that influence post-deployment acceptance and use in low-resource settings.

¹ *mPesa stands for mobile Pesa, a mobile payment system in Kenya. "Pesa" is a Swahili term for money.*

1.5. Mobile-Health Deployment Challenges

Health is a resource for everyday life which permits people to lead an individually, socially and economically productive life. For the past few years, advancement in mobile technologies has motivated deployment of mobile-health (mHealth) artefacts and development frameworks such as MOTECH², RapidSMS and MAMA³ aimed at improving person's health and well-being. The term mHealth refers to provision of healthcare services and information through portable devices such as mobile phones. We argue that, most mHealth solutions have failed to inspire acceptance and use due to poor fit in low-resource settings. This is because complexity of deploying mHealth solutions goes beyond technical dimension. To scale-up utilization of mHealth, there is need for a holistic approach in order to determine factors that determine utilization of mHealth artefacts prior to design and deployment (Mburu, Franz & Springer 2013).

A good example of difficulty in deploying mHealth artefacts was Grameen Foundation (2011) experience in their initiative to deploy a maternal care artefact they called Mobile Midwife. The aim of the intervention was to determine how use of mobile phones could improve health outcomes for mothers and their new-borns. In the course of implementing Mobile Midwife, the Foundation experienced the following challenges:

- *Cultural barriers*: The social aspects made using privately owned phones difficult. Phone access and ownership seemed to be fluid because many individuals shared phones with their family members or they were controlled by the husband.
- *Electricity*: In rural areas, unreliable power supply made recharging of mobiles phones difficult.
- *Professional ethics*: Healthcare workers were unwilling to use their personal phones to execute professional tasks. This forced the foundation to provide them with mobile phones which made the project expensive to run. Moreover, nurses were also asking for “lunch” in return for supporting the project.
- *Communication protocols*: Data transmission method to be used was also a challenge because 85% of phones owned by nurses could only support SMS messaging.
- *Financial constraints*: The logistics of purchasing and setting up more than 40 mobile phones was a challenge due to issues such as cost, loss, theft and misuse.

The experience by Grameen Foundation in rural Ghana points to common challenges faced in trying to push mHealth products into low-resource settings. The Foundation

² MOTECH stands for Mobile Technology for Community Health, a Java-based open Source mHealth toolkit

³ MAMA: stands for Mobile Alliance for Maternal Action, concerned with interventions on maternal health

acknowledged that successful deployment requires a product to be developed together with the stakeholders. Therefore, to scale-up utilization of mHealth initiatives in low-resource settings, there is need for socio-technical strategies to design and deployment of mHealth artefacts if the promises of mHealth are to be realized.

1.6. Healthcare Systems Deployment Models

There are efforts in providing architectural models and theoretical frameworks and standard guidelines that attempt to scale-up deployment of healthcare information systems, mHealth and other ICT innovations in the healthcare sector. The following is a brief highlight on some architectural models, theoretical frameworks and global standards:

- Architectural and design framework: These frameworks are concerned with seamless integration of mHealth application at device, infrastructure and software (application) levels. Example of such frameworks include:
 - o Connected Health Framework Architecture and Design Blueprint (CHF-ADB): Microsoft (2009) provides software developers with reference architecture for design and implementation of healthcare systems. This framework provides architectural design for building interoperable, patient-centric health record systems while taking into account healthcare needs of the stakeholders.
 - o Framework for context-aware mobile eHealth service discovery: Oladosu et al. (2009) provides an infrastructure framework for developing context-aware mHealth applications intended for use in rural and suburban healthcare centres.
- WHO mHealth and ICT Framework for reproductive, maternal, neonatal and child health (RMNCH): This framework combines metrics describing health system functions and needs (WHO n.d.). It contains guidelines on how ICT and mHealth strategies can be used to support reproductive, maternal, neonatal and child health. The framework formulates ten strategies for registration, vital events tracking, electronic health records, scheduling and reminders, decision support, health education, and behaviour change. It also contains guidelines on training and service updates, commodity and human resource management, health financing and incentives, communication, telemedicine, and real-time reporting of indicators.
- Framework for assessing the health system challenges: Leon, Schneider and Daviaud (2012) proposed a framework that would facilitate a systematic evaluation of potential challenges to scaling up mHealth initiatives for community-based health services in

South Africa. The framework consists of four dimensions that need to be considered when implementing mHealth artefacts. These four dimensions are technological (e.g. usability), organizational (e.g. capacity and culture), financial (e.g. cost-effectiveness), and stewardship (e.g. strategic leadership).

- Normalization Process Theory (NPT): Mair et al. (2012) carried out a systematic review of factors influencing implementation of e-Health, focusing on implementation processes rather than outcome. They based their meta-analysis on the four constructs of NPT namely coherence (sense-making), cognitive participation (relationship), collective action (enacting) and reflexive monitoring (appraisal).
- ISO/IEC/IEEE 29148:2011 and ISO/IEC 25010:2011 standards: The ISO/IEC/IEEE 29148:2011 (2011) contain guidelines on requirements engineering while ISO/IEC 25010:2011 (2011) provides metrics for evaluating quality of systems and software products.

In summary, review of socioeconomic settings, challenges in mHealth deployment in low-resource settings, existing frameworks, and guidelines helped us identify the problem that need to be addressed in this study. The study sought to solve the problem by providing holistic approach that potentially minimizes the gap between short-term evidence and actual practice.

1.7. Problem Statement

Despite several mHealth initiatives most of which are being tried in Africa and South Asia, access to healthcare remains a big challenge in developing countries. Though some of the interventions provide short-term evidence on cost-effectiveness and health outcome, haphazard deployment approaches have failed to address realistic challenges in low-resource settings. A global observatory survey on mHealth conducted by World Health Organization (WHO) back in 2009 showed that over two-third of mHealth initiatives were pilot projects (WHO 2011). This slow uptake was also evident in another survey conducted jointly by WHO and ITU in 2013 (WHO & ITU 2014). The survey findings revealed that only 9-16% of developing countries have continued implementing and funding eHealth initiatives for a period exceeding three years. Furthermore, an investigation conducted by UN's independent Expert Review Group (iERG) confirmed that most eHealth initiatives are weak information system platforms that require a holistic perspective (WHO & ITU 2014).

Beale and Heard (2007) notes that system and design models that do not consider the real world in which they operate fails to meet user needs hence high probability of failure. We argue that the low uptake of mHealth interventions is due to disconnect between design and reality in the intended context of use. This is because most mHealth initiatives are weak, short-term donor-driven trial products that are *pushed* to people who are least involved in designing a solution to the “perceived” problem. To narrow the gap between evidence and actual practice, there is need to evaluate suitability of mHealth design concepts in order to predict acceptance and use. This requires a holistic approach in order to determine key factors that influence acceptance and utilization of mHealth artefacts.

1.8. Aim of the Study

The aim of this study was to provide a model for design and deployment of suitable mHealth solutions suitable for low-resource settings. The model is based on predictive modelling to determine factors that strongly influence utilization prior to design and deployment of mHealth artefacts.

1.9. Research Objectives

The objectives of this study were to:

1. Identify key factors that influence deployment and effective utilization of mHealth interventions in low-resource settings
2. Based on existing models and the key factors, derive a model that serves as a blueprint for design and deployment of mHealth solutions suitable for low-resource settings
3. Develop a prototype to validate the proposed model using a practical scenario in maternal and childcare services

1.10. Research Questions

To achieve the stated objectives, this study sought to answer the following questions:

1. Which factors influence deployment and utilization of mHealth interventions in low resource settings?
2. How can a predictive model be used to bridge the gap between design and reality in order to scale-up utilization of mHealth in low-resource settings?
3. How can such model be validated in terms of practical utility in a maternal care scenario?

1.11. Research Hypothesis

To draw inference on cause and effect of experimental treatment, we sought to test the following null hypothesis against the alternative hypothesis:

H₀: Fit of mHealth artefact has no significant effect on utilization in low resource settings

H₁: Fit of mHealth artefact has significant effect on utilization in low resource settings

1.12. Study Justification and Setting

Though mHealth is not a replacement of caregiver practices, it has the potential to provide patient-centred and cost-effective access to healthcare services and information. However, to integrate mHealth into healthcare system, there is need to align the artefacts into stakeholders' needs and healthcare processes in low-resource settings (Beale & Heard 2007, Breen & Matusitz 2010). This will contribute to healthcare transformation agenda of universal access to healthcare services and information at reduced cost and travel. To investigate how use of mobile devices and low-cost clinical devices can enhance access to maternal care, we choose Mwea, a rice growing region, for a reason:

Mwea: Case of Maternal Care in Kenya

Mwea district is located in Kirinyaga County, about 115 km from the capital city, Nairobi. The region was rehabilitated from dry plains and named Mwea-Tebere Irrigation Scheme for commercial rice, tobacco and cotton growing. Rice growing in Mwea was started around 1952 by the then British colony. During the colonial period, landless people considered as criminals by the British colony (Mau Mau rebels) were moved from other parts of central Kenya and settled in poor villages within rice and tobacco plantations to provide cheap labour. The farmers were not supposed to stay with their children once they attained the age of 18 years. This means that young men had to look for alternative places to live while girls had to seek for early marriage by whatever means since they could not be considered in food and basic necessities allocation policy.



Mwea-Kirinyaga: study setting (photo by principal researcher)

After independence, the National Irrigation Board (NIB) responsible for managing rice farming was taken over by Kenyans but never improved the farming processes or living conditions of the poor villagers. In fact, they worsened the situation such that harvesting was guarded by NIB staff so that each family received rice quantities just enough for food. The rest was taken by the board at a price that basically paid for the farm inputs such as seedlings and fertilizers. For this reason, few families in Mwea-Tebere irrigation schemes could afford to take their children to good school or even pay for basic necessities. However, this changed around 1998/1999 after a revolt against NIB led by the then member of parliament, Mr. Alfred Nderitu. The management of rice farming and marketing was taken over by Mwea Rice Farmer's Cooperative Society.

Due to sudden change in management, the problem worsened because farmers could no longer afford to maintain their rice fields due to lack of skilled manpower, finances, quality seeds, water supply and other farm inputs. The government intervened in 2003 by restructuring NIB to provide professional services and water management.

Today, Mwea is the fastest growing region in Kirinyaga County and regarded as the main source of rice in Kenya, particularly the aromatic Basmati rice. However, the historical trends like early marriages and poor education are still noticeable even in the current generation. In this study, we considered Mwea as one of the low-resource settings in Kenya due to the large number of unemployed youths, poor infrastructure (healthcare facilities, transport networks, power supply), illiteracy, and poor living standards.

1.13. Scope of the Study

In Kenya, maternal care services are provided free of charge in public hospitals to serve a large number of patients who could hardly afford to deliver in hospitals. Therefore, mHealth has the potential to transform healthcare delivery in underserved. However, due to financial and time constraints, we only implemented maternal care prototype named mamacare in rural hospital known as Kimbimbi County Hospital.

1.14. Summary of Thesis Report

The main body of this thesis report is organized into the following chapters:

Chapter 1: This chapter starts with background of the study that provides an insight and motivation to the research problem. This is followed by statement of the research problem, purpose, research objectives, research questions, hypothesis and justification of the study. The chapter concludes by delimiting the scope of the study.

Chapter 2: This chapter starts by review of important concepts in public health and clinical health domains. We then reviewed technology innovations in healthcare with emphasis on mHealth. Later, the chapter delves into design science and theoretical models relevant to this study. The chapter concludes by unveiling a predictive model that drives the rest of the study.

Chapter 3: Presents the research methodology that was employed in this study. These include design of experiment, sampling criteria, ethical considerations and data collection. The chapter also highlights on data analysis and development of mHealth prototype used for evaluating the model.

Chapter 4: This study is anchored on theory and practice. Therefore chapter 4 demonstrates how to implement the proposed model. First the model was operationalized into measurable concepts, dimensions and indicators for use in prototype design. The chapter concludes by providing a matrix that maps the model constructs onto mHealth design process.

Chapter 5: This chapter focuses on methodology used in conceptualization, design, implementation and deployment of a maternal care prototype. The prototype called mamacare is a light-weight mobile web prototype used as experimental treatment. Mamacare system can be accessed via: <http://mamacare.uonbi.ac.ke>.

Chapter 6: This chapter presents the results of three months repeated measure experiment. The chapter contains report on pretest before intervention and post-tests taken after exposure to experimental treatment. The chapter finally discusses triangulation approach used to draw inference on the null hypothesis.

Chapter 7: This is a conclusion and recommendation chapter that contains overall review of the study in terms of achievement of objectives, implication of the study to practice, contribution to knowledge, conclusion and recommendation for future research.

References and Appendixes: The remaining part of the document contains references and appendixes. The appendixes section contains definition of model concepts, sample data collection tools, approvals from Ministry of Health and KNH/UoN-ERC, mamacare UI screenshots, and sample code listings.

CHAPTER 2

Literature Review

2.1 Introduction

Telecommunications industry provides infrastructure through which we can interconnect computing and communication devices to access and share information. In this study, we are concerned on how we can take advantage of dynamic growth of information and communication technologies to deploy interventions that improves access to healthcare at reduced cost and travel. We start off by looking at fundamentals of health, and then socio-economic settings need to be considered in deployment of mHealth solutions. Later in the chapter, we describe some of the mHealth initiatives and challenges of porting telemedicine applications to low-end mobile devices. Finally, we unveil a conceptual model named TIPFit model that drives the rest of the study.

2.2 Fundamentals of Health

Nutbeam (1998) defines health as “a state of complete physical, social and mental wellbeing and not merely the absence of disease or infirmity”. Health is a resource for everyday life which can be expressed in functional terms as a resource which permits people to lead an individually, socially and economically productive life. In keeping with the concept of health as a fundamental human right, the Ottawa Charter (WHO 2014) emphasizes certain pre-requisites for health that include peace, adequate economic resources, food, shelter, stable ecosystem and use of sustainable resources. A comprehensive understanding of health implies that all systems and structures which govern socio-economic conditions and the physical environment should take into account implications of their activities in relation to impact on individual and collective wellbeing. Health promotion and interventions should embrace actions directed at strengthening the skills and capabilities of individuals. This is with aim of changing social, environmental and economic conditions that have negative impact on individual and public health. The Ottawa Charter outlines three basic strategies for health promotion:

- Advocacy for health to create the essential conditions for health;
- Enabling all people to achieve their full health potential;
- Mediating between the different interests in society in pursuit of health.

These strategies are supported by five priority action areas as outlined in the Ottawa Charter for health promotion. These are: building healthy public policy, creating supportive

environments for health, strengthening community action for health, developing personal skills and re-orientation of public and clinical health services.

2.2.1 Public Health

Public health refers to the science and art of promoting health, preventing diseases, and prolonging life through organized efforts of a society (Nutbeam 1998). Public health aims at improving health, prolonging life and enhancing quality of life in the society. This can be achieved through health promotions, disease prevention and other forms of health interventions. In every society, provision of primary healthcare is essential. It should be made accessible at a cost the community or an individual can afford using methods that are practical, scientifically sound and socially acceptable. As a set of activities, public health should include health awareness for the whole community, disease prevention and control, nutrition, basic sanitation, and appropriate treatment of common diseases and injuries. Public health should also contribute to global transformation agenda on women and children health through promotions focussing on family planning, immunization and health education.

A common term used in public health is epidemiology. Epidemiology is the study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to the control of health problems. This is why epidemiological studies relating to population and environmental risks are instrumental in public health to provide strategies on disease prevention in the community. In public health, epidemiologists use qualitative and quantitative techniques to investigate cause and effects of diseases in the community. In most cases, epidemiologists make use of the power of biostatistics to test hypotheses grounded on scientific fields to explain health-related behaviour, states and events. This helps a country, health institutions and practitioners identify sources that caused an illness; number of persons who may be infected; potential for further spread and interventions to prevent additional cases or recurrences in the future.

2.2.2 Clinical Health

In Healthcare domain, clinical health refers to a form of healthcare that deals with diagnosis, treatment and prevention of a disease, illness, injury and other impairments of an individual. Unlike in public health whereby practitioners are concerned with collective community well-being, clinicians are primarily concerned with a particular patient's disease, symptoms, medication, clinical tests and reports on how to treat the patient. Figure

2.1 below illustrates some of the typical processes and procedures administered on a patient in clinical health (Mahmood et al. 2012).

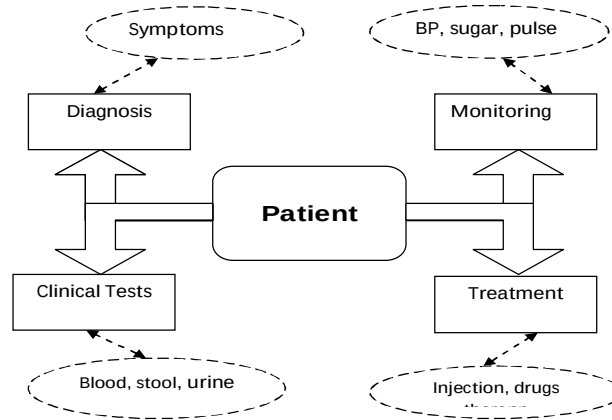


Figure 2.1: Clinical Health Processes

2.2.3 Ontology of Clinical Health Records

To record clinical and administrative information, Beale and Heard (2007) proposed an ontology which they refer to as Clinical Investigator Record (CIR) ontology shown in Figure 2.2. The top-level nodes shows the two categories of information required when dealing with a patient namely *CareInfo* and *AdminInfo*. However, because the focus of this study was on care information, we provide no further discussion on *AdminInfo* sub-tree on the right. The following are five categories of clinical information emphasized by the ontology:

- **Observation:** Information captured by a clinician used to characterise a patient. This information may be captured through observations, measurement, questioning or testing of the patient or related substance (tissue, urine, blood glucose etc.).
- **Opinion:** The clinician infers personal and published knowledge to deduce what the observations mean, and what to do about the findings. Without sound knowledge in health sciences, it is difficult to carryout proper diagnoses, assessments and plan of action to solve a clinical problem.
- **Instruction:** The clinician gives sufficient instructions for procedures and tasks to be executed by agents of care i.e. people or machines to execute required interventions.
- **Action:** This is a record of treatment or interventions that have occurred due to instructions given by a clinician.
- **Administrative event:** This is information relating to business events occurring within a healthcare institution such as admission, booking, referral and discharge.

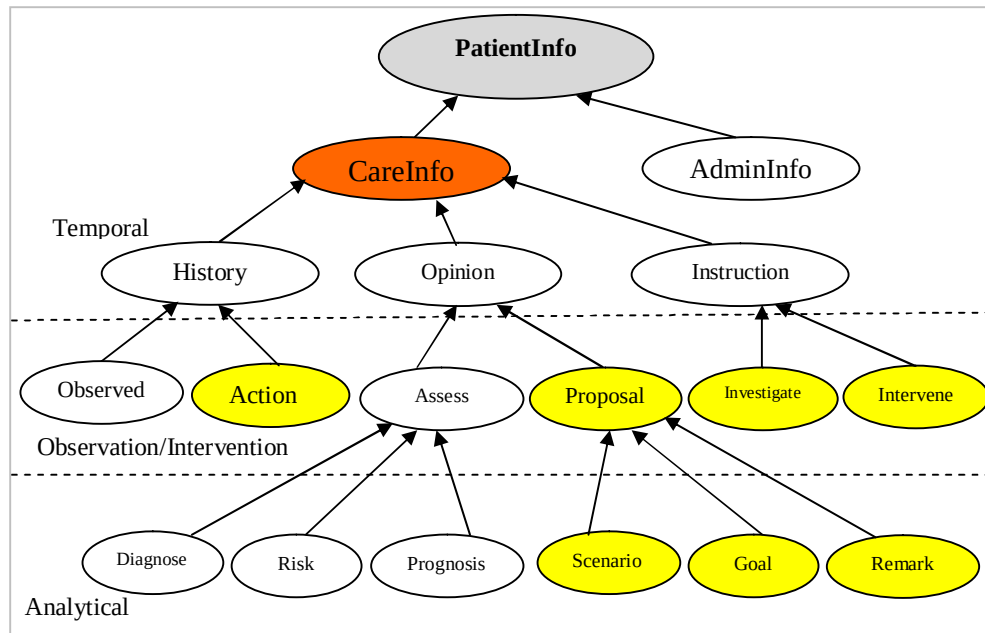


Figure 2.2: Clinical Investigator Record ontology (Beal & Heard 2007)

Top-level Root Node

The root node i.e. *PatientInfo* refers to patient record that contains both administrative and clinical information required in a healthcare process. In the immediate lower level, administrative information (*AdminInfo*) refers to records of patient's admission, booking, referral and discharge details while Care Information (*CareInfo*) contains clinical details such as observations, diagnosis, prognosis and interventions.

Temporal Information Nodes

Temporal information contains clinical information such as patient medical history, opinion of a caregiver on how to solve a clinical problem and instructions to other agents of care on appropriate interventions.

Observation/Intervention Nodes

The observation level nodes contain detailed information on each category of temporal node. History contains recorded observation and actions taken; opinion contains current assessment and clinician's proposal to dealing with health problems. Depending on difficulty of a clinical case, a clinician may provide instructions on need for further investigation or other possible interventions likely to resolve the problem.

Analytical Information Nodes

In CIR ontology, diagnosis, risks and prognosis falls under assessment node. They are used for management of information relating to patient diagnosis, health risks and prognosis.

Scenario, goal and recommendation nodes relates to clinician's ability to deal with challenging clinical cases by formulating scenarios, goals and recommendations to deal with a clinical problem.

2.3 Socioeconomic Settings

Though there is no standard definition for the term socioeconomic settings, it is mostly used in economics to refer to a combination of social and economic factors relating to people in a country or region. Some factors used to measure the socioeconomic status include but not limited to occupation, education, income, wealth, and place of residence (Cattani 2007). In social and behavioural sciences, similar term i.e. socioeconomic status is used in studies designed to predict behaviour. Generally, socioeconomic status can be viewed in terms of economic power and available resources to the society.

2.3.1 Level of Economic Development

In this study context, level of economic development refers to a country's financial ability to develop and nurture human capital. Some of the indicators used to measure economic ability include per capita income, education, health and wellness, workforce, employment and business environment (OECD 2011). Based on economic power, the world has been divided into two types of countries namely developed and developing countries (OECD 2011). Developed countries are more industrialized countries characterized by advanced technologies, good infrastructure, high per capita income, and post-industrialization knowledge economy. The criteria for evaluating the degree of economic development to qualify as developed or developing are gross domestic product (GDP), per capita income, level of industrialization, infrastructure and general standard of living (Aggarwal et al. 2005; OECD 2011). In terms of resources, people in developed countries consume large amounts of natural resources per person compared to those in developing and emerging economies.

Developing countries is a broad term that refers to countries that are less industrialized or undergoing industrialization. Developing countries are also classified as middle-income or low-income countries. Countries like Mexico, China, Indonesia, Jordan, Thailand, Fiji, Brazil and Ecuador are on the higher bracket, while countries in Sub-Sahara Africa, India, and countries in South Asia are low-income. In this study, the focus is on low-income, developing countries that are characterized by low per capita income, poor infrastructure, unemployment, and poor living standards.

2.3.2 Available Resources

A search for a concrete definition of the term did not return a concrete definition. However, in our understanding, the term resource setting is used to classify regions whether in the developing or developed categories. OECD (2011) classified rich and emerging economies as those countries characterized by good infrastructure, education, GDP, per capita income and education. On the other hand, low resource settings are characterized by poor infrastructure, inferior technologies, and poor living standard due to limited access to basic needs. Despite these challenges, there are successful interventions such as enhanced access to banking services. There is no doubt that replicating such success in healthcare will transform the current mHealth initiatives from pilotosis pervasive use. In this context, pilotosis refers to failure at the pilot stage for a product to transit from pilot to practice. In this study, we focused on how available clinical devices and low-end mobile phones can be used to improve quality of life in low-resource settings.

2.4 Challenges in Deploying mHealth

Difficulties in deploying mHealth in low-resource settings points to key factors and challenges that ought to be considered prior to design and deployment of mHealth interventions. These factors greatly influence post-deployment success of mHealth artefacts as Grameen Foundation (2011) discovered in their process of deploying *Mobile Midwife* in Ghana. World Health Organization (2011) observatory survey on mHealth, and a similar study conducted jointly by WHO and ITU (2014) points to the need for a holistic approach in identifying factors that are critical to success of eHealth and mHealth initiatives in developing countries. Furthermore, Yu et al. (2006), Mechael (2010) and ITU (2010) recommend deployment approaches that utilize available resources to deploy mHealth solutions that are cost-effective and suitable to stakeholders' needs. In this section, we highlight some of the factors to be considered prior to design and deployment of mHealth artefacts in low resource settings.

2.4.1 Infrastructure and Resources

In developing countries, infrastructure and healthcare resources are key factors that determine deployment of mHealth artefacts (Yu et al. 2006; WHO & ITU 2014). Infrastructure refers to physical and organizational structures e.g. communication network, buildings, roads, and power supplies needed for operations in a society or enterprise. On the other hand, resources refer to medical equipment, expendables and personnel required for operations in a healthcare system. Infrastructure challenges such as unreliable power supply

and inadequate personnel make it difficult to deploy telemedicine in low-recourse settings, hence the option of trying mHealth artefacts.

Nevertheless, the success of mHealth interventions in low-resource settings is dependent on reliability of wireless networks and cost-effective use of mobile and point-of-care devices. Though developing countries have limited infrastructure, they are currently leading in broadband penetration and mobile-based innovations (ITU 2014). This is evident from numerous mobile-based projects relating to health, banking, agriculture, education and geo-tagging. Currently, there is sufficient evidence in the banking industry that use of mobile innovations can transform the way we conduct business but this is yet to be realized in the healthcare sector. Other infrastructure related limitations to success of mHealth are attributed to inadequate medical facilities and lack of the clinical equipment needed to efficiently serve patients. This has made it difficult to deploy mHealth applications because priority is on improving transport networks, power supply and equipping health institutions with medical facilities (ITU 2010; Mechael et al. 2010).

2.4.2 Technical Expertise

Given that mHealth is a relatively new form of eHealth innovation, there is shortage of technical experts capable of designing and developing mobile applications of good quality in the local market (Yu et al. 2006; InfoDev 2006, WHO & ITU 2014). This explains why there are very few mHealth solutions and those that are available fail to satisfy patients and caregivers needs. Furthermore, most mHealth interventions are short-term donor driven projects that are developed outside Kenya and ‘pushed’ for local adoption. Experience from current mHealth initiatives is clear proof that even though quality of an mHealth artefact may be good, efforts to motivate its acceptance and use may be counterproductive if the stakeholders are not involved in its development.

2.4.3 Standards and Policy Guidelines

To seamlessly integrate eHealth and mHealth into healthcare systems surveillance, there is need to establish universal standards, strategies and policy guidelines that address requirements necessary for enforcing security, privacy, interoperability, mobility and reliability. This is because, in most reviewed case studies and related work, lack of standards and policy guidelines are barriers to upscaling eHealth and mHealth in developing countries (Yu et al. 2006; Mechael et al. 2010; WHO & ITU 2014).

There are challenges in developing universal standards due to lack of health informatics experts, competing interests and insufficient investment into activities that would provide productive engagement with standards development institutions. Despite these limitations, existing standards and guidelines such as Health level 7 (HL7 Security Work Group 2010) and popular country specific standards such as the HIPAA (OCR 2005; Cronin 2011) may be used. However, standard guidelines specific to use of mobile devices and wireless sensors in healthcare should be developed to enforce security, privacy, mobility and interoperability (ITU 2012).

2.4.4 Financial Constraints

A survey conducted by WHO (2011) indicates that, high operational costs incurred in deploying and running mHealth projects is one of the barriers to success of mHealth initiatives (Grameen Foundation 2011; World Bank-ICT Sector 2011). For example, in the case of Safaricom's *Daktari1525*, initial cost of KES 20.00 (US\$ 0.22) per minute was very expensive to most Kenyans to access a doctor compared to prevailing calling rates of about KES 3.00. This forced the company to lower the cost by half to \$0.11 (CIO-East Africa 2012; Breen, Wan & Ortiz 2010)

A global survey conducted by WHO and ITU (2014) indicates that due to poor economic ability of most CoIA, only 9-16% of countries have been able to continue funding eHealth initiatives in a period of three years. Furthermore, most of these initiatives are weak donor-driven projects that hardly go beyond pilot. Therefore, due to economic constraints of low-income countries, mHealth innovators should factor into their designs economic ability of intended consumers to provide cost-effectiveness solutions.

2.4.5 Needs and Priorities

Deployment of mHealth interventions intended to transform current centralized care practices into patient-centred care should consider needs and priorities of the stakeholders (Vital Wave Consulting 2011; Omary et al. 2010). As Bill Gates, the founder of Microsoft noted, it is important to consider basic needs such as food and shelter instead of equipping hospitals and patients with smart technologies that do not reflect the reality on the ground. Though there may be short-term evidence from most mHealth initiatives, they fail to mature beyond the pilot stages due to lack of concrete benefits that justify continued implementation and use (WHO/ITU 2014).

2.4.6 Health Education and Awareness

In most developing countries, lack of education and awareness on benefits of mHealth make it difficult to deploy most interventions (Mechael et al. 2010; ITU 2010; WHO 2011). This is because most of these people have technophobia or do not trust the use of mobile phones to communicate sensitive information. In some countries, though there are several mHealth initiatives, there has been little effort in championing and promoting these projects into use by the wider society. Therefore, designers of mHealth solutions intended for low-resources settings should investigate literacy levels of majority of the target users.

To translate eHealth pilots to actual practice, effective mechanisms to popularize mHealth solutions should be put in place (Idowu, Cornford & Bastin 2008). For example, in Kenya, success of SMS-based mobile payment systems is as a result of aggressive marketing and wide distribution of payment agents. As a result, this approach has been replicated in the banking sector. We argue that, if a similar approach is used to deploy mHealth interventions, it would unlock other potentials that ride on its success. However, unlike in mobile payment where a client gets cash from an agent, mHealth promotion lacks support due to insufficient evidence of its benefits.

2.4.7 Ethics and Legal Framework

Confidentiality is one of the fundamental medical ethics requirements that influence utilization of mHealth innovations. Most countries lack legal guidelines on deployments and use of mobile technologies in healthcare (Mechael 2007; ITU 2010). This exposes innocent citizens to local and foreign organizations whose interest is not to assist but mine data for their own interest. For example, some individuals and non-governmental organizations (NGOs) deploy mHealth projects in slums and rural areas without ethics approval. Let's consider a case where a researcher conducts a survey in a rural hospital to investigate how mHealth can be used to enhance maternal care. Assuming the researcher got access to patients test results for HIV and found that in a particular visit "7 out of 10" tested positive! Because the researcher never cared to go through ethics approval, he/she may report that in country/district xyz, HIV prevalence rate is 70%. The question is; *are there legal provisions that can hold this researcher accountable?* To deal with such ethical issues, governments should put in place legal guidelines that regulate use of information technologies in healthcare to safeguard integrity of patients' privacy.

There is no doubt that success of mHealth interventions depend on how value is driven by adopting a holistic approach to identified challenges. However, technological interventions

that seek to address healthcare transformation agenda should effectively align people, process and technology. Therefore, the factors discussed above points to the need to align *people, processes* and *technology*; a combination referred to as the triangle of information system success. The following is a brief overview of the three factors:

- *People*: Understand the people, their culture, work ethics, living standard and education background to meet their needs.
- *Process*: Understand the problem domain, workflow and procedures on how tasks are accomplished manually or electronically. This is the most misaligned element due to complexity of medical processes.
- *Technology*: Technical deployments are critical to success if aligned to people and processes. Current technical deployments in healthcare are haphazard – some do not rely on methodology, framework or evidence-based standards.

2.5 Healthcare ICT Innovations

Health informatics is concerned with use of information and communication technologies to enhance processing and dissemination of healthcare information. According to Omachonu and Einspruch (2010), information and communication technologies (ICTs) is a key driver to innovations in healthcare. This has resulted to growing interest in use of information systems in the healthcare sector to support decision making, communication and other aspects of care. Current rapid penetration of mobile connectivity has motivated development of eHealth solutions that provide remote access to healthcare services and information. However, implementing cost effective solutions that addresses patient's needs is a challenge. Omachonu and Einspruch suggests that attempts to provide ICT innovations in healthcare must take into account stakeholders' needs and expectations as summarized in Table 2.1.

Table 2.1: Healthcare stakeholders and their expectations

Stakeholder	Needs and expectations
Caregivers	Improved clinical outcomes, diagnosis and treatment
Patients	Improved patients' experience, wellbeing, access to health services at reduced cost and time
Healthcare organizations	Enhanced efficiency of internal operations, reduced operational cost, increased productivity, improved health quality and outcomes
Government Agencies	Improved social wellbeing, reduced risks, improved patient safety and overall productivity
Software providers	Profitability, improved health outcomes

Source: Omachonu and Einspruch 2010

Omachonu and Einspruch proposed a framework shown in Figure 2.3 that classifies healthcare services to be considered when deploying ICT innovations in healthcare. The framework consists of six categories of healthcare services namely treatment, diagnosis, prevention, education, research and outreach. Deployment of ICT solutions for these domains of care should focus on how a patient is seen, heard and needs met efficiently and cost-effectively.

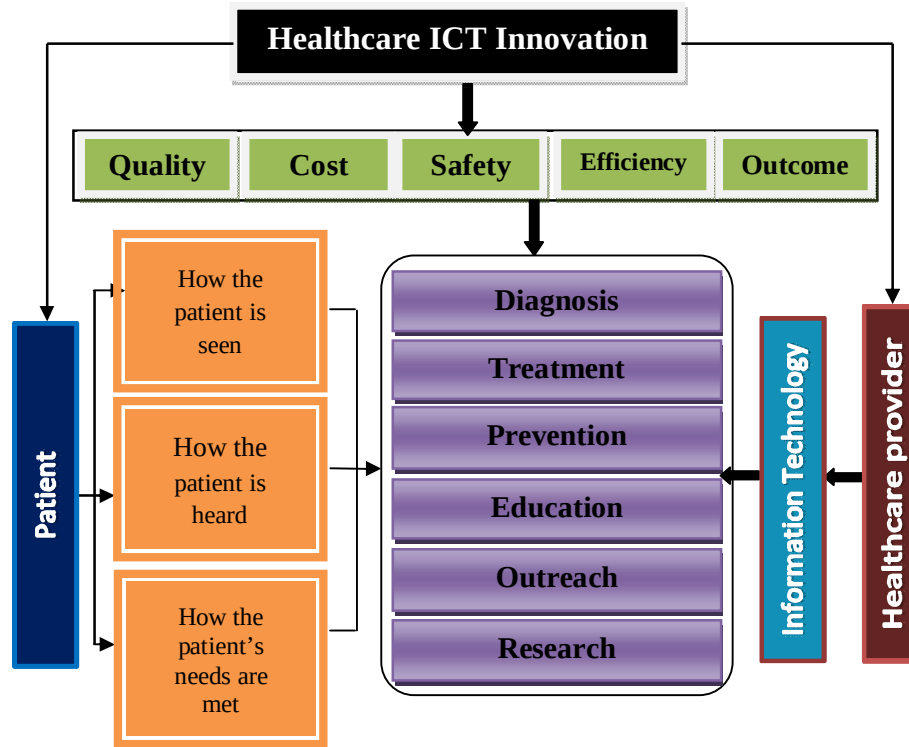


Figure 2.3: ICT innovations in healthcare (Omachonu & Einspruch 2010)

2.5.1 Mobile Technologies in Healthcare

Given that mHealth is deployed over mobile telecommunication and wireless networks, we briefly review mobile technologies necessary for deployment of mHealth. In this context, mobile technologies refer to wireless communication networks, mobile devices and applications that provides interaction between two remote participants. Currently the two main types of mobile communication networks are the Global System for Mobile communications (GSM) and Code Division Multiple Access (CDMA). However, a common method of classifying mobile networks is by evolution into generations namely; first, second, third and fourth generations.

First Generation

The first generation (1G) cellular networks were only used for voice communication using analog signal (Forouzan 2004). The most prominent 1G network was Advanced Mobile Phone System (AMPS) used in North America. Others were Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS).

Second Generation

To provide higher-quality voice, the second generation (2G) of cellular networks were mainly designed for digitized voice and supplementary data services such as short messaging service (SMS) and limited internet access (Forouzan 2004). Second generation cellular networks include Global System for Mobile communications (GSM), Digital AMPS (D-AMPS), Code Division Multiple Access (CDMA), and Personal Digital Communication (PDC). Due to continued demand for better data services, the General Radio Packet Service (GPRS) offered through 2G was upgraded to 2.5G service referred to as EDGE (Enhanced Data rates for GSM Evolution). Currently, EDGE provides higher data rates in places where 3G services are not available due to poor connectivity.

Third Generation

In 1999, the International Telecommunication Union (ITU) came up with a project that was meant to bring mobile technologies together for the purpose of standardization. The standard came to be known as International Mobile Telecommunications-2000 (IMT-2000) simply referred to as Third Generation (3G). ITU defined the following set of requirements for a mobile telecommunication to qualify as a 3G system:

- Allow roaming. Roaming is the ability to use a mobile phone on different networks other than the one the user is subscribed to.
- Allow use of all mobile applications and equipment.
- Support both packet-switched (PS) and circuit-switched (CS) data transmission.
- Offer high data rates of up to 2 Mbps depending on mobility or velocity. ITU set a threshold of 144 kbps data rate available to users in high-speed vehicles over large areas, 384 kbps available to pedestrians standing or moving slowly over small areas and 2.048 Mbps for office use.
- Use adaptive interface to internet to reflect efficiently the common asymmetry between inbound and outbound traffic and should make more efficient use of the available spectrum.

Fourth Generation

Current trends in mobile communications is the emerging 4G technologies, also known as Long Term Evolution (LTE) that provides broadband internet access, advanced mobile applications and services that match those of a typical desktop computer. The 4G architecture is designed to allow seamless integration and communication between heterogeneous mobile devices across diverse wireless standards and broadband networks. Access to different radio technologies is facilitated by use of Internet Protocol in 4G mobile communication systems. Because of this dynamic growth, mobile phones have evolved from limited voice and SMS services to handheld computers with rich hardware and software configurations that match those of a laptop. This has made mobile phones become increasingly capable of handling telemedicine, mobile banking, and videoconferencing applications. These emerging technologies present developers of mHealth solutions with opportunity to design and implement innovative solutions that connect people to healthcare services at their convenience.

2.5.2 Global mHealth Initiatives

Mobile and internet connectivity presents an opportunity to remotely connect patients and caregivers to improve quality of healthcare outcome. In particular, mHealth initiatives are aimed at taking advantage of high mobile penetration to improve access and delivery of healthcare in remote and underserved areas. Some of the benefits of using mHealth include:

- Increased access to healthcare and information particularly in underserved areas
- Increased efficiency and lower cost of healthcare service delivery
- Improved ability to accurately diagnose, treat and track diseases
- Timely and reliable public health information and awareness
- Expanded access to health education and training for health workers

Currently, there are several mHealth case studies and pilot projects focusing on developing countries particularly in African and South Asia (Vital Wave Consulting 2009; ITU 2010; WHO 2011). The following are categorized examples of mHealth initiatives majority of which are donor-driven projects that closed after pilot:

Health education and awareness

Most Health education and awareness applications are SMS-based and are used to provide healthcare providers and patients with vital information (Vital Wave Consulting 2009; WHO 2011). Examples include Freedom HIV/AIDS Project (India), Learning about Living

(Nigeria), Project Masiluleke (South Africa), Text to Change (TTC) and HIV Prevention through SMS Quiz (Uganda).

Data Collection and management

Data Collection and management applications assist health workers in the field to collect and transmit data via mobile phones (Vital Wave Consulting 2009; ITU 2010; WHO 2011; WHO & ITU 2014). Data is collated, analyzed and stored in a centralized database from which information is made available to medical professionals. Some examples include Nokia Data Gathering (Brazil), Community Health Information Tracking System (Philippines), Dokoza System (South Africa), EpiHandy (Uganda, Zambia, and Burkina Faso), EpiSurveyor (Kenya, Uganda, Zambia and 20 other countries), and District Health Information System 2 (DHIS 2).

Remote patient monitoring

Patient monitoring mobile applications are used to monitor health condition of a patient (Vital Wave Consulting 2009). Examples include Chinese Aged Diabetic Assistant (China), Mashavu-Networked Health Solutions for the Developing World (Tanzania), Mobile Phones for Health Monitoring (India) and SIMpill Solution for TB (South Africa). See Vital Wave Consulting (2009), ITU (2010), WHO (2011), and WHO & ITU (2014).

Research and Training

In order for health workers to provide effective patient care, access to timely information is essential, it is important to continually enhance their knowledge and skills. Some of these applications aimed at achieving this goal include Enhancing Nurses Access for Care Quality and Knowledge through Technology (Caribbean), Mobile HIV/AIDS Support (Uganda) and Primary Healthcare Nursing Promotion Program (Guatemala).

Epidemic Outbreak Tracking

When a disease outbreak occurs, timely dissemination of information is crucial. Alerts of disease outbreaks should be sent via multiple mechanisms such as text messages, voice mail and e-mail. More still, users should be able to transmit or access such information through multiple technologies, including mobile phones. Examples of outbreak tracking applications include: FrontlineSMS, GATHER-Uganda, Remote Interaction, Consultation and Epidemiology (Vietnam) and Tamil Nadu Health Watch (India).

Diagnosis and Treatment

Patients in low-resource settings lack sufficient access to specialized healthcare centres and point-of-care medical equipments. However, there are efforts to develop mHealth applications using available resources to aid caregivers in diagnosis and treatment. Some examples include Cell Phone Applications for Clinical Diagnostic Therapeutic and Public Health Use by Front Line Healthcare Workers (Mozambique), Digital Inclusion Kit in Health and Higher Education (Argentina), HIV Mobile Decision Support (South Africa), Mobile E-IMCI (Tanzania), Teledoc-Jiva Healthcare Project (India) and Daktari1525 (Kenya).

2.6 Socio-technical Approach to Design

Low uptake of mHealth interventions should inform on effective strategies to ensure early successes are replicated (Davis & Venkatesh 2004; WHO & ITU 2014). This requires a socio-technical approach in designing mHealth solutions that are grounded on technical and behavioural factors within which utility is intended. To apply socio-technical approach, Hevner et al. (2004) proposed a conceptual framework that integrates behavioural theories into design science. Behavioural theories seek to explain observable reality relating to behaviour while design science is concerned with utility of an artefact to fulfil identified needs (Hevner 2004; Brocke & Buddendick 2006). Therefore, socio-technical approach is a paradigm that holistically considers technical and behavioural factors that influence acceptance and use of technology (Davis 1989; Davis & Venkatesh 2004). In this section, we discussed design science and theoretical models that are fundamental to socio-technical approach to design and deployment of mHealth solutions.

2.7 Systems Development Paradigms

There are several approaches to systems or software development sometimes making it hard to choose the best. In this study we sought to demonstrate on how to use a holistic approach to develop a software product that fits into user's needs. To start with, we look at design science paradigm introduced by Buckminster Fuller (Ben-Eli 2007).

2.7.1 Design Science

Design Science introduced by Buckminster Fuller refers to application of principles of science to the conscious design of our total environment. Buckminster Fuller championed design science as an effective application of the principles of science to make the world's

finite resources meet the needs of all humanity without disrupting the ecological processes of the planet. His design science philosophy is driven by the following principles:

- *Emphasis on the need and possibility of applying a deliberate design approach, rather than relying solely on evolutionary haphazardness to human affairs.*
- Design Science as an “objective” applied discipline integrating architecture, industrial design, engineering and all other sciences.
- *Application of the highest potentials of science and appropriate technologies to the intentional advancement of wellbeing and standard of living for all.*
- Emphasis on deliberate deployment of generalized principles in organizing basic components of the physical world into consecutive waves of increasing advantage-yielding combinations.
- *Emphasis on demonstrating tangible results through the reduction of design concepts into actual practice.*
- A planetary perspective on an integrated, option-expanding, life support infrastructure coupled with an emphasis on individual initiative in enhancing its scope and potential.

The three emphasized principles are relevant in this study because we aimed at applying a socio-technical approach to design and implementation of mHealth artefacts (Hevner, et al 2004; Booch, et al 2007). Creating an artefact using design science approach consists of the following basic steps:

1. *Identify*: Identify requirements from the problem space to derive business needs.
2. *Build*: Based on the requirements, build an artefact that should deliver utility.
3. *Document*: The artefact and constraints should be represented and documented
4. *Evaluate*: In order to analyse utility of an artefact, subject it to an evaluation process.
5. *Communicate*: Provide vocabulary and symbols in which problems and solutions are defined and communicated.

Because system design is inherently an iterative and incremental process, utility and efficacy of an artefact must be rigorously demonstrated via well executed evaluation methods. Some of the metrics used to evaluate an information system artefact include functionality, completeness, consistency, accuracy, performance, reliability, usability, fit and additional metrics relevant to the context. These metrics may also be used to evaluate post-deployment utilization of an artefact to compare predictions with actual outcome.

2.7.2 System Development Methodologies

In software development, System Development Lifecycle (SDLC) has four fundamental phases i.e. planning, analysis, design and implementation (Dennis, Wixom & Tegarden 2005). To implement SDLC, there are several competing approaches referred to as system development methodologies or models. System development methodology refers to the framework used to structure, plan, and control the process of developing an information system (Bennett, McRobb & Farmer 2002). Several development methodologies have evolved over the years due to change in technologies, processes and people's behaviour that necessitate change in strategies to solve dynamically changing social problems. Common examples of system development methodologies include Waterfall (traditional) model, Prototyping, Spiral model, Agile Development, Rapid Application Development (RAD), Extreme Programming (XP), and Rational Unified Process (RUP). The choice of the methodology to employ depends on the nature of the problem, schedule visibility, budget, familiarity with technology, and system complexity (Hull, Jackson & Dick 2005; Sommerville 2011). Due to changing needs and technologies, one system development methodology may not necessarily be suitable for use by all projects. This requires integrating available methodologies to best fit specific projects based on various technical, organizational, and stakeholders' considerations.

Current software development paradigm is a shift from Structured System Analysis Design Methodologies (SSADM) e.g. waterfall model to iterative, incremental, object oriented analysis and design methodologies such as Agile and Unified Process (Bennet, McRobb & Farmer 2002; Booch et al. 2007). This is because of inflexible nature of structured approaches that make it difficult to factor changes. *Most methodologies focus on User-Centred Design (UCD) that requires stakeholder's involvement throughout the development process because they may not be able to clearly define what they need in the early stages of the project.*

Therefore, to address challenges experienced in deploying mHealth artefacts in low-resource settings, there is need for a holistic approach that consolidates best practices from design science, system development methodologies and behavioural models to ensure that user requirements are completely met. This study sought to provide socio-technical approach to design and deployment of mHealth artefacts fit for deployment in low-resource settings. In the next section, we discuss relevant theoretical underpinnings that served as the backbone to this study.

2.8 Information System Models

To align mHealth design concepts to stakeholders' needs and healthcare processes, it is critical to review theoretical underpinnings relating to technology and human behaviour. The four models that were fundamental to this study are the Technology Acceptance Model (TAM), Information System Success (ISS), Process Virtualization Theory and Impact of IT (PVT) and the Task-Technology Fit (TTF).

2.8.1 Technology Acceptance Model

Technology Acceptance Model (TAM) shown in Figure 2.4 published by Davis (1989) is one of the most researched models in the field of information systems. This model has been widely used to evaluate individual's perception towards use of technology.

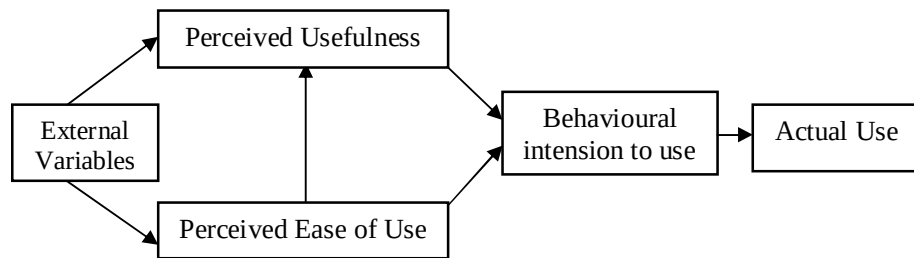


Figure 2.4: Technology Acceptance Model (Davis 1989)

Davis postulates that behavioural intention to use technology is influenced by perceived usefulness and ease of use. Subsequently, behavioural intention influences “actual use” of technology. The model also shows that Perceived Ease of Use influences Perceived Usefulness. In addition, TAM model has a generic “external variables” construct that is posited to influence Perceived Ease of Use and Perceived Usefulness. Therefore, it is the responsibility of a researcher to identify external variables specific to the intended context of technology use.

In a different approach to post-adoption evaluation of technology acceptance, Davis and Venkatesh (2004) used TAM in a predictive modelling approach they referred to as pre-prototyping perceived usefulness and ease of use. They argued that, pre-prototyping usefulness and ease of use could help predict acceptance and use in order to avoid costly post-implementation failure. To test their claim, Davis and Venkatesh employed longitudinal experiments from which they affirmed that predicting usefulness and ease of use can be used to predict post-implementation acceptance and use of a new information system.

Though TAM is a popular model, due to increased complexity and risks resulting from use of ICTs, we argue that intention to use or use of technology is not limited only to perceived usefulness and ease of use. There are other factors especially in healthcare that influence use of technology that may not necessarily be generalized to usefulness or ease of use. This is why for the last two decades TAM has been widely extended by including more constructs or integrating it with other models to give it more explanatory power. Two such models are the Extension of Technology Acceptance Model with Task-Technology Fit (TTF) model by Venkatesh and Davis (2000) and the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. (2003).

2.8.2 Information Systems Success

Evaluating success of an information system is critical to understanding the value and efficacy of information systems management and investments. This necessitated DeLone and McLean (2003) to update their Information Systems Success (ISS) model published in 1992. The model shown in Figure 2.5 is used to measure success of an information system based on three factors namely system quality, information quality and service quality.

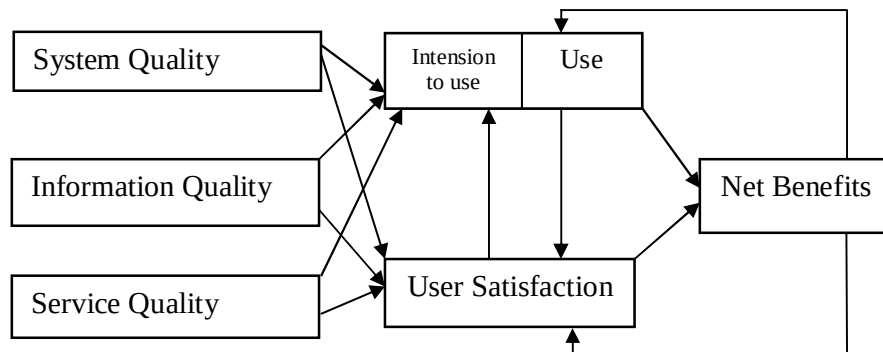


Figure 2.5: Information System Success (DeLone & McLean 2003)

The updated ISS model consists of six constructs namely system quality, information quality, service quality, user satisfaction, “intension to use” or “use”, and net benefits. The difference between “Intention to use” and “use” is that the former is an *attitude*, while the latter is *behaviour*. DeLone and McLean posit that the antecedents of “intention to use/use” and “user satisfaction” are influenced by systems quality, information quality, and service quality:

- *System quality*: used to evaluate technical success, measured in terms of ease-of-use, functionality, reliability, flexibility, data quality, portability, integration and importance.
- *Information quality*: used to evaluate the semantic success of a system in terms of accuracy, timeliness, completeness, relevance and consistency.

- *Service quality*: used to measure performance in terms of output, reliability, assurance and responsiveness.

For successful implementation of a system, it is assumed that attitude towards net benefits from user's perspective ought to be positive. These benefits continuously influence and reinforce subsequent use and user satisfaction. However, according to Davis and Venkatesh (2004), usefulness of a system that determines its success should be predicted prior to its implementation. Therefore, a good model that measures success of an information system should be founded on a predictive approach to identify factors that influences post-implementation success rather than quality of already built system. Furthermore, ISS model only attributes success of a system on quality yet there are quality systems that have failed acceptance in healthcare domain. Therefore, other than quality, there are other factors that make a system succeed in one context but fail in another (Ammenwerth, Iller & Mahler 2006).

2.8.3 Process Virtualization Theory and Impact of IT

Overby's (2008) Process Virtualization Theory and Impact of IT (PVT) model shown in Figure 2.6 is a relatively new theory in the field of Information systems. Overby defines the term process as a structured set of tasks to achieve specified outcome. Therefore, process virtualization refers to completing a process (set of tasks) in a virtual environment where physical interaction has been removed. It is important to note that the term virtualization may not necessarily imply complete automation. Overby notes that process virtualization should not be confused with process automation because virtual processes require active human intervention while an automated process need not. For example, in an online shopping, a user is often actively engaged in products selection to add to a shopping cart.

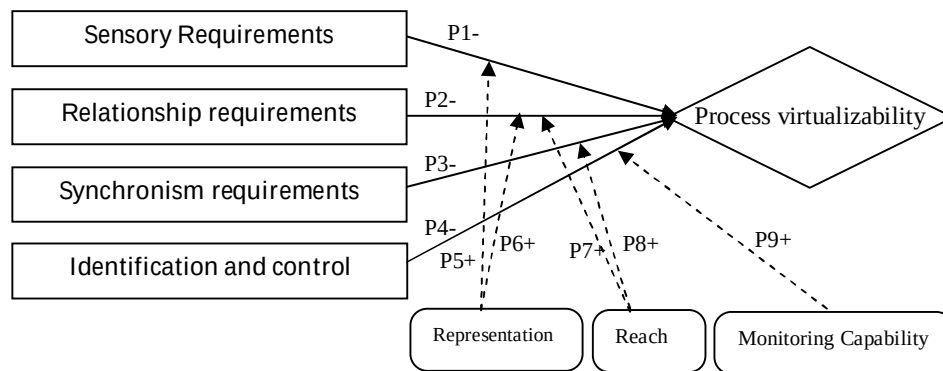


Figure 2.6: Process virtualization Theory (Overby 2008)

The model shows that the four factors posited by Overby to negatively influence virtualizability of a process are sensory requirements, relationship requirements, synchronism requirements, and identification and control requirements. For example, in diagnosis and treatment, sensory requirements of sight, audio, touch, smell and taste may be better fulfilled through physical encounter between a patient and a doctor. Therefore, an intervention that attempts to replicate sensory experience might raise ethical or suitability concerns. Nevertheless, with the current advancement in IT, more processes that have traditionally been conducted via physical mechanisms are being conducted remotely. The key premise to PVT is virtualizability of a process with or without IT. Overby gave an example of mail-order catalogue and e-commerce websites as virtualized processes in which mail-order is a non-IT virtualized process while e-commerce website is an IT-based virtual process.

Overby argues that though IT is not a necessity for process virtualization, it plays a central role in making some physical processes more amenable to virtualization. This explains why in this model he used IT capability of representation, reach and monitoring capacity as moderating variables. Overby points out that though representation, reach and monitoring capability can be fulfilled without need for IT, user-experience and outcome may be qualitatively and quantitatively different. Given that this theory is quite relevant to this study, we discuss the four process requirements and IT characteristics posited to influence virtualizability of physical processes.

Sensory Requirements

Overby (2008) defines sensory requirements as the need for process participants to be able to enjoy full sensory experience of a process. In human, sensory experience include tasting, seeing, hearing, smelling, and touch, as well as the overall sensation that participants feel when engaging in a physical process, e.g. excitement, emotion and love. In clinical processes such as diagnosis and treatment, it may be impractical to simulate sensory experience of touch smell and taste using visual, audio, haptic and olfactory interfaces. For example, if a task requires sensory experience of smell, taste or touch, trying to replicate these requirements in low-resource setting may not be feasible. Overby posits that, the greater the sensory requirement, the less a process is amenable to virtualization.

Relationship Requirements

Relationship requirement is the need for participants in a process to interact with one another in a social or professional context. Such interaction often leads to knowledge

acquisition, trust and friendship development. In a physical setup body gestures such as posture and inflection are part of communication. However, even though some degree of relationship may be achieved by use of multimedia technologies such as videoconferencing, it may not be cost-effective in low-resource settings. Therefore, Overby posits that, the greater the relationship requirements of a process, the less it is amenable to virtualization.

Synchronism Requirements

In this context, synchronism requirement is the degree to which the activities that make up a process need to occur immediately with minimal delay (Overby 2008). Overby argues that physical processes tend to be highly synchronous because participants can interact with each other with minimal or no delay. In contrast, virtual process participants are abstracted from one another and from process objects that can introduce delays in the process. This points to why Overby (2008) hypothesized that the greater the synchronism requirements, the less a process is amenable to virtualization.

Identification and Control Requirements

Identification and control requirement is defined as the degree to which a process requires unique identification of process participants and the ability to exert control over or influence their behaviour. In a physical process the participants involved can easily identify each other but in a virtual environment, it is difficult to certainly confirm the identity of a remote participant. For example, in an online diagnosis, it is difficult to ascertain the identity of a remote participant claiming to be a patient, or whether a patient is sharing confidential information with a real doctor. Both identification and control are important factors regarding trust in a remote process. Overby posits that, the greater the identification and control requirements the less a process is amenable to virtualization.

Representation

According to Overby, representation is a moderating variable referring to capability of information technology to present information relevant to a process including simulations of actors and objects within the physical world, their properties and characteristics. Technology may be used to replicate physical environment by use of wireless sensors and multimedia applications such as videoconferencing. Overby posits that;

- Representation capability provided by IT positively moderates the relation between sensory requirements and process virtualizability.

- Representation capability provided by IT positively moderates the relation between relationship requirements and process virtualizability.

Reach

Reach refers to the IT capability to allow participants in a process to access services and information irrespective of time and space. In regard to time, IT allows many processes to be conducted remotely any time of the day. For example, in mobile banking, cash transfer may be executed any time anywhere without need to physically visit the bank. Therefore, Overby postulates that;

- Reach capability provided by IT positively moderates the relation between relationship requirements and process virtualizability.
- Reach capability provided by IT positively moderates the relation between synchronism requirements and process virtualizability.

Monitoring Capability

In Process Virtualization Theory, monitoring capability refers to capability of IT to authenticate process participants and track their activities. According to Overby (2008), monitoring capability facilitates virtualization of processes that require authentication and privacy. However, in some cases, monitoring may be so strong that it may violate privacy rights such as anonymity. However we note that though Process Virtualization Theory is relatively new, it is potentially an important theory applicable in health informatics.

To evaluate practical utility of the model, it is important to operationalize it using a healthcare scenario to establish how process requirements influence virtualization of clinical processes. Overby acknowledges individual behaviour can also influence process virtualization. However, other than mentioning behaviour in discussions under “relationship requirements” and “control”, Overby does not explicitly provide operational construct for evaluating individual behaviour. Therefore, apart from process requirements, it is important to investigate how people’s behaviour influence virtualization of physical processes.

2.8.4 Task-Technology Fit

Goodhue and Thompson’s (1995) Task-technology Fit (TTF) is a widely researched model used to evaluate fit between task and technology in enhancing individual performance. Figure 2.7(a) shows that *Task-Technology Fit* construct is an intervening variable that influences actual use and performance depending on task requirements and tool

functionality. Task-technology Fit model uses fit as an alternative to Bailey and Pearson's (1983) measure of individual satisfaction on use of technology artefacts.

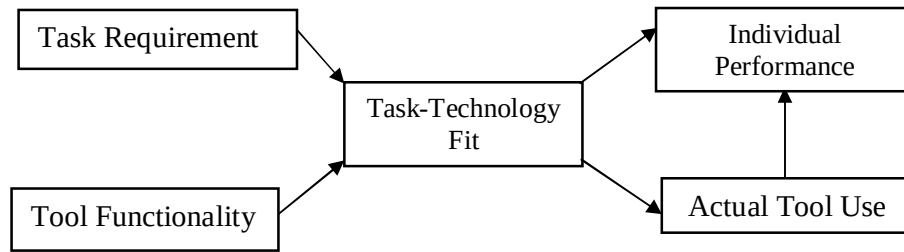


Figure 2.7(a): Task-Technology Fit (Goodhue & Thompson 1995)

According to Goodhue and Thompson, task requirements and tool functionality influences fit that determines actual use and performance. To evaluate fit, a user is the qualified judge on whether a tool has desirable characteristics needed to execute a task. This implies that users will be motivated to use technologies or tools that enable them to easily accomplish a task. However, this model does not provide theoretical underpinning on evaluating user's beliefs and needs. To address concerns raised about lack of construct on user evaluation, Goodhue (1998) adapted his earlier model to that illustrated in Figure 2.7(b) that has individual characteristics construct. In this model, Goodhue hypothesizes that task characteristics, and individual characteristics moderate the relationship between information systems and user's evaluation on task-technology fit. Based on this model, Goodhue operationalized the constructs to provide reliable measurement instruments.

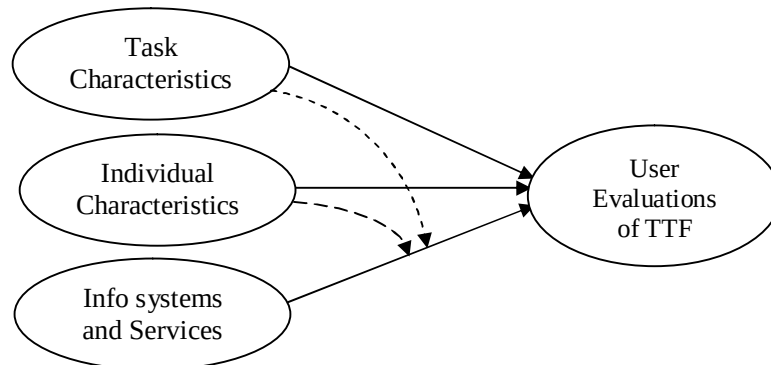


Figure 2.7 (b): Basic TTF model (Goodhue 1998)

The three concepts of TTF i.e. task, technology and fit have been adapted or extended in several information systems research models. One such extension is *Fit between Individual, Task and Technology* (FITT) by Ammenwerth et al. (2006) intended for use in a clinical environment. Another extension of TTF is by Overby and Konsynski (2010) by integrating it with Overby's PVT model.

To justify extension of TTF, most of the researchers cite weaknesses of Goodhue's model as fragmentation and lack of precise dimensions and indicators for measuring each construct. In fact, fragmentation of the model is evident from Goodhue himself because the model used in 1998 as the basic TTF model neither resembles that referenced in 1998 study nor that he published with Thompson (Goodhue 1988; Goodhue & Thompson 1995; Goodhue 1998). However, despite this weakness, TTF is a powerful model that can be extended to any domain and context (Strong, Dishaw & Bandy 2006; Overby and Konsynski 2010). In the following section, we discuss some of the derivatives of TTF model that were found relevant to this study.

2.8.5 Extended TTF Model

To test the efficacy of individual characteristics, Strong, Dishaw & Bandy (2006) extended the model published by Goodhue and Thompson (1995) by using Computer Self-Efficacy (CSE) to measure effect of individual characteristic on fit of technology utilization as shown in Figure 2.8 below.

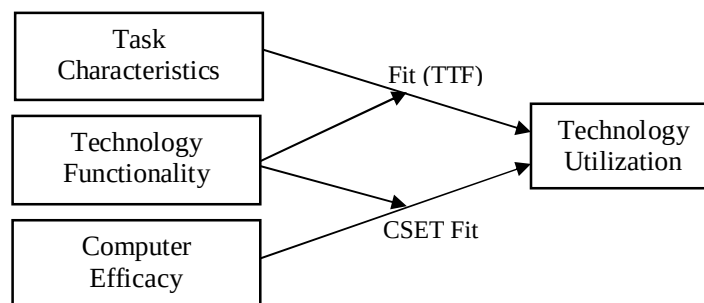


Figure 2.8: Extended TTF model (Strong, Dishaw & Bandy 2006)

Strong et al. argues that though Goodhue (1995) tested computer literacy as an attribute of individual characteristic, he failed to include the construct in his final model. This necessitated Strong, Dishaw and Bandy to extend the basic Task-Technology Fit (TTF) model by including CSE to evaluate significance of individual characteristics on fit. They posit that IT utilization is influenced by users' judgment on their ability to use information systems. That is, given the same task with the same technology choices, users may not have the same capability or ease of accomplishing the task. Strong, Dishaw and Bandy argue that including individual characteristics in TTF model is important because:

- There is increasing evidence that individual differences affect user's choice and use of technology.
- Individual characteristics are supported by work adjustment theory from which the Goodhue's original TTF model was formulated.

Therefore, they justified use of computer self-efficacy because a higher perception of one's ability to perform a task is correlated to amount of effort required to complete a task. However, in their findings, Strong, Dishaw and Bandy observed that CSE *has no significant influence on fit*. They concluded that computer self-efficacy as a measure of individual characteristics applies across information technologies and should not be considered as part of fit. Nevertheless, they recommend *further research be conducted on individual characteristics using more than one variable*. For example, they suggest that instead of testing experience and CSE separately, the constructs could be tested together as attributes of individual characteristics.

2.8.6 FITT Model

Ammenwerth, Iller and Mahler (2006) argues that popular technology adoption models such as TTF and TAM have failed to consider important aspects of interaction between the user and task. Therefore, they proposed a model named “Fit between Individuals, Task and Technology” (FITT) shown in Figure 2.9 below.

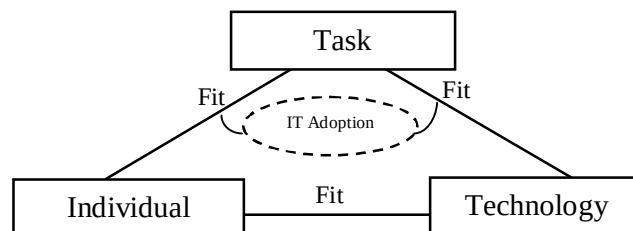


Figure 2.9: FITT model (Ammenwerth, Iller & Mahler 2006)

Their justification of the model is that TTF does not consider the interaction between users and task, which in their opinion is an important measure of IT success in a clinical environment. According to Ammenwerth et al., adoption of IT in a clinical environment depends on the fit between the attributes of individual users (computer anxiety, motivation), technology characteristics (usability, functionality, performance) and clinical tasks (organization, task complexity). This implies that, although an IT system may be successful in one setting, it might fail in another socio-organizational setting.

Though FITT model configuration is different from basic TTF model, conceptually it is a derivative of TTF model tailored to evaluate fit of information systems intended for use in a clinical environment. To operationalize the model, Ammenwerth et al. recommends further extension to tailor FITT to specific context of use. This is because individual perceptions on fit depend on change in context, time, task requirements and available technologies.

2.8.7 Integrated TTF and PVT Model

Overby and Konsynski (2010) points out that though PVT is a powerful model, it is limited in terms of proven empirical evidence compared to widely researched models such as Task-Technology Fit. This justified integrating Overby's (2008) PVT with TTF to provide precise constructs for evaluating individual, task and technology characteristics shown in Figure 2.10.

Overby and Konsynski argue that due to lack of precise measures of task and technology characteristics in the basic TTF model, researchers are left to use any measurements indicators. This leaves the model too open to fragmentation in search of dimensions and indicators of task characteristics and tool functionality. Therefore, Overby and Konsynski's extension of TTF using PVT research is a part of on-going research to provide concrete measures of Fit in Goodhue and Thompson's (1995) TTF model.

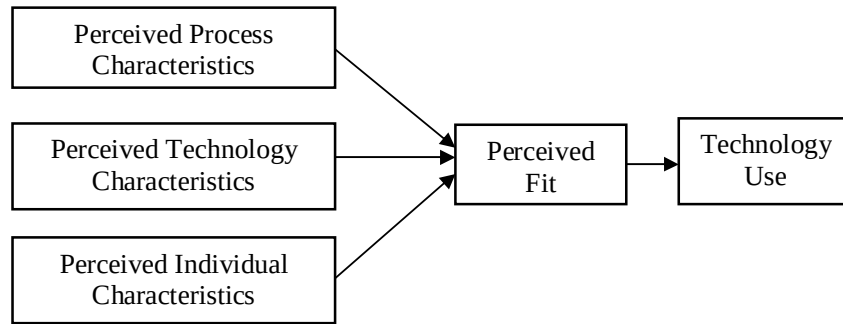


Figure 2.10: Integrated TTF-PVT model (Overby & Konsynski 2010)

Though this model is logically and conceptually viable, we note that Overby and Konsynski used *Computer Anxiety* as the only measure of individual characteristics. However, Strong, Dishaw and Bandy (2006) demonstrated that one construct is not sufficient to measure individual characteristics. Therefore, to enhance explanatory power of this model, we too suggest that more concepts and dimensions be incorporated into the model to provide more reliable measures of individual perceptions on fit.

2.9 Towards a Conceptual Model

In the previous section of this chapter, we discussed the principles and paradigms of system development and technology adoption models such as TAM, ISS, PVT and TTF. In reference to reviewed adoption models, we pointed out gaps that need to be addressed by extending or integrating each model to give them empirical power required in this study. Furthermore, our pre-study experience and mHealth deployment challenges reviewed from related work points to difficulty in aligning mobile technologies to people and processes.

To align people, processes and technology, Hevner et al. (2004) recommend socio-technical approach that requires integrating behavioural theories into design science to provide a practical solution to social problems. Therefore, based on Hevner framework, we derived a model that integrates behavioural principles and information system models into a conceptual model described in the next section.

2.10 Conceptual Model: Main Constructs

From our pre-study experience, mHealth deployment initiatives, and review of existing models, we derived a conceptual model suitable for design, implementation, deployment and evaluation of mHealth artefacts. The proposed model is based on predictive modelling similar to approach used by Davis and Venkatesh (2004) to predict post-deployment acceptance and use of technology.

Deriving a new model was necessary because none of the reviewed models could fit exactly into the context of our study. This is because the proposed model is anchored on predicting probability of future outcome rather than evaluating already deployed artefacts. The proposed model shown in Figure 2.11 is an integration of Goodhue's (1998) Task-Technology Fit and Overby's (2008) Process Virtualization Theory. For purpose of this study and future reference, we named this model *TIPFit* that stands for “*Technology, Individual and Process Fit.*”

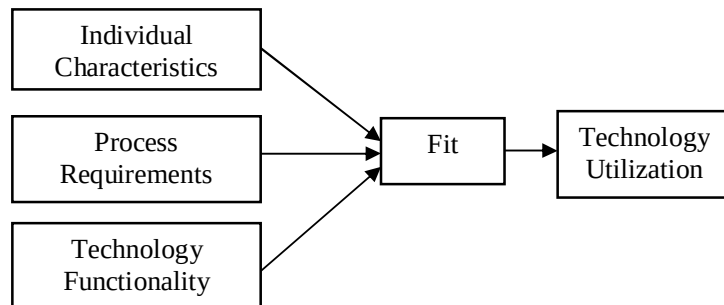


Figure 2.11: *TIPFit Conceptual model: A predictive approach*

This strategy of integrating existing model was informed by Berthon et al. (2002) suggestions on replication and extending existing research models. This is because, in a scientific research, it is reasonable not only to use existing models to address a problem but also to broaden the foundation of individual theories by extending or integrating them where applicable. This is why most researchers have used similar approaches by extending, modifying or integration existing models. For example, Venkatesh et al. (2003) integrated several models into Unified Theory of Acceptance and Use of Technology (UTAUT). Similarly, Venkatesh and Davis (2000) extended TAM published by Davis (1989) to

Enhanced TAM (ETAM) while Dishaw and Strong (1999) extended TAM with TTF constructs. Other similar approaches include Strong, Dishaw and Bandy (2006) extension of TTF model, and Overby and Konsynski's (2010) integration of TTF into PVT.

In this regard, this study takes a step beyond use of widely researched TTF models by integrating it with PVT which is a relatively new theory to test Overby's propositions in clinical processes. The model consists of three main factors namely Individual characteristics, Process requirements and Technology Functionality. The effect of these three variables on technology utilization is hypothesized to be mediated by Fit. The key premise of TIPFit model is that success of mHealth depends on **people, process and technology**. However, in this study, the scope of technology utilization is limited to use of mobile devices to enhance access to maternal care services and information in low-resource settings. The configuration of the model shows that; individual characteristics, process requirements and technology functionality indirectly influence technology utilization through fit. Mathematically this relationship may be expressed as transitive dependency:

$$X_i \rightarrow Y_1 \rightarrow Y_2 \text{ (where } X_i \text{ are predictors, } Y_1 \text{ is mediator and } Y_2 \text{ is outcome)}$$

To investigate this relationship, a multivariate regression or neural network models be employed to analyze data is collected using the predictor variables (X_i). In this study we used multivariate linear regression based on Partial Least Square Structural Equation Modelling (PLS-SEM). The study sought to investigate how (X_i) determines fit (Y_1), and to what extent fit (Y_1) predicts utilization (Y_2) of mHealth artefacts. The following is a brief overview of each TIPFit construct:

- *Individual characteristics*: Although often omitted, there is increasing evidence that individual differences influence choice of technology. The construct is adapted from Strong, Dishaw & Bandy (2006) and reinforced by Ajzen's (1991) Theory of Planned Behaviour (TPB) empirical findings on attitude (Armitage & Conner 2001; Hagger, Chatzisarantis & Biddle 2002).
- *Process requirements*: Goodhue and Thompson (1995) defined task as actions carried out by individuals that turn inputs into outputs, while Overby (2008) defined a process as a "set of steps" followed to achieve an objective. Therefore, we adapted process requirements to replace generic task characteristics in TTF model similar to the approach taken by Overby and Konsynski (2010).

- *Technology Functionality*: Based on design science paradigm, we specifically focused on information technology functionalities and system specifications necessary for design and implementation cost-effective mHealth solutions.
- *Fit*: Fit is used as an intervening variable to predict utilization of mHealth artefacts. This configuration is similar to that used by Goodhue (1998); Goodhue and Thompson (1995); Strong, Dishaw and Bandy (2006); and Overby and Konsynski (2010). This is because fit is a perception that changes due complexity of a task, individual's attitude and ability to use technology to a task (Ammenwerth, Iller & Mahler 2006).
- *Technology Utilization*: Goodhue and Thompson (1995) used the term actual use to refer to behaviour of employing technology to complete tasks. However, Strong, Dishaw and Bandy (2006) used the term *technology utilization* that refers to worthwhile or profitable use of technology. In this study we also adopt the technology utilization concept to evaluate worthwhile utilization of mHealth artefacts in maternal care.

2.11 Conceptual Model: Extended Constructs

To operationalize the proposed model for practical utility, we decomposed it to a detailed model shown in Figure 2.12. This decomposition was an iterative process that involved consultations with health professionals and information systems experts. In the detailed model, individual characteristics construct is extended with attitude and self-efficacy. In the detailed model, individual characteristics construct is extended with attitude and self-efficacy.

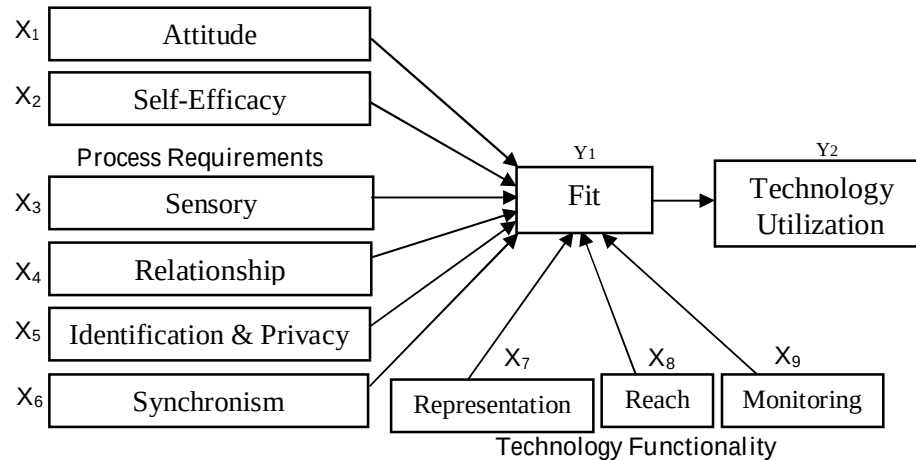


Figure 2.12: Decomposed conceptual model

To extend Process requirements and Technology Functionality constructs, we adapted Process Virtualization Theory constructs but tailored them to fit into the context of this study. The Fit and Technology utilization constructs were not decomposed further but operationalized as first-order constructs similar to approaches by Strong, Dishaw and Bandy (2006), and Overby and Konsynski (2010). One difference between TIPFit model and

Overby's (2008) PVT is configuration Technology Functionality constructs. While in PVT the IT capabilities of representation, reach and monitoring are moderating variables, in TIPFit model, the adapted constructs are configured as independent variables. This is because use of mobile technologies is one of the three pillars of information system success that if removed, mHealth ceases to be.

To demonstrate practical utility of TIPFit model, we limited "technology functionality" to factors necessary for deployment and utilization of mHealth artefacts on mobile devices. This constrained functionality was necessary because during our pre-study fieldwork, majority of the patients indicated they have basic mobile phones that mainly support voice call and SMS. Therefore, to target majority of them, mHealth interventions targeting such people should capitalize on relatively, cheaper services such as SMS as the baseline but the system should be scalable to provide new services as technology and needs of stakeholders change. Therefore, the findings from this study may not necessarily be generalized to high-end applications such as telesurgery, teledermatology and sensor-based patient monitoring. However, though in this study the model is tested on clinical processes, it can easily be tailored to fit into different contexts. In this section, we describe each construct of the detailed TIPFit model for purpose of operationalization and implementation in a practical scenario.

2.11.1 Individual Characteristics

In this study, definition of *individual characteristics* is limited to "individual's attitude and their judgement on ability to use technology to achieve a desired goal or accomplish a certain task". Goodhue and Thompson (1995) argue that if a tool makes it possible to easily accomplish a demanding task, users are more likely to use it. In other words, if technology is perceived to be fit for a task, then an individual is likely to use it. Therefore, assessment of task and technology requirements should be based on behavioural factors that influence acceptance and use of a system. This is the reason behind paradigm shift from structured to systems development methodologies to user-centred design strategies. Use-centred design requires active involvement of users in the entire system development process in order to motivate post-deployment acceptance and use.

In this study, the rationale behind extending individual characteristics with attitude and self-efficacy was to evaluate user's perception on fit of mHealth interventions. This approach is similar to Strong, Dishaw and Bandy (2006) extension of Task-Technology Fit with Computer Self-efficacy and use of *computer anxiety* as a measure of individual

characteristics by Overby and Konsynski (2010). Though the referenced models have no theoretical underpinning on attitude, its inclusion in TIPFit model was informed by experience from our pre-study, and use of the term attitude to refer to “*intention to use*” in DeLone and McLean’s (2003) Information Systems Success model. Furthermore, empirical studies based on Ajzen’s (1991) Theory of Planned Behaviour (TPB) by Ingram et al. (2000); Armitage and Conner (2001); and Hagger, Chatzisarantis and Biddle (2002) confirmed that attitude has strong influence on intention and actual behaviour.

Attitude

In Theory of Planned Behaviour, Ajzen (1991) defines attitude as the degree to which a person has positive or negative judgment of certain behaviour. Ajzen posits that human intention to perform an action (behaviour) is influenced by attitude towards the behaviour. A meta-analysis on empirical findings based on Ajzen’s TPB conducted by Armitage and Conner (2001); and Hagger et al. (2002) indicated that attitude is an important human attribute that influence human judgement on behaviour. Furthermore, DeLone and McLean’s (2003) postulate that intention to use a system is an individual attitude influenced by *system quality*, *information quality* and *service quality*.

Importance of attitude as a measure of individual’s perception on fit was further confirmed during our pre-study fieldwork conducted in June-November 2012. Observations from the pre-study indicated that attitude is one of the key factors that make clinicians reluctant to embrace new ICT innovations. In one of our discussions with health professionals, it came to light that a number of doctors are opposed to electronic means of consultation, a reason to why an mHealth initiative by Safaricom dubbed *Daktari1525* was challenged by the Kenya medical association. However, we noted that younger medics are optimistic that if legal provisions are put in place to protect patient privacy, mHealth may help in addressing some healthcare challenges as a first aid tool.

Although mHealth may not be a silver bullet to most of the challenges in healthcare, its integration into the healthcare system has the potential to provide efficient, cost-effective and convenient patient-centred care. Another important aspect of attitude is trust. User’s intention to use a system may be influenced by perception on its reliability and security. In terms of reliability, mHealth applications should be robust to work as expected even in case of poor connectivity. On the other hand, an individual is more likely to use an mHealth artefact if it does not compromise privacy.

Self-Efficacy

Bandura (1994) defines self-efficacy as people's judgement of their capabilities to use their skills to execute actions required to attain designated type of performances. Bandura's Self-efficacy concept has been widely used not only in behavioural studies but also in the field of information systems. For example, Compeau and Higgins (1995) coined the term computer self-efficacy (CSE) to evaluate "individual's beliefs on ability to use computers". Since then, computer self-efficacy has been widely used in most information systems studies. In their extended TTF model, Strong, Dishaw and Bandy (2006) used CSE as a measure of individual's perceived ability to use technology to accomplish a task.

Further review of related work revealed that, though computer self-efficacy is semantically different from Davis (1989) perceived ease of use, ideally both concepts measure one's ability to use technology. Several empirical findings based on TAM demonstrate that perceived ease of use influences intention and actual use of a system. Another concept close to computer self-efficacy is "behavioural control" in Ajzen's (1991) TPB. Ajzen posits that behavioural control is a non-motivational factor that measure individual's believe on ability to use available resources to perform behaviour.

Behavioural control is one of the widely used concepts in models designed to predict health behaviour. However, since behavioural control implies judgement on individual's ability, it is sufficient to replace it with computer self-efficacy. However, in reviewed studies, computer self-efficacy has been widely used to measure ability to use *computers*. Given that use of mobile applications to execute tasks is a new area, there is no sufficient literature on "self-efficacy" relating to use of mobile devices such as mobile phones. This justifies using Bandura's original term *self-efficacy* without the word *computer* because the concept itself is suitable to any context.

Therefore in our model, self-efficacy refers to individual's ability to use mobile devices such as tablets and mobile phones to accomplish a task. This depends on individual's literacy level, past experience and proficiency in using mobile devices. In our study context, due to resource constraints, evaluation of self-efficacy was limited to use of mobile phones to access SMS-based maternal care services. To evaluate self-efficacy, indicators used were adapted from instruments designed to measure ability to use technology by Davis (1989), Goodhue (1998), Compeau and Higgins (1995), Strong, Dishaw and Bandy (2006) and Overby and Konsynski (2010).

2.11.2 Process Requirements

The model's process requirements constructs were adapted from Overby's (2008) process virtualization theory but tailored to fit into the context of our study. This means that process requirements are limited to *"necessary requirements for accessing and providing maternal care services and information via mobile devices."* This approach was informed by Overby, Slaughter and Konsynski (2010) recommendations for contextualizing PVT to healthcare processes. We used experimental approach to investigate Overby's propositions to identify boundary conditions that limit utility of the model in clinical processes. In this sub-section, we justify inclusion of each of the process requirements construct in TIPFit model.

Sensory Requirements

Sensory requirements refers to the need for entities to be able to enjoy the experience of touch, taste, smell, sight and aural (Overby 2008; Overby & Konsynski 2010). Overby postulates that though a virtual process may simulate sensory experiences inherent in physical processes, they may fall short of capturing natural sensory experience. Moreover, Overby (2008) claims that high sensory requirements especially for touch, taste or smell makes it difficult to migrate most medical processes such as diagnosis and treatment to a virtual environment.

This makes the sensory requirements construct critical in this research because we wanted to establish to what extent sensory requirements influence suitability of conducting maternal care processes via mobile phones. This is because one of the reasons why it is difficult to deploy most clinical processes such as diagnosis may be due to sensory requirements of sight, touch, smell, taste or aural. For example, one of the procedures in antenatal care is for a caregiver to use a stethoscope, Doppler or ultrasound to listen to foetus heart rates. Trying to use such devices at home may be unrealistic due to cost or technical ability to use the device. Furthermore, trying to replicate sensory experiences of touch and smell through haptic and olfactory interfaces may be impractical. During our pre-study, we observed that sensory requirements in clinical procedures e.g. physical examination of a pregnant mother makes it difficult to virtualize most clinical processes.

Identification and Privacy

The identification concept refers to requirements of entities to authenticate physically or remotely to confirm their identity claim. On the other hand, privacy refers to personal responsibility of keeping information about a patient confidential. In this study context, the two concepts are closely inter-related because naturally a person cannot share information

to unknown person until they identify and develop mutual trust to each other. In healthcare, identification and privacy is at the core of medical practice essential for maintaining mutual trust and integrity between patients and caregivers. Therefore, if uncertain of caregiver's identity, patient would not share sensitive health information and vice versa.

In a physical encounter, patients and caregivers can easily identify each other and develop mutual trust that makes it possible to share health information. However, in a remote setup, threats to authenticity and privacy such as phishing, spoofing and identity theft makes it hard to trust remote participants. This is why most caregivers are hesitant to share sensitive information such as prescription and clinical test results via electronic media. In most cases, clinicians prefer using a written note such as: "*come personally for test results*". Therefore, we argue that identification and privacy together or separately influences fit of deploying mHealth artefacts meant for sensitive clinical processes.

To develop trust in the use of mobile devices, design and implementation of systems artefacts should enforce reliable security and privacy mechanisms. The following are some protocols and standards that provide guidelines on how to enforce security and privacy in electronic health systems:

1. Health Insurance Portability and Accountability Act (HIPAA): HIPAA contains privacy guideline published by U.S. Department of Health and Human Services.
2. Health Level Seven (HL7): Health level 7 is a security and privacy protocol guideline based on Role-Based Access Control (RBAC) standards.
3. ASTM E1986-98: ASTM stands for American Standard for Tests and Material, a body that sets standards and guidelines for access to confidential health information.
4. ISO/IEC 15816: International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) published guidelines for specifying the abstract syntax of generic and specific Security Information Objects (SIOs) for access control to private data and information.
5. DICOM: DICOM stands for Digital Imaging and Communications in Medicine. It is a standard published by U.S. National Electrical Manufacturers Association (NEMA) for processing and transmission of medical images in networked environments.

Relationship

Patient-caregiver relationship is one of the fundamentals of medical practice and ethics that helps in building confidence and mutual trust between the two parties. In a physical encounter, both verbal and non-verbal communications convey information that may be

useful in diagnosis and treatment. For example, in psychiatry, non-verbal gestures such as smile, body posture, and mood may form a good percentage in diagnoses of depression. However, such a procedure may be difficult to be accomplished through mobile calls and text messaging. In this study, we sought to investigate the degree to which mobile devices can provide sufficient interaction between maternal care patients and caregivers through use of services such as SMS alerts and voice calls.

Synchronism

Overby defines synchronism as the degree to which the activities that make up a process need to occur quickly with minimal delay. In physical encounter, processes may tend to be faster because participants interact with each other with minimal or no delay. However, in low-resource settings processes such as telesurgery that require real-time streaming may not be feasible. Though synchronism may not be necessary in some cases, some clinical procedures may require timely feedback for a patient to make informed decision or immediate intervention by a caregiver. Therefore, in the context of this study, we sought to identify clinical processes and procedures that require timely or immediate feedback between the caregivers and patients.

2.11.3 Technology Functionality

In the context of this study, technology functionality refers to the capability of mobile devices to replicate physical environment by providing remote access to maternal care services and information. In our model, technology functionality constructs were adapted with minor modification from Overby's (2008) information technology variables. These are representation, reach, and monitoring capability. However, unlike Overby proposition that IT may not be required to virtualize a process, in our context, information technology has direct influence on fit and utilization of mHealth artefacts. This configuration follows the same approach in nomological network of theories by Goodhue and Thompson (1995); Davis (1989); Ajzen (1991); Venkatesh and Davis (2003); Strong, Dishaw and Bandy (2006); and Overby and Konsynski (2010).

Representation

Representation refers to the capability of IT to simulate a physical process in a virtual environment. This may be achieved by use of biometric sensors or multimedia technologies such as voice, digital imaging or videoconferencing. Therefore, representation capability of technology allows many processes that would require physical encounter to be conducted

remotely in a virtual environment. For example, in telesurgery, a videoconference session between a specialist and physicians in a remote hospital may be setup to conduct surgery on a patient. It is important to point out that even the most basic mobile phone supports telemedicine. This is because, once a patients and caregiver develop mutual trust, they can agree on communication protocols through which they can share health information.

Nevertheless, to enhance user-experience and quality of service, mHealth artefacts should be scalable to support high-end technologies such as multimedia (audio, images and video), wireless sensors and internet services. But, due to resource constraints in the context of our study, we investigated degree to which representation could be achieved even by use of basic mobile services to replicate characteristics of a physical process or workflow.

Reach

Information Technology has the capability to provide access to services and information as demonstrated in mobile payments and m-banking. Therefore, the motivation behind most of the mHealth pilots is to reduce hospital visits and cost by replicating success financial sector in healthcare. For example in Kenya, Safaricom partnered with *Call-a-Doc* to provide healthcare services dubbed *Daktari1525* to enable Kenyans access medical services over mobile phones (CIO East Africa 2012). The aim of this initiative was to reduce hospital visits and cost by providing access to doctors at any time to receive advice on health issues.

Besides getting access to doctors, mHealth applications have the potential to provide other healthcare services such as transmitting test results, remote patient monitoring, medication reminders, emergency alerts and other forms of care services. However, there are several challenges discussed earlier that limit deployment of most healthcare services on mobile devices. Therefore, suitability of mHealth interventions in providing access to healthcare should be judged on its fit rather than complexity of their configurations. This is because, although it is possible to provide access to healthcare using smart devices such as, biometric sensors and smartphones, there are other factors that limit utility of such technologies in low-resource settings. In this study, our interest was to explore how available mobile phones and medical devices can be configured to provide sufficient access to maternal care services and information in low resource settings.

Monitoring

In the context of this study, monitoring refers to the capability of technology to provide continuous follow-up of patient's health status. Currently, there are several studies

particularly in developed countries that are focusing on use of smart technologies to provide home-based care and follow-up of patient health status! This is because remote patient monitoring using wireless sensors and mobile devices has the potential to save on cost and improve health outcome (Overby, Slaughter & Konsynski 2010). For example, biometric devices can be used to remotely capture and transmit to hospital vital signs such as temperature, foetus heart rate, blood pressure and haemoglobin. This would save cost on hospital visits as well as help in early detection of cases such as preeclampsia and gestational diabetes that require immediate attention. However, in low-resource settings, it may be impractical to deploy real-time patient monitoring applications due to cost, infrastructure and device limitations.

In this study, we argue that, regardless of limitations imposed by infrastructure, patient monitoring can also be achieved using low-cost medical and mobile devices. For example, due to unstable BP, a pregnant woman may be required to make regular visits to hospital for close monitoring. However, we observed that some of these women ignore such instructions resulting to pregnancy complications such as haemorrhage and stillbirth. In such cases mobile phones and available medical devices may be used to provide basic monitoring of patient's status through alerts on nutrition, danger signs and preventive care.

During our pre-study, we noted that, patients and caregivers are eager to use available devices to continuously monitor their pregnancy status and child development. However, there were concerns on how in absence of biometric sensors, basic medical and mobile devices can provide reliable and sufficient patient monitoring without compromising integrity and privacy. Therefore, this study investigated how low-end mobile devices and locally available medical devices may be configured to provide secure, effective and sufficient patient monitoring to reduce maternal and child mortality in underserved areas.

2.11.4 Fit

As depicted in TIPFit model, fit is a moderating variable adapted from related work in Goodhue and Thompson (1995); Strong, Dishaw and Bandy (2006); and Overby and Konsynski (2010). However in our context, Fit refers to “suitability of mobile devices to enhance access to maternal care services while reducing caregiver's workload”. We argue that Fit is a perception which depends on user's evaluation on her ability and the task to be accomplished. In other words, whether an artefact yields fit or provides sufficient representations of physical encounter is a subjective assessment based on context of use. This is why we considered Fit as a mediating variable that indirectly determines utilization.

This approach is not different from that taken by Strong, Dishaw and Bandy (2006) and Overby and Konsynski (2010). To estimate Fit, this study employed repeated measures experiment to evaluate respondents' perception and judgement on suitability of mHealth artefact before and after exposure to an intervention.

2.11.5 Technology Utilization

According to Collins English dictionary, the term utilization refers to making practical or worthwhile or profitable use of something. In TIPFit model, Technology Utilization is configured as a dependent variable that measures utilization of mHealth artefacts. Therefore, technology utilization is hypothesized to be influenced by fit of mHealth artefact in terms of individual, process and technology factors. In healthcare, patient and caregivers may be motivated to use mHealth artefacts if they judge it fit to their needs (Davis & Venkatesh 2004; Legido-Quigley et al. 2008; Arah 2006).

In Human-Computer Interaction (HCI), usability and user experience are key parameters used to evaluate satisfaction from use of an artefact. Therefore, in our model, technology utilization is the ultimate goal that should be predicted or evaluated against strong determinants of fit as expressed in TIPFit model relationships ($X_i \rightarrow Y_1 \rightarrow Y_2$). In predictive modelling, technology utilization may be evaluated as intention before exposure to mHealth intervention (Davis & Venkatesh 2004). After exposure to an intervention, the variable may be evaluated in terms of post-deployment acceptance and use.

2.12 Summary of Literature Review

In this chapter, we started with an overview of important healthcare concepts and (CIR) ontology. We then highlighted on technical and socioeconomic challenges and barriers to healthcare in developing countries. In the chapter we also reviewed global ICTs interventions in healthcare with emphasis on deployment of mHealth in low-resource settings. To scale-up mHealth deployment and utilization in low-resource settings, this study proposed a socio-technical approach informed by design science, behavioural and information systems theories e.g. TAM, ISS, TTF, and PVT and TPB. It is from these models and our pre-study experience that we derived an integrated model referred to as TIPFit. To validate TIPFit model in a practical scenario, we operationalized it by developing a prototype used in an experiment as discussed in remaining chapters.

CHAPTER 3

Methodology: Model-Driven System Development

3.1 Introduction

Justification of a theoretical model should be evaluated in light of its practical utility in solving a problem (Henver et al 2004). Therefore, TIPFit model is anchored on design science philosophy that emphasizes on demonstrating tangible results through the reduction of design concepts into actual practice. Furthermore, design science underscores the need for applying a deliberate design approach rather than relying solely on evolutionary haphazardness to human affairs. In this chapter, we demonstrate practical utility of TIPFit model by configuring appropriate technologies to the advancement of health and wellbeing of women and children in underserved low-resource settings.

To translate the model to tangible results, we used human-centred design to develop a maternal care prototype named *mamacare*. The word *mamacare* is derived from two words namely *mama-* and *-care*. The prefix *mama-* was chosen because it is widely used by children across many communities to refer to “mother” while the *-care* suffix refers to maternal and child healthcare services. Therefore, the research methodology in this study cuts across two inter-related chapters as follows:

1. Chapter 3: This chapter demonstrates how to apply the proposed model in developing a prototype suitable for use in low-resource settings. The chapter starts with mapping the model to human-centred system development approach used in this study. This was informed by our pre-study experience and related work.
2. Chapter 4: This discusses the experimental design employed in this study. These include design of experiment, sampling criteria, data collection, and data analysis. This chapter also discusses how to operationalize the proposed model in order to validate it in practical scenario.

The socio-technical approach adopted in this study is intended to provide innovators of mHealth solutions with blueprints that are suitable for development of mHealth artefacts intended for use in low-resource settings.

3.2 TIPFit Operationalization Roadmap

To scale-up utilization of mHealth artefacts in low-resource settings, we derived a conceptual model named TIPFit that was a product of related work, pre-study experience,

extensive consultations with healthcare professionals and scholars. This informed on key factors used in deriving the conceptual model unveiled in chapter 2. Figure 3.1 shows an illustration of the process we used to derive the model and the roadmap to validating the model in a practical scenario.

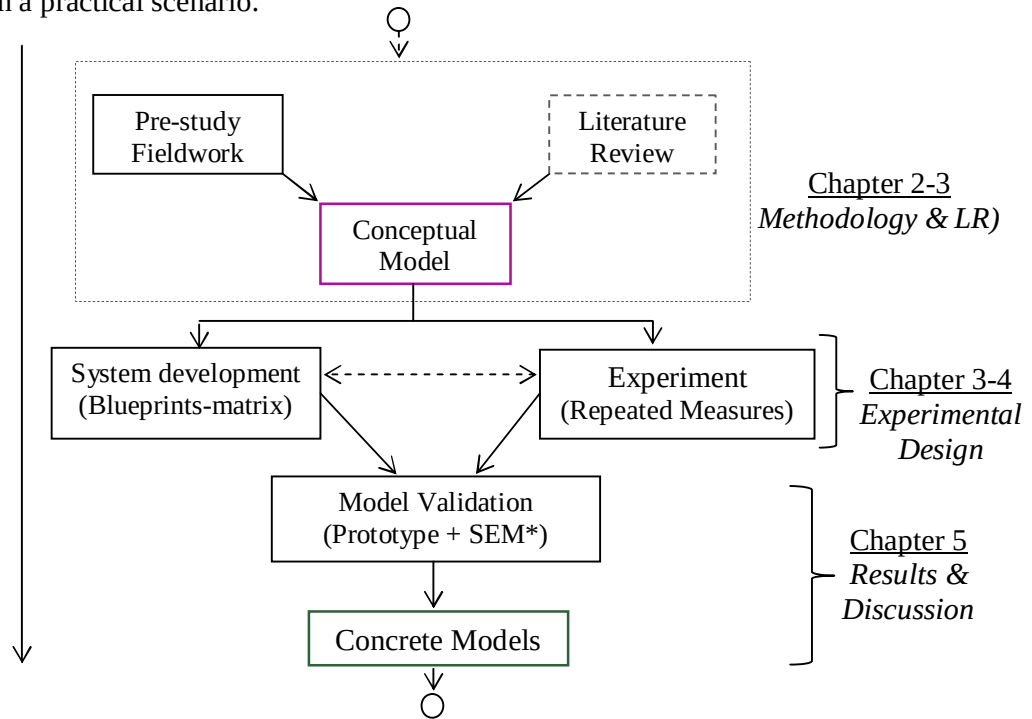


Figure 3.1: Roadmap to TIPFit model operationalization

The acronym SEM in the diagram stands for *Structural Equation Modelling*. SEM may be used to predict future outcome before deploying an intervention. Also note that **conceptual model in red** is an abstract idea to be **validated to green** through prototyping and repeated measures experiment. The two sided broken arrow between system development and experiment indicate that this was an iterative refinement process using beta versions that contributed to deployment of our final mamacare prototype

3.2.1 Pre-study Fieldwork

To conceptualize on healthcare problem to be addressed in our study, we embarked on a pre-study fieldwork in June 2012 to acquaint ourselves with the healthcare ecosystem. During the six-month fieldwork, we visited several hospitals among them Karen Hospital, Kenyatta National Hospital, Kiambu District Hospital, Ruiru Sub-district Hospital and Kimbimbi Sub-district Hospital. The purpose of the fieldwork was to investigate challenges that hinder access to healthcare in low resource settings. The study also set out to explore how low-cost medical and mobile devices could be used to meet patient's needs while

improving the caregiver's performance. During our pre-study, the following challenges were uncovered:

1. Large numbers of maternal clients visiting public hospitals for antenatal, delivery, and postnatal services resulted to numerous internal and external inefficiencies.
2. Large number of outpatients and inpatients overstretch the hospitals that are suffering from inadequate facilities, drugs and caregivers.
3. Due to poor working conditions, low pay and poor management, most health workers are demoralized and at times have to go on industrial strike. In the course of our study, this problem became worse after healthcare was devolved to county governments.
4. There are delays and misreporting of vital statistics and other important health reports in line with WHO guidelines. This is because in most of these hospitals, clinical reports are processed manually.
5. Most rural hospitals experience unstable power supply, but due to financial constraints they have no power backup facilities. This affects critical operations in critical hospital departments and sections such as theatre, finance, records and laboratories.
6. Most rural hospitals have no reliable access to internet.

To address these challenges we approached doctors, nurses and some patients in Ruiru and Kimbimbi Sub-district Hospitals. Four doctors and five nurses voluntarily agreed to share their expertise and experiences with our research team throughout the study. This team contributed immensely to this study and their views are reflected in the detailed TIPFit model and maternal care prototype. Figure 3.2 shows two of our pre-study meetings with doctors, two of whom were Medical Officers in-charge of Kimbimbi and Ruiru Hospitals.



Figure 3.2: Pre-study session with caregivers

Through informal and formal discussions with these health professionals and views from selected patients, we identified pertinent issues that are instrumental to deployment of information systems in public hospitals. Some questions raised during our discussions were:

- Who bears the initial development and installation cost of deploying mHealth systems in financially constrained healthcare institutions?
- Who bears the running cost such as voice calls and messaging? Is it the hospital, the government or the patient?
- What benefits does the hospital stand to gain in deploying such mHealth services compared to established procedures?
- How do mHealth solutions compare in terms of running cost and access to healthcare services against patients' physical visits to the hospital?
- How do proposed mHealth solutions offer meaningful benefits to the patients to justify use in accessing healthcare services and information?
- What is more important? Is it reducing cost of visiting hospitals or risking the privacy of patient health information? For example, how safe is it to send test results through SMS?

During the pre-study fieldwork, our approach was mainly qualitative to understand the problem domain, and socio-economics factors such as residents' lifestyle, infrastructure and economic activities. The Pre-study ended in November 2012 by conducting an online interview with caregivers using a sample instrument attached in Appendix 8A. Figure 3.3 shows analysis of responses from the four caregivers who filled the questionnaire.

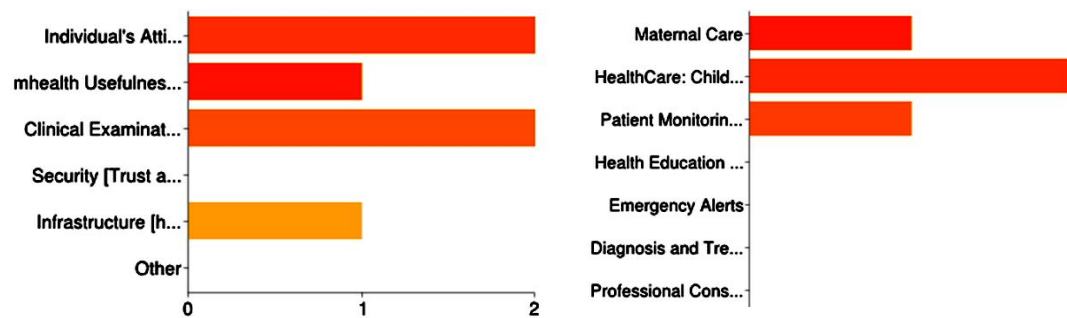


Figure 3.3: Pre-study responses from health practitioners

Table 3.1 summarizes key responses in terms of people, processes and technology based on informal and formal observations from our pre-study fieldworks.

Table 3.1: Summary of pre-study discussions with caregivers

Key factors	Reference Subject	Comments
People	Caregivers (Doctors, Nurses, and CHWs)	75% of the 4 who participated indicated that attitude and privacy is a barrier to effective use of mHealth services. Also, most clinicians lack sufficient ICT skills. Caregivers are bound by ethics that limit them on use of ICTs due to patient confidentiality and fear of litigations.
Process	Healthcare processes	75% felt mobile phones are not capable of executing clinical processes e.g. clinical tests. Phones may be used for emergencies and awareness.
Technology	Mobile phones and point-of-care devices	It was also observed that hospitals have inadequate facilities, unreliable power supply and funding. Also, most patients have basic phones and cannot afford to pay for point-of-care services.

Though these findings may not represent a wide view of caregivers, they motivated our choice of deploying mHealth intervention for maternal care. During one of the pre-study interviews, a doctor commented “mHealth can act *synergistically* to reduce morbidity and mortality in acute cases. Also, mHealth has the potential to *greatly boost the outcomes* of patient’s health and *reduce the cost and time* spent coming to the hospital”.

One of the doctors pointed out that, ‘*mHealth would be fit to her if it can help decongest the maternal ward which is always full beyond its capacity*’. Another suggestion from the health professionals was that mobile-based interventions should be used as a first-aid to provide access to basic services for effective management of antenatal, delivery and postnatal care. There were suggestions that during pregnancy and six weeks after delivery, mobile phones together with certified medical devices may be used by paramedics to capture vital signs e.g. blood pressure, blood sugar, temperature and haemoglobin, and send the results to the hospital. This could potentially adjust the number of visits to the hospital and identify high-risk cases that require special follow-up.

Using this information as a baseline, our design concepts were optimized to make use of available low-cost mobile and medical devices to provide better access to maternal care in underserved parts of Kenya. The design started by formulating a maternal care scenario illustrated below:

Maternal care Scenario:

Mr. and Mrs. Mulumba have been married for a year now, and for the last few months they have been planning to have their first baby. One month after their marriage, the couple moved from Thika town to a rented house in Mwea located about 115 Km from Nairobi on Nairobi-Embu highway. In February this year, Mrs. Mulumba started to get feelings that suggested she was pregnant. After sharing her feelings with Dr. Njoka in Kimbimbi Hospital, the doctor referred her to the lab for a pregnancy test; true to her feelings, the results confirmed that she was pregnant. This being Mrs. Mulumba first pregnancy, she wanted to know how to go about managing her pregnancy given that she resides in a village known as Ciagini, about 10 km from the main road and the only possible means to the highway is by bicycle or *Boda Boda* (commuter motorbikes).

Given that there is no any other health centre close to her residence, she has to make regular visits to the hospital for antenatal tests such as haemoglobin (Hb), blood pressure, temperature, blood sugar, urine test, weight and the foetus growth. Due to free maternal care provided by the government in public hospitals, Mrs. Mulumba has to sacrifice a whole day to attend clinic appointments and which she feels will be complicated in the later stages of her pregnancy. At some point, she wonders if there is a way she can use her phone to keep track of her pregnancy status to save some days, travel cost and time. It is at this point that Mrs. Mulumba wishes Kimbimbi Hospital, the most convenient to her, makes use of mobile-based services for convenient access to antenatal and postnatal care services and information!

This scenario points at providing suitable mHealth interventions that would help Mrs. Mulumba to:

1. Monitor vital signs such as BP, Hb, blood sugar, and temperature in order to identify any complication early enough for necessary action.
2. Save on time and travel cost by reducing the number of visits and time wasted in the hospital waiting to see a doctor or get test results.
3. Get home-based care via mobile-based SMS alerts on reminders, danger signs, safe delivery, nutrition, medication, counselling, and other preferred maternal care services.

Based on pre-study findings that identified maternal care as the priority area, we focused on how to address challenges experienced by women and children in low-resource settings. To start with, we interviewed 29 randomly selected patients to get their opinion on use of mobile phones to enhance access to maternal care using the questionnaire attached in appendix 8B. Figure 3.4 (a) shows that majority of the respondents use mobile phones for voice calls or calls and SMS, while Figure 3.4 (b) indicates over 85% were interested in using mobile phones to access maternal care services.

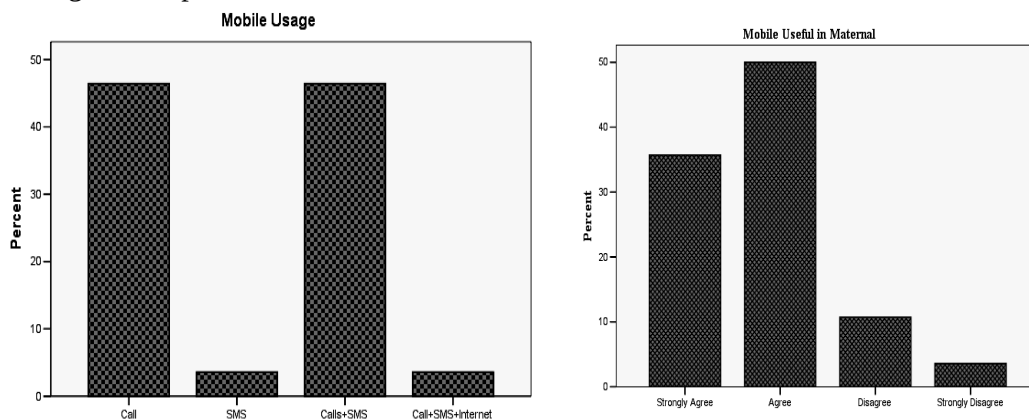


Figure 3.4 (a): Voice calls and sms services Figure 3.4 (b): Mobile use in maternal care

Table 3.2 summarizes the responses from the 29 patients in terms of people, processes and technology factors.

Table 3.2: Summary of pre-study interview with clients/patients

Key factors	Reference Subject	Comments
People	Maternal clients/patients	Attitude, privacy and low-literacy affect use of mobile phones by clients/patients (about 82.8% have basic education). Majority had no idea on use of mobile in healthcare. Respondents also indicated that patients have poor interaction with caregivers
Process	Maternal care processes	About 85.7% of respondents indicated use of mobile phones is useful in maternal care but cannot replace going to hospital for review and seek for health advice from caregivers.
Technology	Mobile phones and point-of-care devices	About 96.4% respondents have basic phones which they mostly use for voice calls and SMS. 75% respondents indicated that they have limited access to healthcare facilities due to cost and long distance.

3.2.2 System Development Blueprints

Software development should be based on best practices and principles that make the artefacts fit for the real world in which they are intended to be used. Davis and Venkatesh (2004) demonstrated that pre-prototyping usefulness of a system prior to implementation predicts its future acceptance and use. This study employed a similar model-driven approach to scale-up deployment of mHealth artefacts fit for low-resource settings. Although we follow the typical of software development process, we argue that the point of failure of most mHealth artefacts is conceptualization which we referred to as the *black-box* shown in Figure 3.5. This is because most mHealth deployment initiatives are based on “perceived problem” rather than the “real problem” or stakeholders’ needs. This was evident during our pre-study when we went to Mwea with a perception that malaria is among the challenges in the region only to discover that malaria prevalence has been reduced almost to zero.

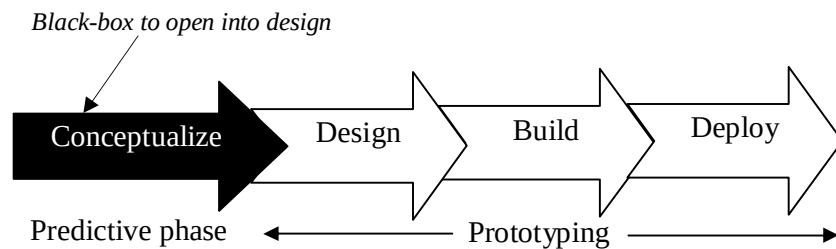


Figure 3.5: Typical Software development process

To open the black-box shown in the figure above, the designer identifies a problem or opportunity that could be addressed using mobile mHealth interventions. During conceptualization workflow, the designer may use strategies such as creative thinking, pre-prototyping, ethnographic surveys, collaborative design and low-fidelity prototypes to formulate solution to the problem.

After the conceptualization, the conceptual designs that fit into the stakeholders’ needs are translated into physical designs. Once the designs are validated with the stakeholders, the developers can then implement executable artefacts that are suitable for deployment in the context of use. In this section, we operationalize the conceptual TIPFit model by mapping the constructs onto software development blueprints using the four technical workflows depicted in Figure 3.5 above. Later, we provide a universal blueprint that contains artefacts i.e. outcome of each workflow activity.

Individual Characteristics Blueprint

From our pre-study experience and related work, it is evident that individual differences in attitude and self-efficacy affect choice and use of technology. Table 3.3 is a matrix that serves as a blueprint for considerations of individual characteristics workflow activities in development of mHealth artefacts.

Table 3.3: System development matrix for individual characteristics

Concept	Conceptualize*	Design	Build	Deploy
Attitude	Use strategies e.g. creative thinking and field surveys to formulate solution to the problem. Pilot tests or pretest attitude to predict utilization	mHealth physical designs should be based on explicit understanding of target through participatory or collaborative design approaches	Involve stakeholders where possible during implementation. This may be achieved through piloting and release of beta versions	During deployment, conduct training and support. Also administer user acceptance tests to evaluate utilization and user satisfaction.
Self-Efficacy	Investigate individual's ability and competences in using computers and mobile devices. Pilot tests or pretest self-efficacy to predict utilization	Responsive or context-aware design approach may be used to enhance usability and user experience. Low-fidelity prototypes and mock-ups may be used to identify optimal content and navigation presentations	Using software development toolkits implement cost-effective mHealth artefacts that are responsive to patient and device profiles.	Evaluate user's feedback on ease of use and experience. The feedback may be used to enhance the artefact interface and workflow/content representation

The Conceptualization column marked with an asterisk is the core of our study. It maps onto the box shaded in black (black-box) in Figure 3.5 above that indicate that once the we get stakeholder's needs and expectations right, we can easily implement **fit** solutions. In regard to product at each stage, individual characteristics should inform on the outcome of each workflow that feeds into the next workflow. Table 3.7 towards the end of this subsection provides a summary of workflow artefacts in which attitude and self-efficacy should be reflected.

Process Requirements Blueprint

From our pre-study experience and related work by Overby, Slaughter and Konsynski (2010), Table 3.4 is a matrix that serves as a blueprint for process requirements activities during development of mHealth artefacts.

Table 3.4: System development matrix for process requirements

Concept	Conceptualize*	Design	Build	Deploy
Sensory	Explore how low-cost clinical and mobile devices can be used in patient monitoring of vital signs e.g. Temp, BP, sugar and Hb. Pilot tests or pretest sensory requirements to predict utilization	Design architectural or deployment models depicting how sensory experience may be fulfilled in low-resource settings in absence or presence of biometric sensors	Implementation of sensory requirements is the most challenging in low-resources settings. In absence of biometric sensor, configure mHealth artefact to make use of available resource to offer some degree of sensory experience	Evaluate whether mHealth artefacts provide satisfactory sensory experience such as aural and affection between patients and caregivers
Relationship	Study the interaction between patients and caregiver. Conduct pilot tests or pretests to identify cost-effective communication mechanisms likely to enhance interaction.	Provide interaction architectural models for patient-caregiver interactions. This may require use of interaction models	Implement interaction models using cost-effective and suitable communication protocols. In low-resource settings, SMS-based applications are the most common and some have been successful	Evaluate on effective of patients-caregivers interaction provided through mobile devices
Identification and Privacy	Conduct pre-study to identify care services and clinical information that may be provided physically or electronically. Classify clinical records from least to confidential to highly confidential	Use HL7 security and privacy domain analysis models and security standards or guidelines to design system security models	Implement server-side and client-side security mechanisms using security standards and privacy policy guidelines such as HL7 and HIPAA.	During deployment, test on any form of violation to patient's anonymity and privacy resulting from use of mobile devices
Synchronism	Investigate clinical cases that require immediate action or response from caregivers.	Model and deploy prototypes to pilot responsiveness of time-critical events and processes.	Implement and evaluate the system response time. Pilot to test if scheduled events are fired in satisfactory time	During deployment, evaluate on availability and timeliness of services and information provided through mobile devices

Based on the context of use, the four process requirements should inform on the outcome of each workflow that feeds into the next workflow. Table 3.7 towards the end of this subsection provides a summary of workflow artefacts in which sensory requirements, relationship, identification and privacy, and synchronism should be reflected.

Technology Functionality Blueprint

Based on design science paradigm, our pre-study experience and reviewed case studies relating to ICT interventions, it is evident mHealth has the potential fast-track attainment of MDGs 4 and 5. Table 3.5 is a matrix that serves as a blueprint for ICT-based activities to be executed during development of mHealth artefacts.

Table 3.5: System development matrix for technology functionality

Concept	Conceptualize*	Design	Build	Deploy
Representation	Make observations on target users' literacy, devices available, common language and content presentation	Using low or high fidelity prototypes, discuss with users the design to clearly capture content and clinical workflow.	During implementation, involve stakeholders in testing the system functional capability to represent clinical workflows/process	Evaluate patients and caregivers responses on suitability of mobile devices on representing workflow and processes.
Reach	Explore how well the planned mHealth intervention would enhance access to care via mobile	Create system designs or models that illustrate how the system connects patients to care services and info	Implement artefacts that optimizes on available devices to provide convenient and reliable access to care services and information	Evaluate patients on convenience, reliability and cost-effectiveness of mobile devices in providing access to maternal care services
Monitoring	Investigate the degree to which patient monitoring can be realized in low-resource settings using available clinical devices and mobile phones	Create system designs or models illustrating how patient monitoring would be achieved in low-resource settings with or without biometric sensors	Implement an artefact that optimizes on available devices to provide sufficient data for patient monitoring	Evaluate users' satisfaction from mobile-based monitoring. Use the feedback to revise or provide additional services.

Based on the context of use, the three technical requirements should inform on the outcome of each workflow that feeds into the next workflow. Table 3.7 at the end of this subsection provides a summary of workflow artefacts in which representation, reach, and monitoring specifications should be reflected.

Fit and Technology Utilization Blueprint

In this study, fit is an individual's perception that changes due complexity of a process, attitude and ability to use technology. These factors are posited to influence utilization of mHealth interventions in low-resource settings. Table 3.6 is a matrix that serves as a blueprint for considerations in development of mHealth artefacts suitable for low-resource settings.

Table 3.6: System development matrix for fit and technology utilization

Concept	Conceptualize*	Design	Build	Deploy
Fit	Investigate how fit in terms of individual, process and technology factors may predict post-deployment acceptance and use of an mHealth artefact	Creative thinking and participatory design approaches can enhance chances of design of artefacts that fits into stakeholders' needs	Use cost-effective deployment toolkits to implement the designs into artefacts that fits shareholder's needs and context of use	During deployment, evaluate degree to which mobile-based interventions provide sufficient data for effective monitoring of patient health status
Technology Utilization	Use the model to predict likelihood of post-deployment acceptance and use of an mHealth artefact	Use iterative design and pilot tests to create and refactor design models to optimize on acceptance and use of the final mHealth artefacts	Implement a simple but cost-effective mHealth artefacts that satisfies shareholder's needs and inspires continued use	Evaluate stakeholders' satisfaction from mobile-based services. Their feedback may be used to provide additional or continued services.

Based on the context of use, the three fit and technology utilization should be evaluated at every stage in the design of the system. This is by using measurements instruments such as those provided in Appendix 2, 3 and 8C. Table 3.7 indicates that fit and utilization should be evaluated using milestone blueprints right from conceptualization to deployment.

In summary, Table 3.7 provides a blueprint describing workflow artefacts expected at the end of each stage in system development process based on TIPFit approach. For simplicity, we only provide high-level artefacts but during each phase, it's important to provide actual *specifications based on individual characteristics, process requirements and technical properties*.

Table 3.7: Summary of the four workflow outcomes

Construct	Conceptualize*	Design	Build	Deploy
Individual Characteristics Process Requirements Technology Functionality	Vision document, use-case models, business model, validated requirements, behavioural prototypes, initial risks list	Refined use-case models, system models, software architecture, executable prototypes, preliminary user manual	Deployment diagrams, software artefact (source files, binaries, executable), test plan, technical manual, user manuals, migration plan	Completely tested artefact, user manual, security and privacy policy
Fit Technology Utilization	Milestone evaluation blueprint	Milestone evaluation blueprint	Milestone evaluation blueprint	Milestone evaluation blueprint

3.2.3 Prototype Development Approach

To convert the blueprints into a practical software development process, we integrated Agile Unified Process (AUP) into UML-based Web Engineering (UWE) methodology (Koch, Kraus & Hennicker 2007). The rationale was to use an approach that adheres to ISO 9241-210:2010 (2010) standard on user-centred design. The standard outlines the following:

- The design should be based on explicit understanding of users, tasks and environment
- Target users are involved throughout development
- Design is driven and refined by user-centred evaluation
- Development process is incremental and iterative
- Design process addresses the whole user experience
- Design team includes multi-disciplinary skills and perspectives



The methodology used in this study follows the 2-Dimensional Unified Process (UP) shown in Figure 3.6 below. The illustration shows the four phases under which are our core workflows namely *conceptualization*, *design*, *build* and *deployment* depicted earlier in Figure 3.3.

1. Inception Phase: In this phase, more emphasis is on **conceptualization** to identify stakeholders' needs through business modelling and requirement elicitation.
2. Elaboration phase: Detailed analysis of requirements using UML-based system models.
3. Construction phase: Design and implementation of system artefacts suitable for the stakeholders' needs.
4. Transition phase: Deals with deployment of the system, training of users and system maintenance. The red broken line indicates management workflows that went hand in hand during the four technical workflows.

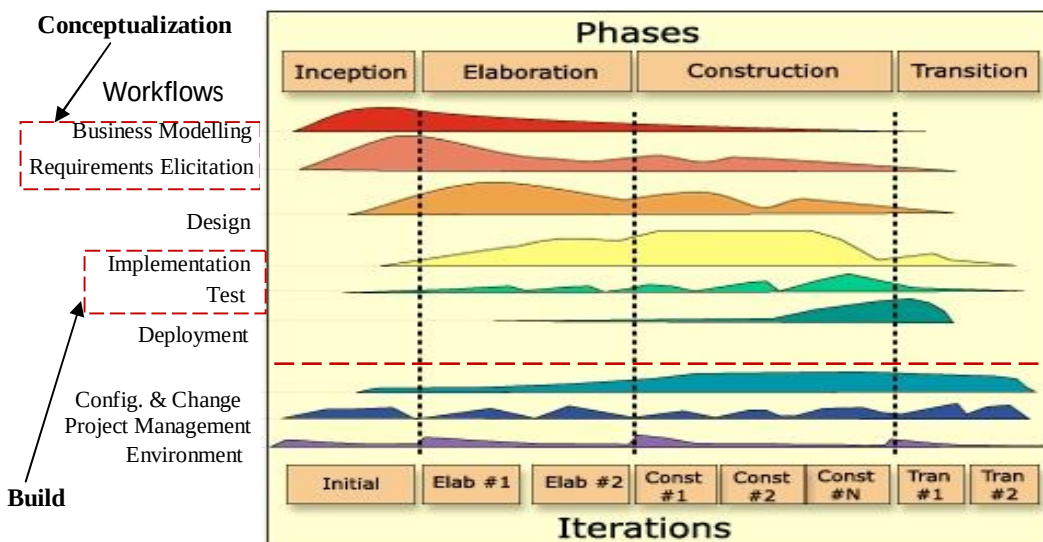


Figure 3.6: Rational Unified Process (Booch et al. 2007)

3.3 Inception Phase

The purpose of inception phase is to understand the domain context and identify stakeholder's needs and expectations. In this context, stakeholders refers to subjects of care mainly patients, doctors, nurses and community health workers. This section highlights workflow of activities during inception stage.

3.3.1 Conceptualization: Modelling and Requirements

After taking the stakeholders through the model to shed light on what we expected, we started conceptualizing on suitable solutions. Our conceptualization process was similar to that used by Davis and Venkatesh (2004) to pre-prototype usefulness, but in our case we were pre-prototyping fit.

Some of the methods used during conceptualization stage includes brainstorming, joint application development (JAD), storyboards, mock-ups, low-fidelity prototypes and to some extend throwaway prototypes. Figure 3.7 shows a picture during one of such conceptualization sessions with nurses at Kimbimbi Hospital in Mwea.



Figure 3.7: Conceptualization session with caregivers

Though the stakeholders are not competent in IT, we took them through fundamental principles that made us equal partners in discussions. This started by exposing them to TIPFit model described in chapter two explaining to them each construct in a layman's language. From these pre-prototyping sessions we identified functional requirements from problem domain and stakeholders needs.

Functional Requirements

The following are functional requirements that went into the *StructuredRequirements* shown in Figure 3.8 below:

- a) The system should allow a privileged user register and maintain clients and patients demographics and health data relating to antenatal, delivery and postnatal care.
- b) The system should allow users with administrative privileges to register new users grant and revoke privileges as per defined security policy.
- c) The system should be able to trigger and send event-based alerts such as appointment reminders, medication adherence, preparation for safe delivery, and other messages depending on patient profile.
- d) Depending on profile, the system should allow the registered patients or community health workers (paramedics) to post vital signs or query for specific information.
- e) The system should allow authorized users to efficiently search for any records using key words such as name and/or registration number.
- f) The system should generate a variety of periodic and on-demand tabular and graphical reports useful for clinical intervention and management of maternal care.

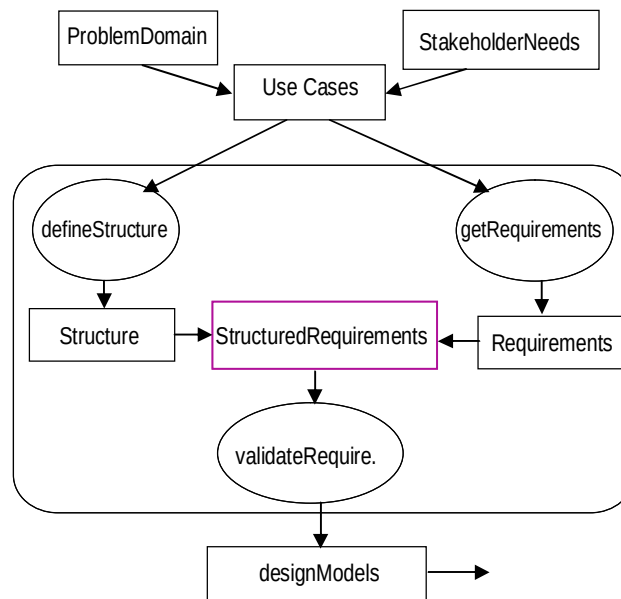


Figure 3.8: Requirements discovery model

Non-functional Requirements

The following are non-functional requirements that went into the *StructuredRequirements* box highlighted in the flow diagram above:

- a) Based on HL7 (2010) security and privacy policy, mamacare should enforce, multi-layered security at socket level, application and on-air transmission encryption
- b) Using simple consistent navigation and content presentation, the system should be easy to learn and use.

- c) Based on context, the artefact should be a one web-based artefact solution that adapts to multiple mobile and desktop devices and platforms. This will make it possible to continue using the system when out of the hospital or in case of power failure.
- d) To run on most mobile devices, the system should optimize on minimal resources and limited bandwidth while maximizing on response turnaround time on cellular networks.
- e) To maximize on usability and user-experience, the system should be user-friendly, consistent with workflow, localized to context and with appealing look and feel.

Benefits of Mamacare System

The following benefits of deploying mamacare system were identified from brainstorming sessions, interviews and observations:

1. The hospital is capable of attending more clients resulting to reduced non-compliance and unfulfilled diagnosis, treatment and follow-up appointments.
2. Reviews from similar systems have demonstrated that mobile SMS alerts and reminders motivate clients' adherence to scheduled maternal programmes or interventions outcome.
3. The hospital can meet client's satisfaction through improved service delivery. From related work, this has demonstrated patients feel psychologically valued hence indirectly contributing to health outcome.
4. Computerization of recording and reporting workflow has the potential to improve staff morale due to reduced stress and fatigue experienced in performing tasks manually.
5. Availability and reliability of clinical reports such BP, blood sugar and Hb helps in making timely decisions or necessary corrective intervention.

In the next sections of this chapter we demonstrate how to implement *mamacare*, a context-aware mHealth prototype optimized to run in different execution environments including low-end mobile phones. Mamacare is also a context-aware system because it automatically generates event-based SMS alerts and clinical statistics depending on patient's demographic profile. Furthermore, the system is scalable because it can be extended to receive context information from biometric sensors depending on change in technology and stakeholders' needs. Mamacare is scalable because it can easily be tailored or extended to take advantage of broadband penetration in developing countries in order to enhance user experience and health management (ITU 2014). For example, functional specifications based on SMS interaction may be replaced or enhanced by using biometric sensors and rich mobile applications running on 3G and 4G networks.

3.4 Elaboration Phase

In AUP, elaboration phase is when requirements are specified in greater details to discover possible high-risk use cases for necessary mitigation. This requires a closer collaboration with primary stakeholders (caregivers and patients) to review, agree and come up with the best implementation strategy. During this elaboration phase, stakeholders were involved in transforming identified requirements into system models discussed in the next section.

3.4.1 Functional Modelling

In system modelling, use cases are used to visualize the functionalities the system will provide based on user requirements. Though we used several use cases to uncover requirements, we only illustrate samples of functions executed by *primary actors* namely patient, admin staff and caregiver. In functional modelling, we used *patient* for both maternal care client and patient, *caregiver* for clinicians and *staff* for administrative staff.

Staff Perspective

Figure 3.9 shows a sample use case diagram for outpatient and maternity subsystems for managing patient's clinical records consistent with clinical investigators record (CIR) ontology. More use cases were modelled for registration process of maternity subsystem.

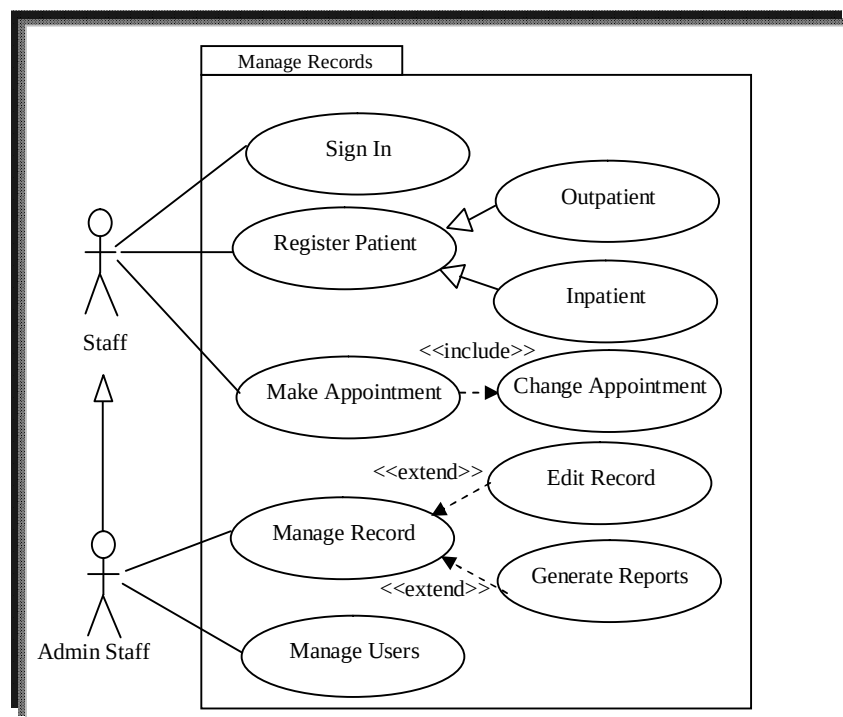


Figure 3.9: Mamacare Admin use case diagram

Caregiver Perspective

Figure 3.10 shows a sample use case diagram for functions performed by the caregiver such as a nurse to manage antenatal and postnatal patients. Though not shown, such a use case was further decomposed to show details of managing pregnancy and delivery services.

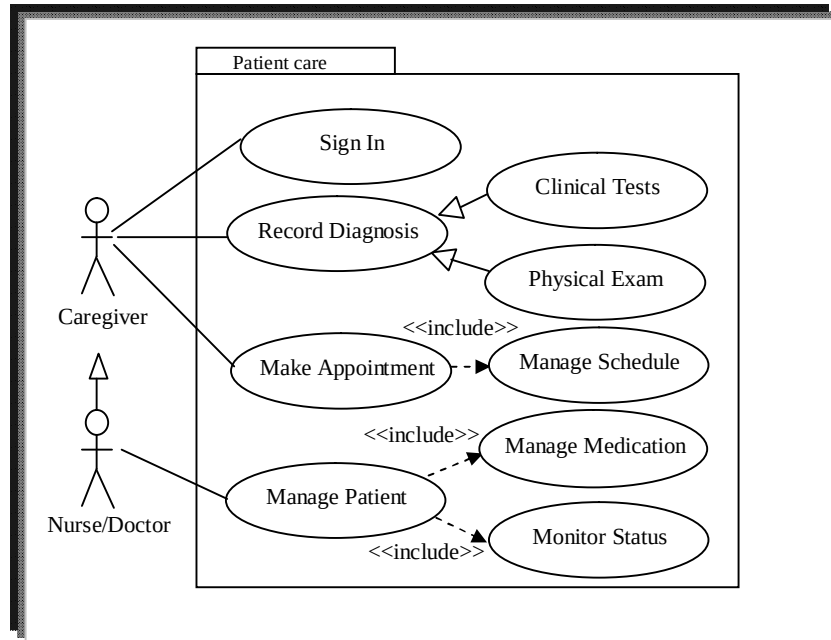


Figure 3.10: Mamacare Caregiver use case diagram

Patient Perspective

Figure 3.11 shows a use case diagram for SMS module that connects patients to the mamacare system. Such a use case was also used to model interaction of mamacare other stakeholders such as patient's next of kin in case of emergency or urgent need.

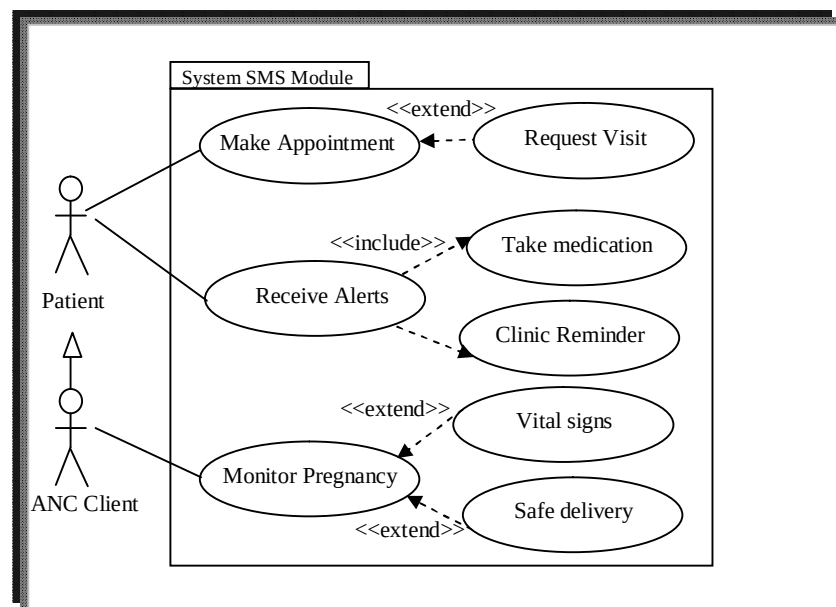


Figure 3.11: Mamacare Patient use case diagram

Sequence Diagram

The purpose of sequence diagram is to elaborate how the underlying objects in the system collaborate to achieve each of the use case. Figure 3.12 shows the sequence of interaction required to make appointment upon request by a patient.

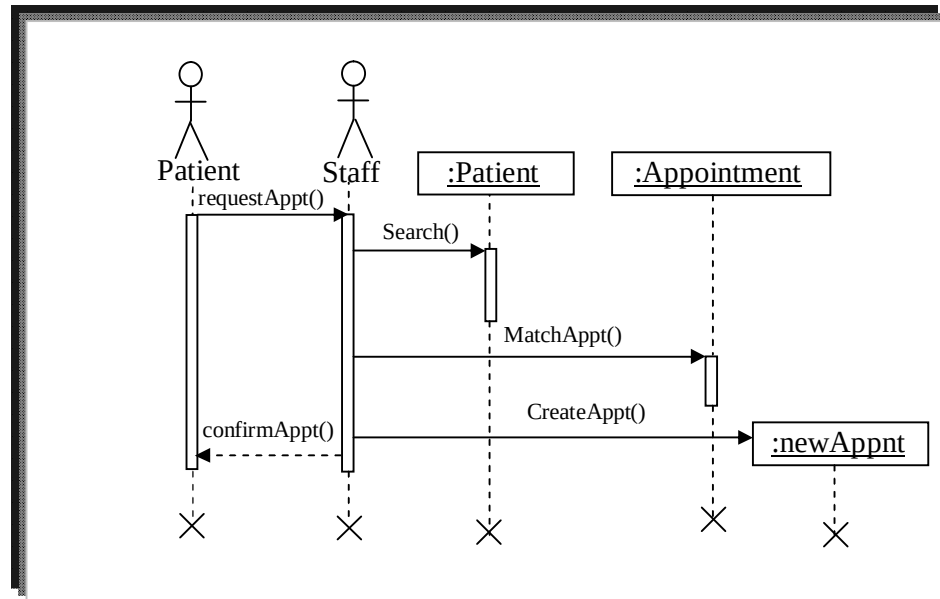


Figure 3.12: Patient appointment sequence diagram

Similarly, though not shown here, other interactions between objects depicted by the use case diagrams were modelled using sequence and activity diagrams.

3.4.2 Static Models

Static modelling also referred to as content modelling is concerned with the static view that describes collections of static objects whose information need to be stored by the system. This is where the Clinical Investigator Record ontology comes into play in modelling class and entity relationship diagrams depicting mamacare will be used to manage patients' health records.

Class Diagram

In mamacare the focus of interest is on patients with some attributes as antenatal (ANC) or inpatient (IP) identifier, name, phone number and address. Once a patient record has been created, it means that she can start receiving maternal care services such as clinical examination, counselling, and medication. Figure 3.13 shows the class diagram of mamacare application limited to the clinical information described in the CIR ontology.

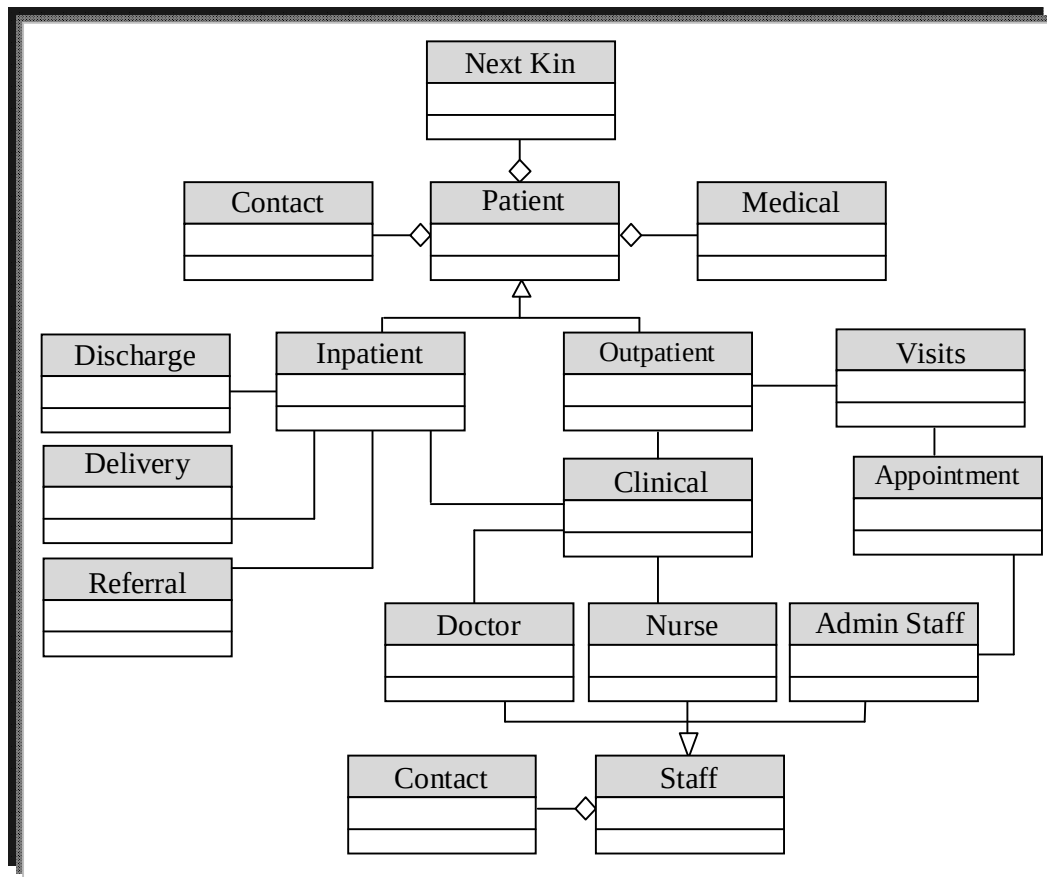


Figure 3.13: Mamacare class and data modelling

Database Schema

Though a better solution would be to map our classes to an OODBMS or ORDBMS, relational database management systems (RDBMS) are still the mostly widely available both commercially and as open source. Therefore, the approach used was to flatten the classes by defining the object states as attributes while the operations were implemented in application layer using server-side PHP web development language. The concrete classes are mapped into entity types while aggregation and association are defined as entity relationships.

In case of inheritance, inpatient and outpatient subclasses inheriting from patient super class are represented using super-type and subtype entities in relational database models. Figure 3.14 shows a normalized entity relationship diagram of the data model in crow-foot view that was designed using Oracle's MySQL Workbench.

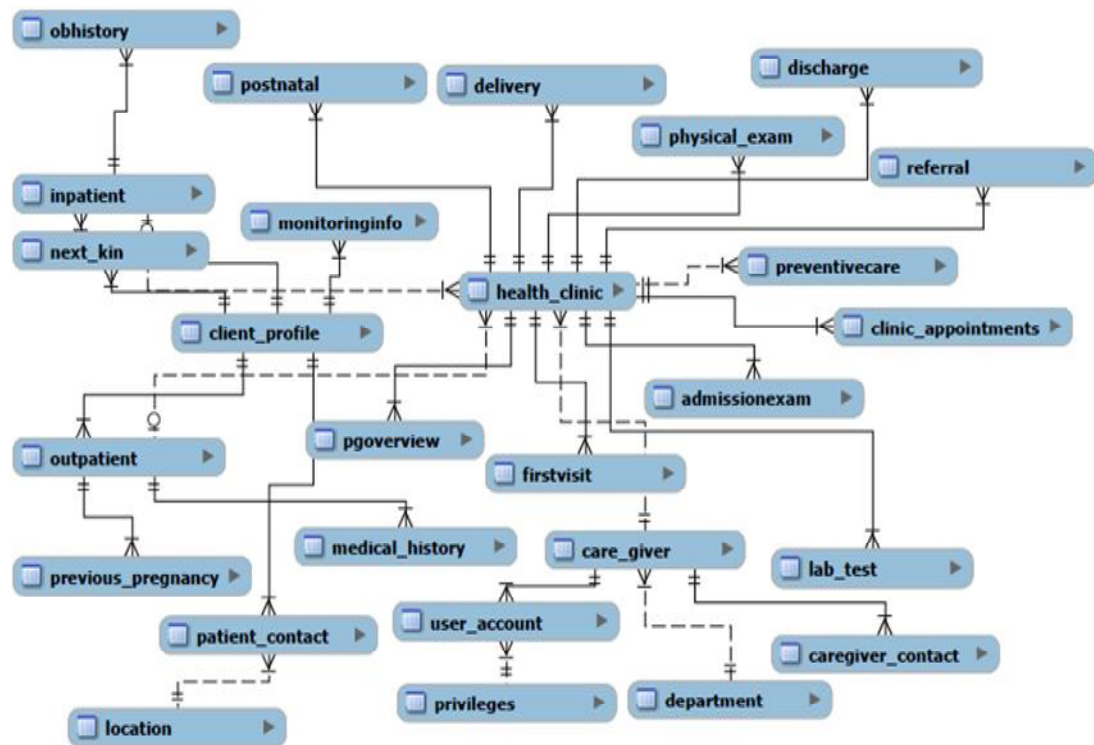


Figure 3.14: Mamacare entity relationship diagram

Navigation Model

In web engineering, navigation modelling of web applications comprises the construction of two navigation models, i.e. the navigation space model and the navigation structure model. The former specifies which objects can be visited through navigation while the latter defines how these objects are reached. *A well designed navigation structure helps avoid user disorientation and cognitive overload when using the application.* The navigation classes represent traversable nodes of the hypertext structure while the navigation links show direct links between navigation classes.

Figure 3.15 shows the stereotyped navigation model that represents the client-side navigation structure of mamacare web portal. The model presented in the diagram is modelled using horizontal navigation menus that are further divided into submenus. This navigation map makes it easy for the system users to navigate through data entry forms and clinical reports. The figure further shows how to extend each navigation class using the circled *AdminHome* class.

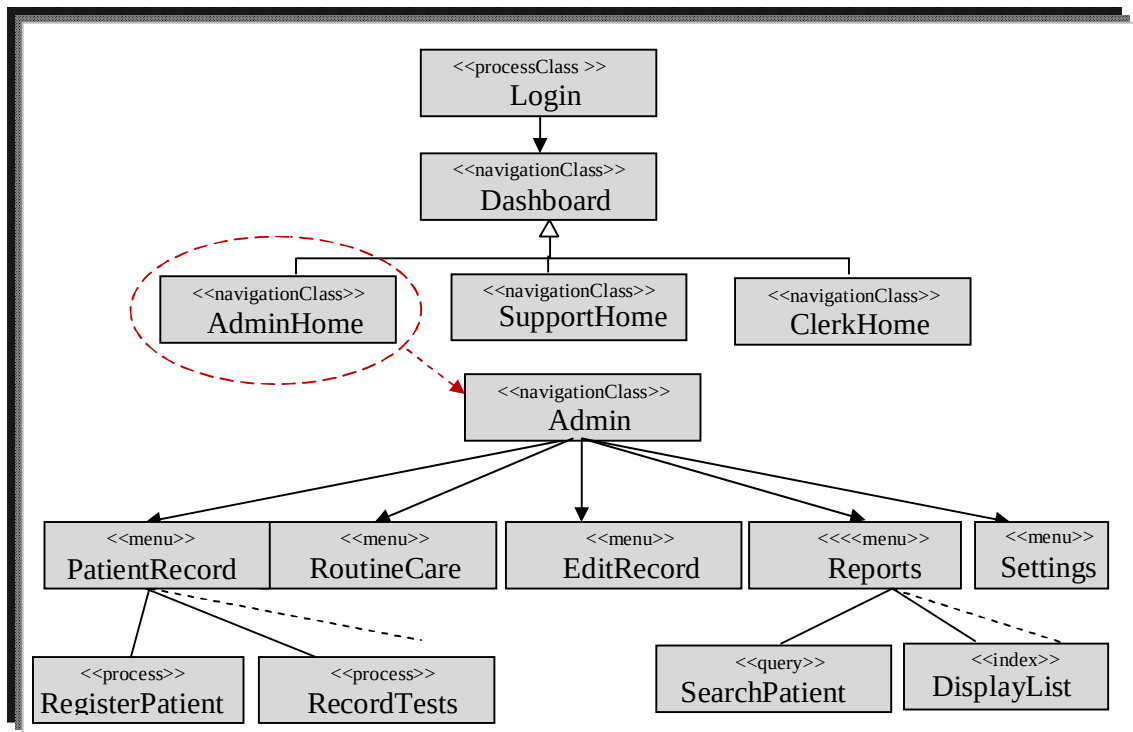


Figure 3.15: Mamacare navigation model

3.4.3 Responsive UI Design

Emerging trends in web engineering is responsive design of web applications that dynamically adjusts to different multiple platforms and device profiles. For example, when a user switches from a desktop to mobile phone, the website dynamically scales to fit into screen size, orientation and device resolution.

Home Screen

Figure 3.16 shows the template of mamacare application when loaded on a mobile phone. The page dynamically shrinks and the menu bar collapses to fit into a mobile phone viewport. This improves usability and user experience because the user does not have to scroll horizontally.

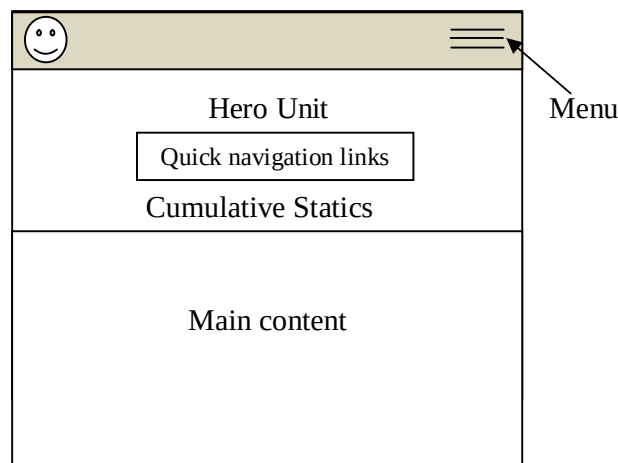


Figure 3.16: Mamacare view on mobile

Figure 3.17 shows how the same mamacare application would appear when loaded on a desktop PC or tablet in horizontal orientation.

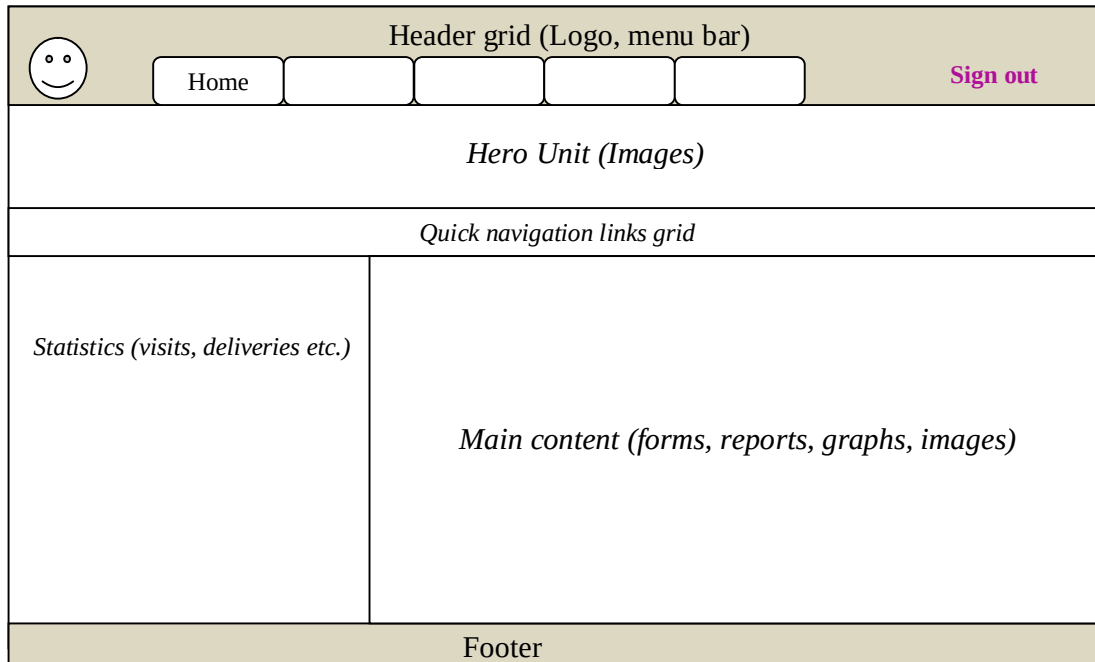


Figure 3.17: Mamacare view on desktop computer and tablets

Forms and Reports

Similarly, forms and reports were designed to dynamically adapt into multiple device profiles for a presentable content display and navigation. For example Figure 3.18 (a) shows how patient registration form would appear on a desktop computer or tablet while Figure 3.18 (b) show the same form on a mobile phone. Though not shown here, the same responsive behaviour applies to reports.

Figure 3.18 (a): Desktop and tablet form

Figure 3.18 (b): Mobile form

3.4.4 SMS-Alerts Considerations

Most developers of mobile applications that utilize SMS messaging protocol fail to consider the point of view of maternal care patients or their next of kin. This is why we conducted a pilot test on 28th to 31st January 2014. Following results of the pilot and the GSM SMS specifications, we came up with guidelines on how the messages should reach the patients or their next of kin such as the husband. Some of the considerations in designing SMS-based applications are:

- **Text density:** Though one SMS can be composed with up to 160 characters, we found that most respondents did not like long text messages.
- **Content:** Though short, SMS messages should be simple but clear and informative enough to the recipient. This requires careful choice of key words that best conveys the message.
- **Language:** Majority of the residents of Mwea have basic education up to secondary school level. This makes choice of language to be used important. Figure 3.19 on the left shows that out of 29 respondents 41.1% preferred English followed by Kiswahili at 34.5% and *Kikuyu* a common language in the region was chosen by 24.1%. To take care of those who may not be good in English, we settled on both Kiswahili and English while leaving use of local languages to specific cases.
- **Tone:** The tone used in a text message particularly in case of emergency like informing the next of kin about death should be carefully done to convey the message without raising anxiety.

Figure 3.19 on the right shows a draft design of how a clinic follow-up alert would be received by the client or next of kin taking into consideration the four SMS messaging guidelines.

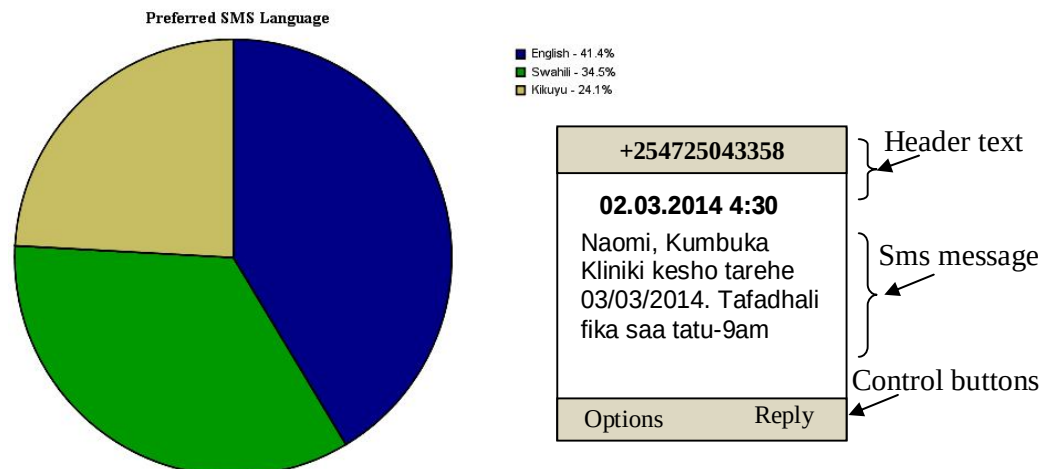


Figure 3.19: Mobile SMS design using preferred languages

3.5 Construction Phase

The focus of construction phase is to convert the system models into a system artefact ready for deployment. At this point, emphasis shifts from modelling to implementing or acquiring an artefact that satisfies stakeholders' needs. If necessary, early releases of the system may be deployed to obtain users' feedback.

At the end of this phase, the designer should hold a collaborative operational capability review with experts and primary stakeholders in order to assess the suitability and usefulness of the artefact. To implement *mamacare* models into a system artefact that is responsive to device profile and patient's context, the following web and mobile technologies were used:

1. *SMS Server Tools 3*: The mobile SMS module was implemented using SMS Server Tools 3, an open source UNIX-based SMS gateway. SMS Server Tools can support up to 64 redundant modems.
2. *HTML5, CSS3 and JavaScript*: For the caregiver's mobile web, HTML5, CSS3 and JavaScript (jQuery and Ajax) were used. JavaScript was used for client-side validation and enhancing user experience. To make the application adaptive to any device profile and most mobile browsers, a framework called twitter Bootstrap was used.
3. *XAMPP 1.8.1*: XAMPP is an open source distribution that comes with Apache server, MySQL, PHP and Perl. XAMPP was used to implement PHP, web server and database functionalities. For Rapid server side scripting, CodeIgniter was used to write PHP classes and methods.
4. *MySQL Workbench 5.2 CE*: For ease of physical implementation of mamacare database, MySQL Workbench from Oracle was used to forward engineer the database schema shown earlier in Figure 5.11 into MySQL server.
5. *Aptana Studio 3*: Aptana Studio is an open source integrated development environment (IDE) that supports web application development using HTML5, CSS3, JavaScript, Ruby, Rails, PHP and Python. This is the IDE environment we used to implement mamacare application.

3.5.1 Server-side Implementation

For server-side implementation, CodeIgniter framework was used to implement the models, controllers and views (MVC) software architecture. The framework made it easy to implement the system client-web server interactions and validation. Server side validation

is important because it blocks malicious cross-site scripting attacks in case JavaScript is turned off. The database design shown earlier in Figure 3.14 was forward engineered to MySQL using Oracle MySQL Workbench that allows forward and reverse engineering of entity designs and database schema respectively. The physical schema is attached in Appendix 8E.

3.5.2 Client-side Implementation

For client-side implementation, the tools used include JavaScript core and libraries such jQuery and Ajax to enhance user-experience, validation and blocking of malicious cross-site scripting attacks. To make the system responsive to device profile, we used Twitter Bootstrap that supports HTML5 and CSS3.

Caregiver's Dashboard

Mamacare portal has a user dashboard that is loaded as home page once the user enters correct login credentials. The appearance of the dashboard depends on the device used because *mamacare* dynamically adapts to fit onto the viewport depending on the device size and orientation. To simplify data entry and enforce integrity, Ajax and jQuery validation libraries were used. This approach optimizes the system response time because only in few incidences server-side validation is invoked.

During testing, we observed that whether on desktop computer, tablets and mobile phones, the login screen, the application loaded pretty fast and used very low bandwidth. Figure 3.20 (a) and (b) shows how the same form appears on desktop PC and mobile phone viewports. The forms are used for recording patient's next antenatal clinic appointment. Once a visit is recorded, the system automatically sends a reminder to them before the appointment is due. See Appendix 8D for more mamacare user interface samples.

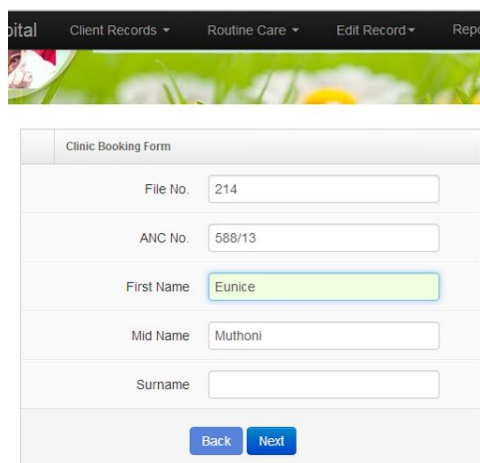


Figure 3.20 (a): Form on computer

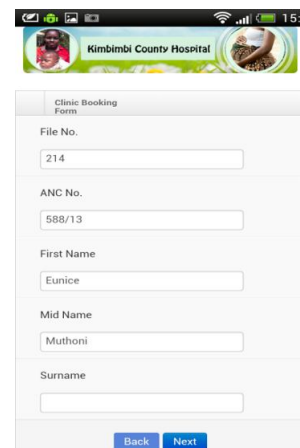


Figure 3.20 (b): Form on mobile

Patient-side SMS Service

An ordinary SMS message as specified by GSM 03.40 and GSM 03.38 documents can be made up of 160 characters, where each character consists of 7 bits. For privacy and cost reasons, instead of using commercial gateways, we implemented the SMS messaging module using an open source called SMS Server Tools 3 gateway. SMS Server Tools runs on UNIX environment to send and receive SMS messages through a GSM modem or mobile phone. A sample SMS Tools configuration script that handles incoming and outgoing messages is attached in Appendix 8F.

Incoming Messages

Mamacare has a PHP script that reads received SMS from a bash script and then extracts the phone number and payload message. Once the message is received, the SMS daemon executes an *eventhandler* that invokes a PHP method to compare the phone number against patients' contacts in the database. If the number is valid, the patient ID is used to insert the message into relevant database tables. The PHP script for validation and storage of received vital signs SMS is listed in Appendix 8F.3.

Outgoing Messages

Mamacare makes use of event scheduler and *cron daemon* to automate most application and database level operations. Cron daemon sleeps and wakes up to execute scheduled tasks such as sending SMS alerts to a particular patient using a *cronjob* entry. Figure 3.21 shows a test SMS message automatically sent by cron daemon through a modem using SMS Server gateway. The event scheduler is used at database level to manage records such as archiving, deleting and updating table records. The listing in Appendix 8F.2 shows the PHP script that creates SMS text file from an array fetched from relevant database tables.

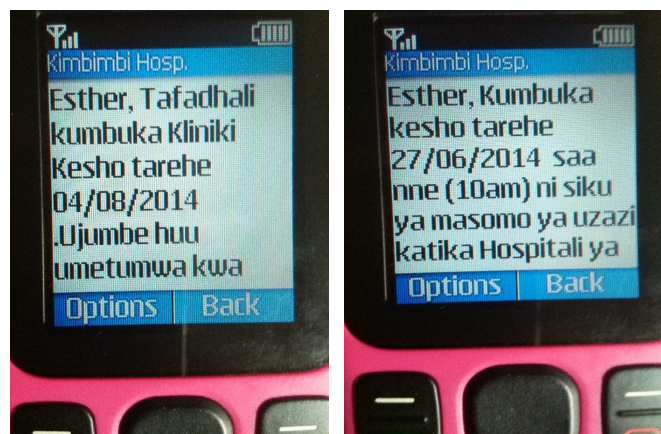


Figure 3.21: Sample sms-alerts from mamacare server

3.5.3 Security and Privacy

It is the responsibility of software developer to implement security mechanisms that protects integrity and privacy of patient records. Therefore, to safeguard patient privacy, protocol describing how to handle patient's privacy was submitted for approval to KNH/UON ERC and approved in November 2013 (attached in Appendix 6). This protocol binds us to enforcing security and piracy mechanisms that protects integrity and confidentiality of patient's health records.

To enforce system security and privacy in mamacare, we used HL7 Composite Security and Privacy Domain Analysis Model (HL7 2010). The model documents role-based access control and consent directives policy required to protect patient's privacy. In mamacare the following three user-access roles were implemented:

- Admin: Admin privileges are assigned to nurses, physicians or senior staff who plays crucial role in managing sensitive patient health records. This role gives a user full read/write to access patients' data.
- Support: This is a mini-administrative role that allows users with support privileges to access some read/write functionalities but have no access to patient reports. This is mostly applicable to IT support staff with no professional training on health sciences.
- Data clerk: Data clerk role is a role limited to tasks such as registering patients and entering clinic appointments.

To implement role-based access control, users are authenticated against assigned roles using encryption key and *SHA256 hashing algorithm* implemented using CodeIgniter method shown in the code listing attached in Appendix 8F.5. A session is then established after secure login that control the web pages and system objects a user is allowed to access. This role-based access control was implemented as follows:

- Dynamic menus: Depending on user's role, a dashboard loads with menu options accessible to authenticated login session. For example, an authenticated clerk dashboard does not display reports menu.
- Sessions: Each authenticated login is assigned a session to ensure that only that person holds the session key. If unauthenticated user tries to access the page directly the website redirects the user to the login page. Session-based security mechanism ensures that only registered users can get access to authorized patient records.

Due to sensitivity of patient health data, the system should transmit data in encrypted format using Secure Socket Layer (SSL) connection. This required acquisition of encryption certificate from a commercial Certificate Authority (CA).

3.6 Transition Phase

Transition phase is the final phase that primarily focuses on delivering the system into the production environment. The initial transition stage involved beta testing of mamacare prototype by experts and the end-users for possible errors and usability issues. Once the system was refined and installed, an elaborate training and support of the end-users was put in place. Finally, the system development team held a product release milestone review with the stakeholders to evaluate their satisfaction with mamacare. This was conducted using the instrument attached in Appendix 8C.

3.6.1 Mamacare Deployment

The UML deployment diagram of Figure 3.22 shows that mamacare was implemented as an integrated mobile web and SMS application that is adaptive to user profile.

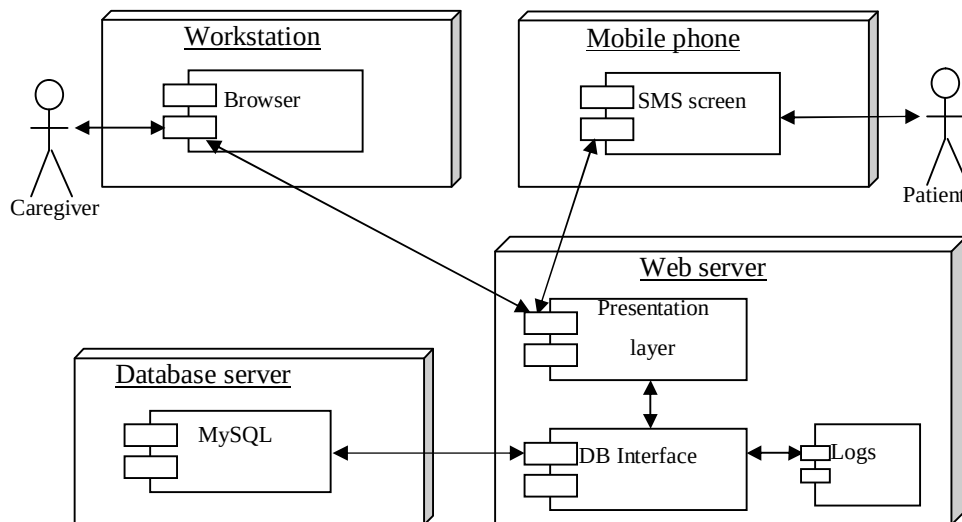


Figure 3.22: Mamacare deployment diagram

The diagram shows that both patients and caregivers sends or receives messages from the system. To send SMS alerts, the server periodically monitors on-demand, scheduled or time-based events. Figure 3.23 shows the physical architecture on which mamacare is deployed.

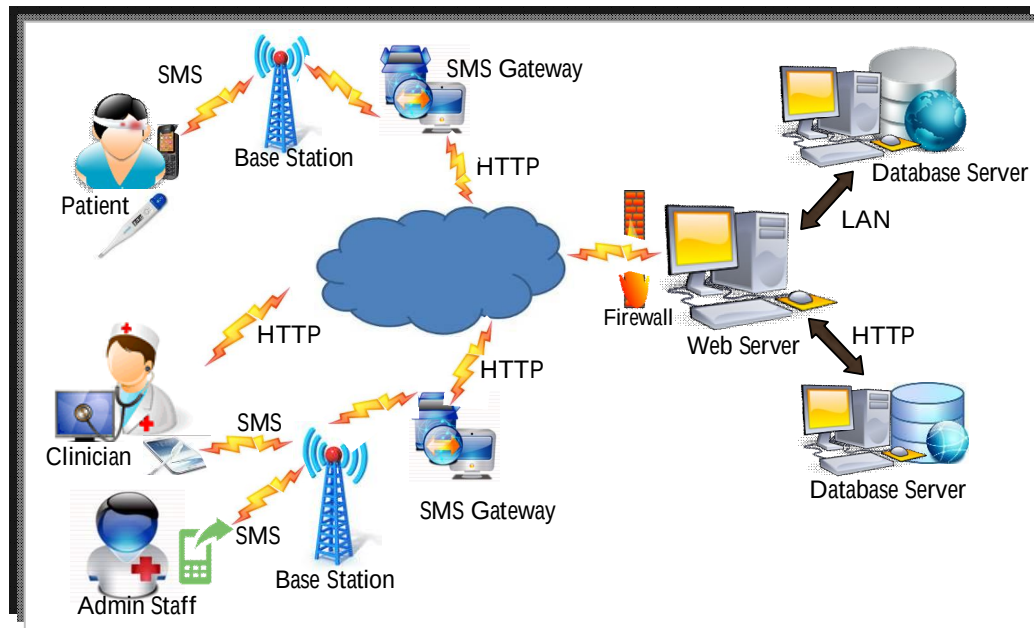


Figure 3.23: Mamacare physical deployment architecture

3.6.2 Prototype Testing

To ensure that mamacare is robust and meet patient's needs, beta testing was conducted at three levels namely unit, module and integration levels. During server-side and client-side implementation, modules, controllers and views were tested and errors corrected. Both the outpatient and inpatient subsystems were tested before integrating them into mamacare beta version. To ensure robustness, the beta version was thoroughly tested and piloted by the researchers, caregivers in Kimbimbi hospital, and system developers from School of Computing-UoN and Network Group in Technische Universität Dresden, Germany.

3.6.3 Training and Awareness

During pre-prototyping phase, we observed that most of clinicians have limited or no computer literacy skills. On the side of patients, though they were only required to use mobile phones to access *mamacare* services, a number of them did not have their own phones. Due to financial constraints and need to inculcate realistic use of mamacare, we did not provide patients with mobile phones but sensitized them on need to acquire one for convenience and privacy.

To equip selected caregivers with necessary skills, we held weekly training on basic computer applications in Microsoft Windows and internet services. During this period, we also trained them on how to use *mamacare* system. *Mamacare* is a web-based mobile

application that runs on both computers and portable devices as shown in Figures 3.24 below.

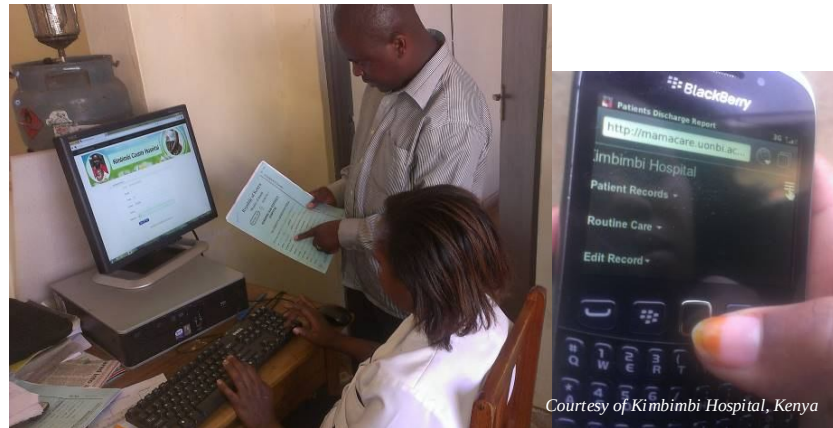


Figure 3.24: User training in maternity section

This training from proficiency skills to use of mamacare was observed to bear fruits because some caregivers decided to buy their own laptops to access the system at their convenience. This portrayed positive indicator of *technology acceptance*. To maximize on ease of use and user experience, we used iterative approach to test several user interface designs. This informed on the final mamacare prototype that has only one-level of dropdown menus and stepwise navigation forms.

3.6.4 User Acceptance Testing

Before mamacare was deployed, user acceptance testing that involved selected caregivers and patients was conducted to verify whether the system meets their needs and expectations. The chart of Figure 3.25 on the left shows responses from the nine caregivers (picture on the right) who evaluated mamacare system using instrument attached in Appendix 8A.

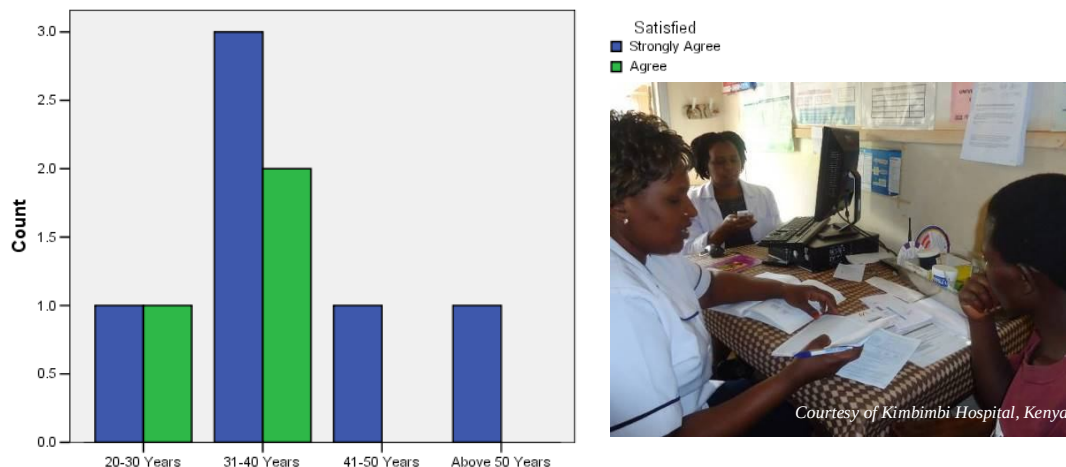


Figure 3.25: User acceptance testing on caregivers

Similarly, to get patient willingness to continue receiving SMS alerts and reminders, we conducted user acceptance testing using the instrument attached in Appendix 8C. Figure 5.23 on the left shows responses from 29 respondents (sample picture on the right) who had been enrolled to receive trial SMS alerts and reminders for at least a month. The pilot phase that ran between February and March 2014 informed on issues that needed to be addressed to make mamacare more responsive to the patient’s needs and expectations.

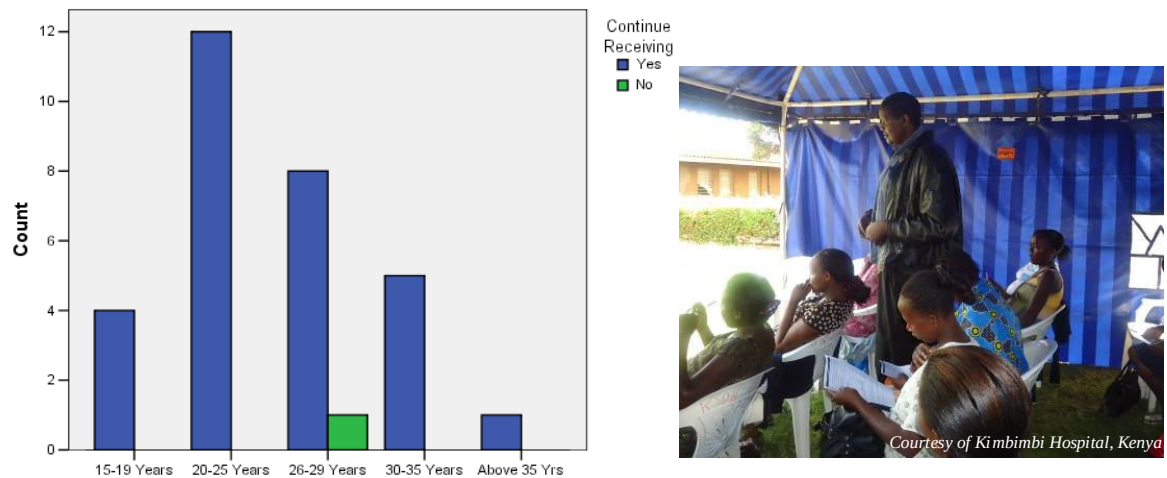


Figure 3.26: User acceptance testing on patients

“Translating evidence to actual practice requires a deliberate design approach, rather than relying solely on evolutionary haphazardness to human affairs”

CHAPTER 4

Methodology: Design of Experiment

4.1 Introduction

The purpose of this chapter is to highlight the experimental design used in this study to validate the model unveiled in chapter 2 and operationalized into blueprints for development of mHealth artefacts in chapter 3. We start by describing the design of repeated measure experiment, sampling criteria, data collection, design of data collection instruments and analysis. Finally, based on operationalized TIPFit model, we demonstrate how to apply predictive modelling using Partial Least Squares Structural Equation Modelling.

4.2 Experimental Design

In health informatics research, evaluation of impact of an intervention designed for specific healthcare may be evaluated using randomized clinical trials consisting of control and experimental groups. However, situations arise when randomization raises challenges of group-selection procedures and ethical issues. In such cases, quasi-experimental designs are often used to evaluate benefits of a specific intervention. However, quasi-experimental designs such as within-subjects designs suffer from internal and external validity due to:

- Attrition: Loss of subjects, noncompliance and poor response in longitudinal within-subjects study may produce biased outcome due to data loss before or after treatment.
- Instrument decay: In repeated measures design, if the same instrument is used over time, participants may become fatigued or bored. For example during the pretest when an idea is new and interesting, participants may be more realistic than during post-tests if the same tool is used.
- Maturation: Naturally, events occurring concurrently with intervention make it hard to justify whether the effect was really caused by the treatment.
- Regression towards mean: When sample units are selected from extreme scores, they often have less extreme subsequent scores, an occurrence that can be confused with effect of an intervention.
- Cross-over effect: Depending on time allowed or treatment conditions between repeated observations, cross-over effect causes current treatment condition or time point to influence observations from subsequent treatment conditions or levels.

Despite these shortcomings in quasi-experiments, Harris et al. (2006) observed that most clinical experiments make use of before-and-after quasi-experiments to investigate causal effect of treatment(s).

Repeated measures design is used whenever multiple observations on the same experimental unit are to be collected at different time points or treatment conditions. For example, in a clinical experiment, a pregnant woman suffering from hypertension may be assigned to a special follow-up programme in which her blood pressure (BP) is repeatedly measured in a day or within a week. The observations obtained from such multiple BP measures may be analysed to decide whether further intervention is required.

In this study, we employed repeated measures design to predict the effect of independent variables on fit that subsequently influences utilization of mHealth artefacts. In the context of this study, evaluation of fit was based on use of mobile phones to enhance maternal care services in low-resource settings. This approach was deliberately meant to discover best strategies that can be used to configure low-end medical and mobile devices to provide maternal care services in a rural setup characterized by poor infrastructure, inadequate caregivers, lack of medical facilities, and illiteracy.

Because randomization was not practically viable, multiple observations in a distributed time lag enhanced reliability of our cause-effect conclusions. Furthermore, repeated measures designs such as within-subjects are desirable in clinical and social environments where true randomization may raise political, ethical or legal issues.

4.2.1 Within-Subjects Design

In this study, the experiment was designed to compare predictions before an intervention, and experience after exposing the same subjects. After setting up the experiment, a pretest was administered on subjects to get their opinion on use of mobile phones in maternal care. One month later after exposure to treatment, the first post-test was conducted on the subjects to get feedback on effect of the treatment. Later after three months, a second post-test was conducted to get their reaction after prolonged exposure to treatment and more services. Figure 4.1 below shows how the model was used to evaluate effect on the dependent variable (technology utilization) in a time lag distributed to three months to minimize crossover effect.

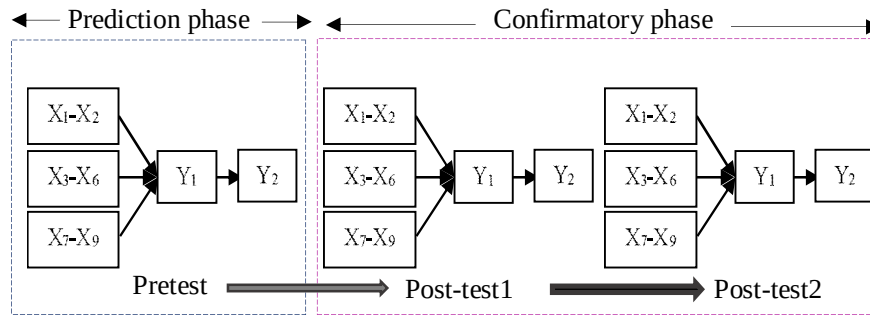


Figure 4.1: Repeated measures experimental design

NB: X_1 - X_2 are individual characteristics constructs; X_3 - X_6 - process requirements, X_7 - X_9 are technology functionality, Y_1 fit and Y_2 tech. utilization as shown in Figure 4.1.

Table 4.1 shows how the eleven constructs of TIPFit model were measured in the repeated measures experiment for structural equation modelling and pairwise comparisons between sample means. This approach of taking a pretest before exposing the cohort to experimental treatment helped in evaluating predictive power of TIPFit model.

Table 4.1: Repeated measures design

Concept Measured	Pre-test: June 2014	Treatment: June-August 2014	
	Test0: June-79 Subj	Test1: July-75 Subj	Test2: Aug-73 Subj
Attitude	A_0	A_1	A_2
Efficacy	E_0	E_1	E_2
:	:	:	:
Utilization	U_0	U_1	U_2

This timespan between observations is important because in repeated measure designs, the control conditions are the subjects themselves and time. Though there were limitations of using this approach such as attrition from 79 subjects in June 2014 to 73 in August, this experimental design is superior because:

- The pretest and multiple post-test observations on experimental subjects minimized chances of committing Type I error by maximizing reliability and internal validity from multiple observations
- In situations where randomized experiments are impractical, repeated measures are more powerful in confirming persistence of causal effect hence minimizing variance due to random error.
- Unlike cross-sectional surveys which require large sample sizes to achieve statistical power, repeated measures designs requires fewer subjects.

4.2.2 Experiment Procedure

The following procedure was used to conduct the repeated measures experiment:

1. On the patient's side, participants were randomly selected from a finite population of registered prenatal and postnatal clients using education, gravid, age, ethnicity and ownership of a mobile phone as inclusion criteria. Regarding caregivers, though their responses were not our primary focus, we purposively selected 25 caregivers from MCH section of Kimbimbi County Hospital.
2. After sampling, we conducted initial awareness seminar in which participants were trained by the caregivers on danger signs, nutrition, family planning and preventing mother to child transmission (PMTCT) of HIV (PMTCT). Before the end of the seminar, we exposed the participants to benefits and limitation of using mobile phones and self-monitoring medical devices.
3. Before closing the seminar, we administered a pretest on participants using a questionnaire attached in Appendix 3. The purpose of the pretest was to establish a baseline measure and perceptions of the participants on use of mobile phones in antenatal and postnatal care.
4. One week after analysing responses from the pretest, we exposed the subjects who consented to receive mobile alerts to the experimental treatment. Each subject demographic details were used to post alerts tailored to patient's needs.
5. Later, we conducted two post-tests to evaluate patient's evaluation of fit as a determinant of utilization of maternal care artefact. This was followed by a comparative analysis between the pretest results and consolidated post-test results. This comparative analysis required use of predictive modelling techniques such as Partial Least Squares (PLS) and statistical inferences such as repeated measures ANOVA and Bonferroni pairwise comparison between means.

4.2.3 Sampling Criteria

Two important considerations when evaluation cause-and-effect in intervention studies are the sample size (n) and statistical power ($1-\beta$). For more on sampling, see Cohen (1992); Goodhue, Lewis and Thompson (2006); and Overby and Konsynski (2010). To get a representative sample (cohort), we used simple random sampling taking into consideration education, ethnicity, gravid, age and ownership of a mobile phone. To get the minimum sample size sufficient for detecting small and medium effect (f^2) as recommended by Cohen (1992), we used the formula for finite population (Chin & Newsted 1999; Kothari 2004).

$$n = \frac{z^2 \times p \times q \times N}{e^2 (N - 1) + z^2 \times p \times q}$$

$$n = \frac{1.96^2 \times 0.02 \times 0.98 \times 226}{0.02^2 (226 - 1) + 1.96^2 \times 0.02 \times 0.98} = 102$$

NB: n = sample size; z = critical value at 95% confidence; p = sample proportion based on experience; N is a finite population; e is 2% acceptable estimation error, and q = p – 1.

Though a cohort of at least 100 subjects was required, Overby and Konsynski (2010) demonstrated that a sample size of about 60 participants is sufficient to detect small and medium effect sizes. A Monte Carlo simulation by Goodhue, Lewis and Thompson (2006) demonstrated that a sample of 40 subjects is sufficient to achieve reliable PLS results. This is also supported by several simulations that indicate that a minimum sample of 30 observations is sufficient for the Central Limit Theorem (CLT) to hold. Therefore we were satisfied with a sample of 79 subjects that were recruited after the pretest. These 79 subjects were later exposed to experimental treatment which entailed receiving mobile alerts such as appointment reminders, safe delivery, danger signs and preventive care.

4.2.4 Cohort Preparation

Before conducting the pretest (T_0), a formal training workshop dubbed “*Maternal Health Education Day*” was conducted on 79 antenatal and postnatal clients shown in Figure 4.2 below. Based on Cohen’s (1992) recommendation for minimum sample size, and a Monte Carlo simulation by Goodhue, Lewis and Thompson (2006), a sample of 79 subjects was sufficient to detect between small effect (0.02) and medium effect (0.15) in our experiment.



Figure 4.2: Study cohort in Kimbimbi Hospital

During the two-hour workshop, the participants were taken through maternal care best practices such as danger signs, safe delivery, breastfeeding, nutrition, family planning, and HIV/Aids. After training on maternal care services, we were given a chance to sensitize them on personalized care through use of mobile and low-cost clinical devices such as Doppler and BP monitor.

After the study, the participants who filled consent forms such as shown in Appendix 4 to participate in our experiment were recruited and their health records entered into mamacare system. To identify each subject uniquely, their forms were marked with unique IDs such as A03 that matched a serial number on the attendance list. For privacy reason, this ID was only meant to track subsequent responses from the participants during the experiment treatment. For confidentiality, the subject's electronic medical records stored in our database server were maintained by the principal researcher and caregivers who have administrative access to mamacare system.

4.2.5 Ethical Considerations

Given that this study involved human subjects, medical ethics and practice required the researchers to uphold human rights, privacy, informed consent, and protection against physical, psychological and social risks. In this regard, a research protocol submitted to Kenyatta National Hospital/University of Nairobi Ethics Research Committee (KNH/UON-ERC) was approved on 26th November 2013. Later, we submitted the protocol and letter of approval from KNH/UON-ERC to the Ministry of Health headquarters. The Ministry gave approval to collect data in Kiambu County and Kirinyaga County as we had requested. The two approval documents are attached in Appendix 6 and 7. In the submitted protocol we addressed concerns on ethical issues that might arise from research conducted in a clinical environment involving human subjects. The following is a sample extract from the protocol highlighting key ethical considerations to participants' rights, safety, self-beliefs and privacy.

Risks and Benefits

Potential risks involved in participating in this research as well as benefits expected by the participants have been identified for management during the experiment. The goal is to minimize potential physical or psychological harm while maximizing potential healthcare benefits.

Human rights

The researcher will ensure protection of human rights regarding ethical principles of autonomy, beneficence and justice. In case subjects' identities are to be undisclosed, anonymous questionnaires will be used. Moreover, participants will have the right to withdraw at any time without penalty.

Informed consent

It is essential that subjects who serve as respondents in a scientific research provide informed consent either explicitly or implicitly. In this study, information that must be printed on consent forms (see Appendix 4) is obtained from the formal guidelines provided by KNH/UoN-ERC.

4.3 Data Collection Methods

The following is a brief highlight of data collection methods that were employed in this study since the start with a pre-study fieldwork in June 2012:

- *Questionnaires*: Two types of questionnaires were used to capture responses mainly from patients. During pre-prototyping phase, selected caregivers filled questionnaires that guided our design process. Responses from these questionnaires were integrated within prototype development chapter.
- *Face-to-face interviews*: We conducted structured and unstructured face-to-face interviews with patients and caregivers in order to investigate their needs, expectations and suitability of using mHealth interventions.
- *Shadowing*: By observing caregivers and patients, we captured their daily routine in order to understand the perspectives and complex relationships between them that need to be considered in mHealth design and implementation.
- *Focus group discussions*: Focus groups discussions were conducted with caregivers and patients to understand their social and behaviour patterns. The participants contributed to various standpoints regarding feasibility and challenges of integrating mHealth into healthcare processes.
- *Clinical documents study*: To align the mHealth design specifications and functionalities to clinical workflow, we reviewed several maternal care documents such as admission registers, antenatal/postnatal booklets, clinic follow-up registers and other documents relevant to pregnancy, delivery and postnatal care procedures.

4.4 Operationalizing TIPFit: Measurement Indicators

To evaluate effectiveness of mHealth interventions, it is important to use reliable measurement indicators. Similar to approach used to operationalize TIPFit into prototyping blueprints, in this section; we mapped each construct onto concepts, dimensions and measurable indicators. The indicators were used to develop data collection instruments shown in Appendix 2 and 3.

Though our focus was on patients' access to maternal care, the model also provides metrics that are useful in measuring caregiver's perspective on service delivery. Where applicable in summary tables, we have used *future/current* tenses depending on the time of measurement. For example "I would/like getting reminders" means: "*I would like getting reminders*" is used during pretest while "*I like getting reminders*" is used during post-tests. For operational definition of dimensions, see Appendix 1.

4.4.1 Individual Characteristics

In our empirical context, individual characteristics were operationalized using Davis (1989) measures of perceived usefulness and ease of use, Ajzen's (1991) measures on attitude and behavioural control, Compeau and Higgins (1995) computer self-efficacy, Goodhue (1998) TTF measurement indicators, Venkatesh et al (2003) UTAUT instrument, Overby and Konsynski's (2010) measurement instrument and metrics from ISO/IEC 25010:2011 (2011) standard for software and systems quality.

Attitude Indicators

Though the operational definition of attitude is relative, in our context, attitude was operationalized using three dimensions namely usefulness, beliefs, and effectiveness. During pretest and post-tests conducted on sampled respondents, the three dimensions may be measured using indicators shown in Table 4.2 at the end of this sub-section.

Self-efficacy Indicators

Self-Efficacy concept was operationalized using three dimensions namely literacy, ease of use and confidence. Each dimension was measured using indicators shown in Table 4.2 below. In summary, Table 4.2 demonstrates how the two concepts of individual characteristics are operationalized using dimensions and indicators for pretest and post-tests evaluations on experimental subjects. For sample instruments, see Appendix 2 and 3.

Table 4.2: Dimensions and indicators of individual characteristics

Concept	Dimension	Pre-test /Post-tests Indicator	
		Client/Patient	Caregiver
Attitude	Usefulness	Use of mobile phone in antenatal and postnatal can be/is useful to me	Use of computers and mobile phones in maternal care services can be/is useful
	Beliefs	Use of mobile phone can/make(s) MCH improve service delivery	Use of computers and mobile phones can enhance service delivery to clients/patients
	Effectiveness	Use of mobile phone in maternal care can/help(s) adhere to clinic schedule	Using mobile-based services can/enhance(s) patients and clients adherence to intervention
Self-Efficacy	Literacy	Because of my level of education, I easily learn how to use a mobile phone	Due to my basic computer literacy skills, I can/easily learn how to use a maternal care system
	Ease of use	I have necessary skills in using a mobile phone to read, write and send SMS messages	I would like a maternal care system that is/because it's easy to use (<i>pre-test</i>) I find the care system easy to use
	Confidence	I'm comfortable using a mobile phone to access money transfer services (pre) I'm comfortable using a mobile phone to read SMS sent to me (post)	I'm confident in my ability to use a computer to record and manage patient health records

4.4.2 Process Requirements

To operationalize process requirement constructs, we used our experience from our pre-study and extensive consultation with health professionals and academia. Further, we adapted some indicators from Overby and Konsynski (2010) instrument and ISO/IEC 25010:2011 (2011) SQuaRE metrics.

Sensory Requirements Indicators

In our pre-study, it was evident that sensory experience is the most demanding and difficult requirement to replicate in clinical processes. However, despite difficulties of implementing sensory requirements in our study context, we tried to get perceptions on how mobile devices can be configured to realize some form of sensory experience. Hence, we operationalized the construct using see, touch and hear with indicators listed in Table 4.3 at the end of this sub-section.

Relationship Indicators

Due to poverty and illiteracy, there is a wide gap between patients and caregivers in low-resource settings. This makes the interaction between patients and caregivers more of a master-servant relationship. Therefore, we operationalized relationship using accessibility, rapport and harmony whose indicators are listed in Table 4.3 at the end of this sub-section.

Identification and Privacy Indicators

The concepts “identification” and “privacy” are inter-related because a patient would not share sensitive health information unless she is certain of identity of the caregiver. Therefore, we deliberately used the same dimensions for the two concepts namely authenticity, trust, consent and confidentiality shown in Table 4.3.

Synchronism Indicators

Poor connectivity and unreliable power supply in most rural areas affect fit of mHealth interventions that immediate feedback or real-time interaction. In this context, synchronism was operationalized using timeliness and responsiveness as shown in Table 4.3. In summary, Table 4.3 shows how the concepts of process requirements may be operationalized using context specific dimensions and indicators necessary for observation of patients and caregivers. See sample instruments used in Appendix 2 and 3.

Table 4.3: Dimensions and indicators of process requirements

Concept	Dimension	Pre-test/Post-tests Indicator	
		Client/Patient	Caregiver
Sensory	See	Use of mobile phone can/minimize(s) need of going to hospital to see caregiver	I believe use of mobile phone services can reduce workload
	Touch	I would be/interested in checking my conditions e.g. BP, bleeding and send observations to hospital via mobile;	I would/like a system that maintains client's vital signs e.g. Hb, BP immediate action
	Hear	I would/like getting advice through phone instead of going to ask a caregiver	Use of mobile can sensitize can/reduce(s) complications
Relationship	Accessibility	In case of health issue, I've no problem a caregiver contacting me through mobile phone	Use of system can/enhance(s) relationship between caregivers and clients/patients
	Rapport	I believe use of mobile phone services can/improve(s) relationship with medical staff	In case of urgent issue, a system should/ easily help(s) contact patient/next of kin
	Harmony	Use of mobile phone can/help(s) in updating caregiver on health status	I would/like a system that helps in getting up-to-date information
Identity and Privacy	Authenticity	I can/easily distinguish genuine SMS and calls and those received from suspicious source	The system should/receive(s) messages only from registered patients/clients
	Trust	If my record is to be in a computer, it should be available to people I trust MCH should handle my records stored in the computer as confidential (post)	I can use a system if I'm sure it does not violate patient confidentiality
	Consent	I would like to be/was consulted in order to receive SMS messages from MCH	The system should/send(s) SMS messages to patients who give verbal or written consent
	Confidentiality	I would/accept to receive or send SMS if/because my privacy is protected	I can/use the system if assured/I trust patient privacy is protected
Synchronism	Timeliness	I would like to/ receive clinic reminders in good time enough to prepare for visit	The system should/send(s) SMS messages at convenient time
	Responsiveness	I would/appreciate getting timely info e.g. danger signs via mobile phone	The system should be/is fast and efficient in processing crucial clinical documents

4.4.3 Technology Functionality

In this study, the scope of technology functionality is limited to mHealth artefacts. The three concepts were operationalized using measurements indicators adapted from Goodhue (1998); Davis and Venkatesh (2004); Strong, Dishaw and Bandy (2006), Overby and Konsynski (2010), ISO/IEC/IEEE 29148:2011 (2011) and ISO/IEC 25010:2011 (2011) SQuaRE metrics.

Representation Indicators

Though representation is an abstract concept, in our context we used the concept to measure the capability of mHealth to replicate physical workflows in maternal care processes. Such workflows include registering patients/clients, follow-up and recording of clinical observations as documented in Clinical Investigator Record (CIR) ontology. Therefore, we operationalized representation using format, content and workflow dimensions as shown in Table 4.4 at the end of this sub-section.

Reach Indicators

To operationalize reach, we used two dimensions namely; convenience and reliability. The purpose was to investigate whether mobile phones can enhance patient's access to maternal care services and information. Similarly, the dimensions may be used to evaluate caregiver's perspective on suitability of mobile-based interventions to reach patients in case of urgent need. Indicators applicable to both perspectives are listed in Table 4.4 at the end of this sub-section.

Monitoring Indicators

To evaluate fit of mHealth artefact in patient monitoring, two dimensions may be used i.e. consistency and sufficient data, each measured using indicators shown in Table 4.4.

In summary, Table 4.4 illustrates how technology functionality of representation, reach and monitoring were operationalized using context specific dimensions and indicators. For sample data collection tools used during the pretest and post-tests, see Appendix 2 and 3.

Table 4.4: Dimensions and indicators of technology functionality

Concept	Dimension	Pre-test/Post-tests Indicator	
		Client/Patient	Caregiver
Representation	Format	I would like to/receive messages in my preferred language	The system features and flow should be/ are consistent with workflow tasks
	Content	Content of SMS messages I receive should be/are easy to understandable	The system should/provide(s) clinical reports for intervention and decision
	Workflow	I would/like getting SMS reminders	The system should/is consistent

		relevant to current clinic follow-up programme	with the client/patient follow-up clinic
Reach Reach	Availability	Mobile phone services provided by MCH should be/are always available	For better access, the system should/ run on mobile for use anywhere/during power failure
	Convenience	Use of mobile phone should/improve(s) access to antenatal/postnatal care	Use mobile phone should/ help sensitize clients/patients on preventive care
	Reliability	MCH should/make(s) it possible to access vital info via mobile phone	The system should /provide better access to maternal care
Monitoring	Consistency	Regular and timely use of mobile services can help prepare for safe delivery	The system generated alerts should be/are consistent with current patient's care plan
	Sufficient data	Mobile alerts should be/sufficient to help in monitoring my own/baby's health progress	I would/like a system that provides sufficient info to help monitor clients

4.4.4 Fit and Technology Utilization

For assessment of user-perception on Fit and Technology utilization, we used similar approach to that of Goodhue (1998), Strong, Dishaw and Bandy (2006), and Overby and Konsynski (2010). Though this implied conflating fit, we argue that measuring fit and technology utilization as first-order variables was essential because evaluating them otherwise would not explain qualitative and quantitative effects which are equally important.

In this regard, fit was measured using suitability and expectation while technology utilization was evaluated using satisfaction and “continued use”. Table 4.5 below shows a summary of dimensions and indicators that may be used to operationalize the two concepts. See sample instrument in Appendix 2.

Table 4.5: Dimensions and indicators of fit and technology utilization

Concept	Dimension	Pre-test/Post-tests Indicator	
		Client/Patient	Caregiver
Fit	Suitability	I hope/use of mobile phone services will be/ is suitable to my healthcare needs	Computer mobile should be/is suitable for providing maternal care
	Expectation	I believe/use of mobile phone will/meet(s) my expectation.	I believe use of technology will/help meet patient's needs and expectations
Technology Utilization	Satisfaction	Overall, I would recommend the idea of use of mobile phones in maternal care	I would/appreciate using IT to manage patients/clients records
	Continued use	I would/appreciate getting maternal care services via my mobile phone	I would/ like to use technology to enhance my personal and work profile in hospital

4.4.5 Operationalizing TIPFit: Hypotheses

In this chapter we operationalize the model into a concrete data collection tool using testable hypotheses measurable indicators. To test the relationships P_1 to P_{10} shown in

Figure 4.3, we formulated ten sub-hypotheses for analysis using Partial Least Squares Structural Equation Modelling (PLS-SEM).

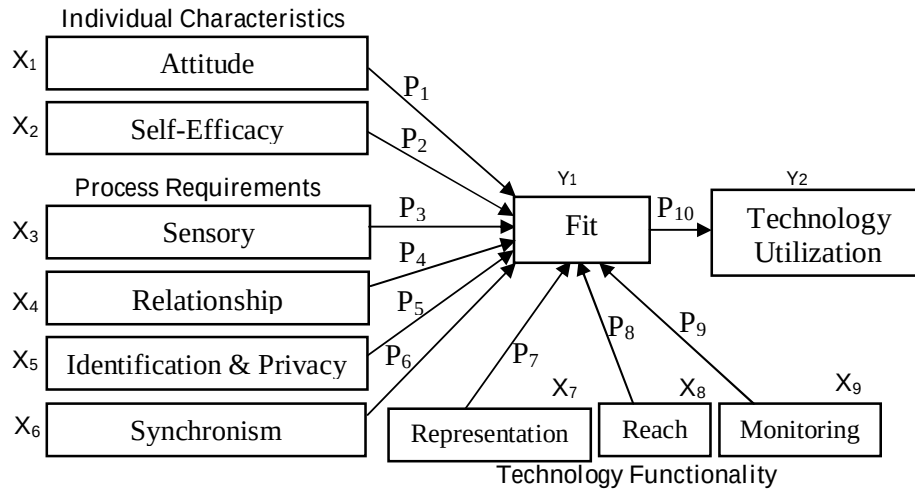


Figure 4.3: TIPFit predictive modelling

P1: Attitude

The abstract nature of attitude makes it difficult to provide specific measures because expected outcome depends on the goal of the study. In this study, attitude was limited to evaluating patients and caregivers judgement on technology use in maternal care. Therefore, we hypothesize that:

P₁: Attitude towards technology has no significant effect on fit of mHealth intervention

P2: Self-efficacy

The Self-efficacy is not a directly measurable concept because perception of one's competence and ability to perform a specific task. This is why we limited the scope of Self-efficacy concept to evaluation of patients and caregivers ability to use mobile devices or computers to accomplish a task. Hence, we posit that:

P₂: Self-efficacy on using mobile devices or computers has no significant effect on fit of mHealth intervention

P3: Sensory requirements

In maternal care processes involving clinical examinations and treatment, sensory experiences of touch, smell, taste, sight and aural may be required. This makes it difficult to deploy mHealth applications that are fit for such processes. We hypothesize that:

P₃: Sensory requirements of touch, sight and aural experience have no significant effect on fit of mHealth intervention.

P4: Relationship

This construct measures degree to which mHealth artefacts can provide sufficient remote interaction between patients and caregivers through mobile phones. This is tested using the following proposition:

P₄: Relationship requirement between patient and caregiver has no significant effect on fit of mHealth intervention

P5: Identification and privacy

Identifying each other in a patient-caregiver encounter is crucial in establishing mutual trust in order to share sensitive health information. Without certainty on identity claim, a doctor or patient hesitates to share sensitive information through mobile phone to safeguard privacy. Thus we hypothesize that:

P₅: Identification and privacy requirements between patient and caregiver have no significant effect on fit of mHealth intervention

P6: Synchronism

There are some healthcare processes that require immediate feedback or attention by the caregiver. This suggests that mHealth artefact can be perceived as fit if a patient in urgent need can get timely intervention. Therefore, we hypothesize that:

P₆: Synchronism requirement of time-constrained processes has no significant effect on fit of mHealth intervention

P7: Representation

In the context of this study, representation measures degree to which an artefact can provide required information and services without physical encounter between patients and caregivers. Hence, we postulate that:

P₇: Representation capability of mHealth artefact has no significant effect on perceived fit

P8: Reach

In TIPFit model, reach measures the degree to which mHealth artefacts enable patients and caregivers get access to maternal care from anywhere any time. Hence we posit that:

P₈: Reach capability of mHealth artefact has no significant effect on perceived fit

P9: Monitoring

One of the limitations of electronic monitoring is violating patient's privacy. For example, an antenatal client undergoing antiretroviral (ARV) therapy may not trust use of mobile phones in receiving alerts on adherence to therapy. Thus, we posit that:

P₉: Monitoring capability of mHealth artefact has no significant effect on perceived fit

P10: Technology Utilization

Technology utilization is posited to be influenced by perceived fit of an mHealth intervention. The effects of hypothesized relationships P₁ to P₉ are used to compute the path weights (P_i). Subsequently, fit determines technology utilization tested using sub-hypothesis P₁₀ that states:

P₁₀: Fit has no significant effect on utilization of mHealth artefact in low resource settings

Table 4.6 below gives a summary of the main constructs, operationalized concepts and testable sub-hypotheses used to draw conclusion on cause-and-effect.

Table 4.6: Hypothesized cause-and-effect relationships

Main Construct	Concept	Pi	Sub-hypothesis
Individual Characteristics	Attitude	P1	Attitude towards technology has no significant effect on fit of mHealth intervention
	Self-Efficacy	P2	Self-efficacy on using mobile devices or computers has no significant effect on fit of mHealth intervention
Process Requirements	Sensory	P3	Sensory requirements of touch, sight and aural experience have no significant effect on fit of mHealth intervention.
	Relationship	P4	Relationship requirement between patient and caregiver has no significant effect on fit of mHealth intervention
	Identification and Privacy	P5	Identity and privacy requirement between patient and caregiver has no significant effect on fit of mHealth intervention
	Synchronism	P6	Synchronism requirement of time-constrained processes has no significant effect on fit of mHealth intervention
Technology Characteristics	Representation	P7	Representation capability of mHealth artefact has no significant effect on fit
	Reach	P8	Reach capability of mHealth artefact has no significant effect on fit
	Monitoring	P9	Monitoring capability of mHealth artefact has no significant effect on perceived fit
Technology utilization	Fit (Artefact)	P10	Fit has no significant effect on utilization of mHealth artefact in low-resource settings

4.5 Data Preparation and Processing

Preparation of data is a crucial step before embarking on analysis because the research outcome depends on the quality of data. To prepare the pretest and post-test data for analysis, the following steps were followed:

1. *Questionnaire checking*: Questionnaires from the pretest and post-test observations were checked and those found incomplete or incorrectly filled eliminated.
2. *Coding responses*: The codebook such as shown in Table 4.7 was used to code responses to numerical values for analysis using Microsoft Excel, SmartPLS (Ringle, Wende & Becker 2014) and Statistical Package for Social Scientists (SPSS).
3. *Transcription*: After coding the responses on the questionnaire, the numeric values were keyed into Microsoft Excel and SPSS for further processing.
4. *Cleaning*: To ensure no errors and outliers, descriptive analysis in SPSS, and PLS data validator were used to inspect the dataset for inconsistencies, outliers and missing values. Statistical adjustments were applied on data that required transformations.
5. *Data analysis techniques*: After cleaning the datasets, three strategies for analyzing the observations were selected. These are Partial Least Squares Structural Equation Modelling (PLS-SEM) for predictive modelling, repeated measures ANOVA, and Bonferroni post hoc test for comparisons between sample means. Data modelling in PLS-SEM was accomplished using SmartPLS (Ringle, Wende & Becker 2014).

Table 4.7: Codebook for representing responses

Q1.1 (Age)	Code	1.2 (Ed)	Code	1.3 (Gravid)	Code	1.4 (Kid)	Code	1.5 (Phone)	Code	Q2.1 - 12.2	Code	Q12.3
15 - 19	1	Primary	1	1	1	0	1	Yes	1	Strongly Agree	1	If not Blank. Write the Service
20 - 25	2	Secondary	2	2	2	1	2	No	2	Agree	2	
26 - 30	3	College	3	3	3	2	3			Not Sure	3	
31 - 35	4	University	4	Abv 3	4	3	4			Disagree	4	
Above 35	5	None	5			Abv 4	5			Strongly Disagree	5	

4.5.1 Predictive Modelling

In predictive modelling, a model based on linear equation or neural network may be used to analyze the data to predict the likelihood of future outcome. To predict the outcome, data may be collected before and after the intervention to evaluate the power of the model. In this study, predictive modelling was employed to determine utilization of mHealth artefacts before and after deployment. To evaluate predictive power of TIPFit model, Partial Least Squares Structural Equation Modelling (PLS-SEM) was used to test the hypothesized cause-effect relationships. The rationale behind choosing PLS-SEM was:

- We were not re-using an existing model like Davis (1989) TAM or Goodhue's TTF (1995) but evaluating a conceptual model consisting of latent constructs derived from reviewed models.

- Modelling using PLS-SEM is suitable for dealing with complex models comprising of many latent constructs. Since the TIPFit model has a total of 11 constructs, it is appropriate to use PLS-SEM.
- Compared to covariance-based Structural Equation Modelling (CB-SEM) such as LISREL or Amos, PLS-SEM is tolerant to smaller sample sizes. Henseler, Ringle and Sinkovics (2009) suggest a rule of thumb for determining the sample size that PLS can provide reliable results. Due to importance of sample size, Chin and Newsted (1999) and Goodhue, Lewis and Thompson (2006) used Monte Carlo simulations to determine the minimum sample in structural equation modelling. Whereas Chin and Newsted demonstrated that a minimum of 20 observations is sufficient to use PLS-SEM, Goodhue's simulation study indicates PLS requires a minimum of 40 observations to provide reliable outcome.
- Unlike CB-SEM techniques, PLS-SEM may be used to analyse a model with variables measured using only one indicator. Though it is sufficient to measure a latent variable with only one indicator, this gives the researcher flexibility in situation where it is difficult to use multiple indicators. This is not the case with covariance-based structural equation modelling techniques that requires multiple indicators for each variable.
- Currently, PLS-SEM modelling tools such as SmartPLS and PLS-Graph as well as open source software are getting popular. This makes it easier to use PLS modelling techniques on observations that do not satisfy requirements of covariance-based SEM.

In this study we settled for PLS modelling because it was not practically and economically viable to recruit large samples recommended for CB-SEM techniques. Our choice was also motivated by the desire to provide a predictive approach to design and deployment of mHealth interventions suitable for low-resource settings. Studies conducted by Cohen (1992), Chin and Newsted (1999) and Goodhue, Lewis and Thompson (2006) provide guidelines on minimum sample size required to get reliable outcome from PLS-SEM. In this study, we tested hypothesized cause-and-effect relationships P_1 to P_{10} using PLS-SEM technique that is a special implementation of a system of multivariate linear regression mode stated mathematically as:

$$Y_j = \beta_0 + \beta_i X_i + \mathcal{E}_i$$

Where; $i = 1, 2, \dots, 9$; $j = 1, 2$; β_i are path weights and $\mathcal{E}$ is random error. The β_0 variable is Y intercept which is not important in our model.

Most PLS-SEM software implements this equation using a graphical model such as shown in Figure 4.4 consisting of measurement model and structural model:

- Measurement model represented using X_1 to X_9 are the independent variables (constructs) that are measured using indicators shown in yellow boxes.
- The *structural model* comprises of the path weight from β_1 to β_9 hypothesized to influence fit, and β_{10} between fit and technology utilization.

Using PLS-SEM software tools such as SmartPLS or PLS-Graph, it is possible to convert a conceptual model into a visual model using collected dataset. In this study, SmartPLS (Ringle, Wende & Becker 2014) was used to generate factor loadings and path coefficients. These coefficients were then subjected to significance test to predict effect of $X_1 \dots X_9$ on Fit (Y_1); and Fit (Y_1) on utilization (Y_2).

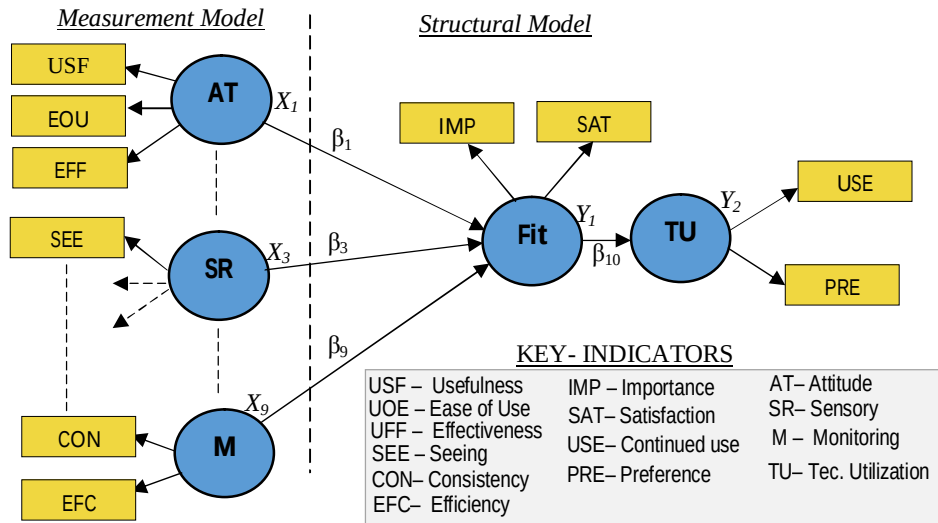


Figure 4.4: Predictive modelling using PLS-SEM

4.5.2 Comparative Analysis

To enhance reliability of our conclusions, parametric tests such as repeated measures ANOVA and Bonferroni tests were used as confirmation on findings from structural equation modelling. To apply comparative analysis, a pretest was administered to evaluate participants' perceptions on a planned mHealth intervention. Later, after exposure to experimental treatment, two post-tests were taken to validate the model, hence determine the impact of the experimental treatment.

CHAPTER 5

Results and Discussion

5.1 Introduction

The motivation behind this study was to identify key factors that would be useful in predicting post-deployment utilization of mHealth interventions in low-resource settings. In the study, the following research objectives stated in chapter one were the key drivers:

1. Identify key factors that influence deployment and effective utilization of mHealth interventions in low-resource settings
2. Based on existing models and the key factors, derive a model that serves as a blueprint for design and deployment of mHealth solutions suitable for low-resource settings
3. Develop a prototype to validate the proposed model using a practical scenario in maternal and childcare services

To address the first objective, we reviewed studies relating to health challenges in low-resource settings, ICT interventions, research models and mHealth deployment strategies. This gave us an insight into socio-technical factors that influence design and deployment of mHealth artefacts. To validate these factors, we derived the model unveiled in chapter 2 which was operationalized in a maternal care practical scenario. Therefore, we achieved the second objective by operationalizing individual characteristics, process requirements, and technology functionality using system development blueprints and data collection instruments.

To answer the third question, we conducted repeated measures experiment to validate the model using the same cohort for a period of 3 months. During the experiment, time difference of at least one month was allowed before recording the next observation to minimize the crossover effect. Furthermore, exposing the subjects to experimental treatment for a long duration gave us an opportunity to investigate how perceptions based on sensitization on importance of using mobile phones in maternal care predicts post-deployment utilization. Therefore, repeated measures experiment used in this study was within-subjects design that we considered powerful in drawing reliable conclusion on the null hypothesis that states: “*fit of mHealth artefact has no significant effect on utilization in low resource settings.*” In this chapter, we discuss results from the pretest, post-test1 and post-test2 datasets. In each case, we start with descriptive statistics, followed by reliability

and validity tests. Later, we analyze the datasets using PLS-SEM and two parametric tests ie Repeated Measures ANOVA (RM-ANOVA) and Bonferroni post-hoc test.

5.2 Discussion of Pretest Results

The main data collection instrument used during the pretest was a questionnaire attached in in Appendix 2, developed from the operationalized TIPFit model in chapter 2. To ensure reliability and construct validity, the instruments were developed and validated through experts' reviews and pilot tests on selected maternal clients and patients in Kimbimbi Hospital, located in Mwea District, Kirinyaga County.

5.2.1 Participants' Demographic Details

Having prepared the pretest dataset for analysis, we used SPSS to analyze demographic details of 73 valid responses from the sample of 79 respondents who participated in the pretest. The respondents were antenatal and postnatal clients and patients who are enrolled for maternal care services in Kimbimbi County Hospital. Figure 5.1 shows that more than half of the subjects i.e. 64% (11% and 53%) are young adults between 15 and 25 years of age.

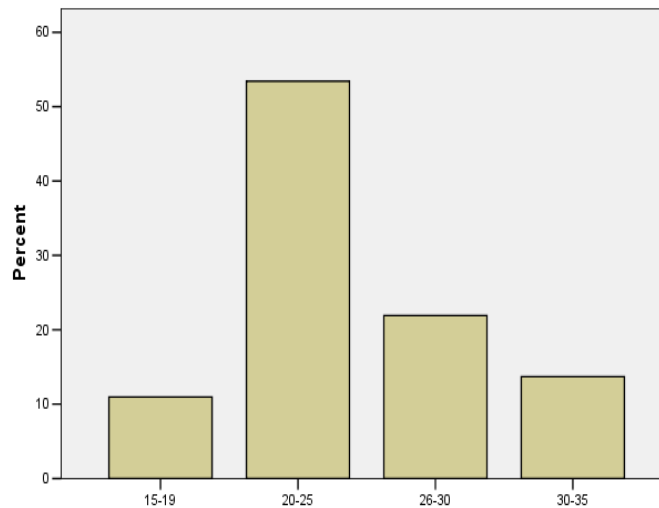


Figure 5.1: Participants' age distribution

Table 5.1 shows distribution of the subjects' age ranging from 15 to above 35 years. The reason behind 35 years being considered the ceiling was because it is the limit of active reproduction age in women.

Table 5.1: Participants' age distribution

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	15-19	8	11.0	11.0	11.0
	20-25	39	53.4	53.4	64.4
	26-30	16	21.9	21.9	86.3
	30-35	10	13.7	13.7	100.0
	Total	73	100.0	100.0	

To get insight on participants' competence in using mobile devices, we interviewed them on their education level. The results shown on Figure 5.2 indicate that about 82% (34% primary and 48% secondary) of the respondents have basic education. Only a small fraction of about 15% attained college education and 3% have gone up to university.

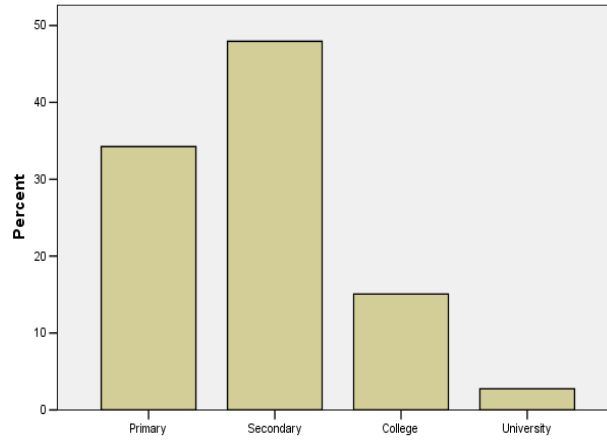


Figure 5.2: Participants' education level

Apart from age and education, Table 5.2 (a) and (b) gives a summary of other demographic details relevant to this study i.e. gravida (number of pregnancies), number of children and possession of a mobile phone. The table shows that about 55% were in their first pregnancy while 23% were in second pregnancy. Concerning number of children, 60.3% had no children while 27.4% had only one child. Table 5.2 (c) shows that out of the 73 subjects, more than 97% have mobile phones.

Table 5.2(a): Pregnancies

Codebook Index	Gravida
1	54.8*
2	23.3
3	16.4
4	2.7
5	2.7

Table 5.2(b): No. of children

Codebook Index	No. of Children
1	60.3*
2	27.4
3	8.2
4	4.1

Table 5.2(c): Owns mobile

Value	Has Mobile Phone
Yes	97.3*
No	2.7

NB: In Table 5.2(a), the 54.8 in asterisk means subjects are in their first pregnancy (Gravida 1). In table 5.2(b), 60.3 in asterisk means the subjects have no children.

In summary, demographic details of the subjects who participated in the pretest indicated that majority were young women aged between 15 and 25 with only basic education. The results also showed that majority of these young adults are in their first pregnancy meaning that they fit into our use case scenario narrated in Chapter 4 with *Mrs. Mulumba* as the persona. Luckily, because majority of them have mobile phones, it was possible to recruit the 79 participants to our experimental treatment.

5.2.2 Reliability and Validity Tests

In studies involving theoretical models comprised of indirectly measureable variables, the first step in data analysis is to test reliability and validity of measurement instruments. To assess reliability and validity of the pretest instrument, we used the dataset from 73 valid responses to check for internal consistency, convergent validity and discriminant validity.

Reliability Analysis

Reliability analysis checks on internal consistency i.e. the extent to which the measurements of an underlying latent variable are repeatable (Goodhue 1998). Traditionally, Cronbach's alpha has been used as an estimate of reliability with alpha scores above 0.70 considered satisfactory. However, given that alpha test uses inter-items correlations, it tends to provide conservative values in PLS. To relax this condition, Bagozzi and Yi (1988) suggested use of composite reliability as a possible replacement of Cronbach's test in partial least squares (PLS).

Since Cronbach's alpha is the most widely used test of reliability, SmartPLS also checks data for internal consistency using alpha test. Figure 5.3 (a) and (b) shows graphical illustrations of composite reliability and Cronbach's alpha generated from pretest dataset using SmartPLS. The graph on the right indicates that Reach with alpha of 0.68 and Synchronism with 0.66 are the only constructs that scored reliability coefficients below the 0.70 threshold. See Table 5.3 for more details on reliability analysis.

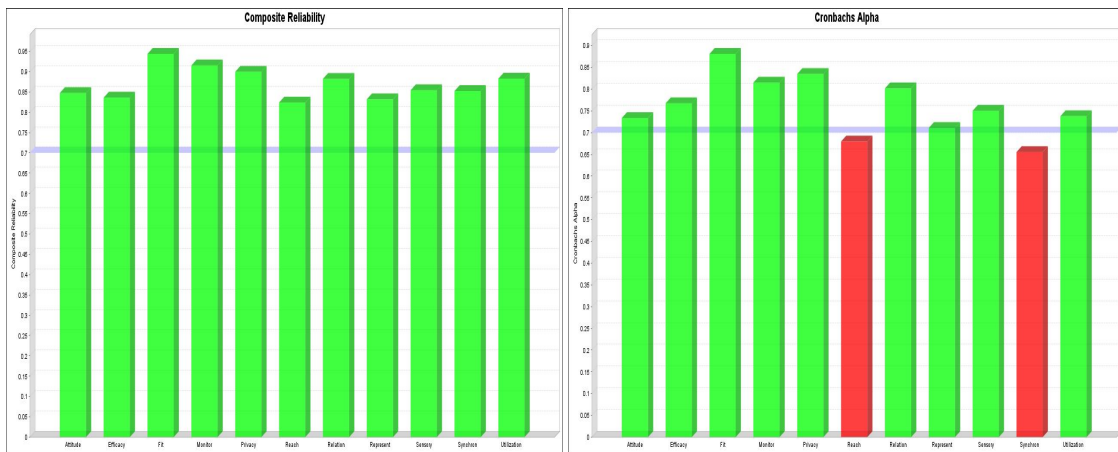


Figure 5.3: Pretest instrument reliability analysis

Convergent Validity

Convergent validity measures the degree to which two or more attempts to measure the same construct are in agreement. To check for convergent validity, Average Variance Extracted (AVE) coefficients are used. Each construct's AVE indicates how well different measurement indicators explain the underlying construct. Given that the recommended

minimum AVE for a construct is 0.50 (50%), Figure 5.4 indicates good convergent validity because all the AVEs are above 50% threshold



Figure 5.4: Pretest AVE coefficients

Table 5.3 shows a summary of AVEs, internal consistency, convergent validity and R^2 indicating high level reliability and validity of the pretest measurement instrument.

Table 5.3: PLS Reliability and validity tests

	AVE	Composite Reliability	R Square	Cronbachs Alpha
Attitude	0.649374	0.847458		0.733665
Efficacy	0.633531	0.835939		0.767437
Fit	0.893738	0.943888	0.802364	0.881131
Monitor	0.843818	0.915292		0.815060
Privacy	0.749627	0.899704		0.834832
Reach	0.609668	0.823962		0.679566
Relation	0.714494	0.882221		0.801774
Represent	0.629325	0.831981		0.710804
Sensory	0.661636	0.854326		0.750290
Synchron	0.742907	0.852420		0.655404
Utilization	0.790559	0.882954	0.638795	0.737711

Discriminant Validity

To examine an instrument for discriminant validity, pattern of responses for each construct are compared against responses of other constructs. Discriminant validity is achieved if there is empirical evidence that the construct being singled-out is distinct from the other model constructs. To demonstrate discriminant validity, Fornell and Larcker (1981) suggests use of the square root of AVE of a latent construct against inter-correlation of other constructs. To determine discriminant validity of the pretest dataset, we created Table 5.4 below in which calculated square roots of AVEs were written diagonally in bold. Though the correlation of relationship against fit (0.8370) marked in asterisk is very close to the square root of *relationship* AVE, the model demonstrates good discriminant validity. This is

because all the correlations of other latent variables placed vertically and across the lower triangle are lower than the square root of AVE of the construct being singled out.

Table 5.4: Pretest Instrument discriminant validity

	Attit	Self	Sense	Relat	Priva	Sync	Repre	Reach	Mont	Fit	Use
Attitu	0.8058										
Self	0.5259	0.7960									
Sense	0.6073	0.3793	0.8134								
Relat	0.7168	0.5389	0.6351	0.8453							
Priva	0.5366	0.3887	0.5217	0.5349	0.8658						
Sync	0.4228	0.2355	0.4742	0.4872	0.7367	0.8619					
Repre	0.7025	0.5933	0.5588	0.7255	0.6679	0.4448	0.7930				
Reach	0.6118	0.4498	0.5620	0.6556	0.6384	0.48739	0.6612	0.7808			
Montr	0.6297	0.5193	0.5758	0.6784	0.4409	0.2431	0.6869	0.6313	0.9186		
Fit	0.7133	0.4293	0.5902	0.8370*	0.5695	0.5271	0.6591	0.6490	0.7334	0.9454	
Use	0.6402	0.3943	0.5093	0.7993	0.5484	0.6326	0.6554	0.6701	0.4955	0.7993	0.8891

5.2.3 Path modelling and Analysis

The purpose of the pretest was to evaluate fit of mHealth artefacts in order to predict post-deployment utilization. SmartPLS software uses a series of multi-linear regression to predict such causal effect (Haenlein & Kaplan 2004; Henseler, Ringle & Sinkovics 2009). Figure 5.5 shows the pretest factor loadings and path coefficients (*See indicators' key below*).

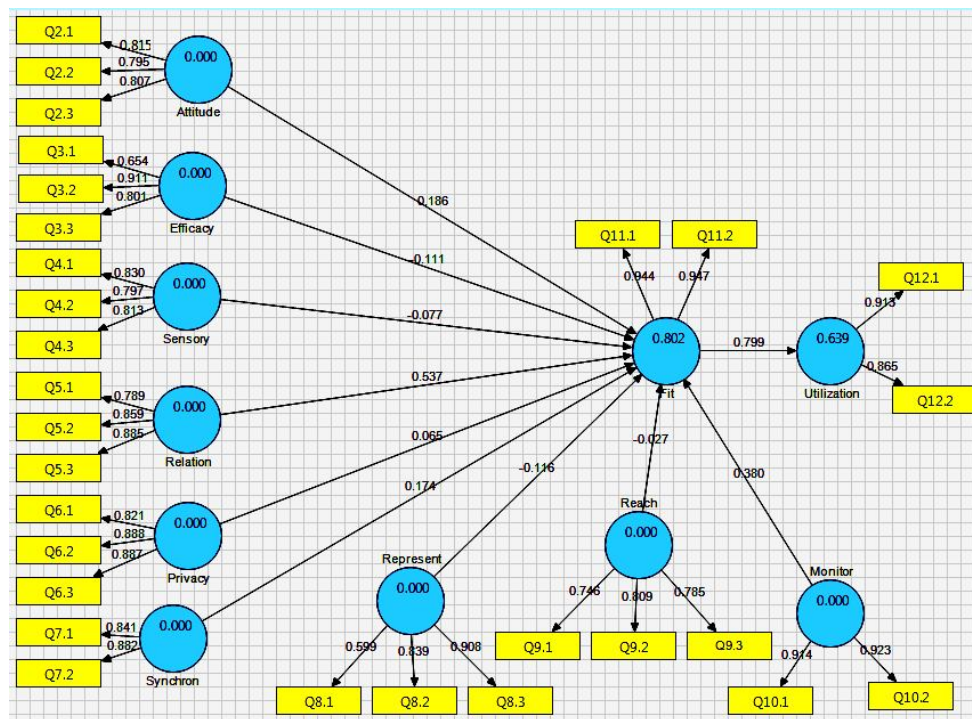


Figure 5.5: Predictive model from pretest dataset

INDICATORS KEY

2.1 – Usefulness	4.2 – Touch	6.2 – Consent	8.3 – Workflow	11.1– Expectations
2.2 – Ease of Use	4.3 – Hear	6.3 – Confidentiality	9.1 – Availability	11.2 –Suitability
2.3 – Effectiveness	5.1 – Accessibility	7.1 – Availability	9.2 – Convenience	12.1 –Continued use
3.1 – Literacy	5.2 – Rapport	7.2 – Responsiveness	9.3 – Reliability	12.2 –Satisfaction
3.2 – Ease of use	5.3 – Harmony	8.1 – Format	10.1–Sufficient data	
3.3 – Competence	6.1 – Authenticity	8.2 – Content	10.2–Timeliness	
4.1 – See				

Factor Loadings

After running the PLS algorithm, the measurement indicators cleanly loaded onto their latent constructs with most of them scoring coefficients above 0.80 as shown in Figure 6.6 above. Table 5.5 below shows a summary of factor loadings after the algorithm converged in only four iterations.

Table 5.5: Pretest factor loadings

Factor	Attit	Effic	Sense	Relat	Privac	Sync	Rep	Reach	Monit	Fit	Util.
Factor1	0.8145	0.6541	0.8299	0.7890	0.8212	0.8410	0.5994	0.7464	0.9137	0.9437	0.9131
Factor2	0.7953	0.9113	0.7973	0.8593	0.8879	0.8823	0.8391	0.8094	0.9235	0.9471	0.8646
Factor3	0.8072	0.8014	0.8128	0.8847	0.8866		0.9081	0.7853			

Path Coefficients and R²

In practice, analysis of a conceptual model requires use of a conventional 5% significance level, 80% statistical power and coefficient of determination i.e. R² of at least 0.25 (Wong 2013). Using these specifications, we analyzed the structural model path coefficients and the R² on fit and technology utilization. The R² value of 0.802 indicates that the independent variables accounted for 80.2% variance on fit. Consequently, Fit explains 63.9% variance on technology utilization hence indicating good explanatory power.

In the context of predictive modelling, it implies that responses from the 73 observations on the nine independent variables (P₁ to P₉) predicted 80% on fit and about 64% probability of acceptance and use of mobile-based maternal care services. The figure also shows path coefficients between the latent constructs and fit with relationship construct registering the strongest positive effect of 0.537. Representation construct returned the strongest negative effect of -0.116. Fit as a mediating variable revealed perception on suitability of mHealth intervention in maternal health has strong effect on technology utilization. Table 5.6 gives a summary of the path coefficients.

Table 5.6: Pretest path coefficients

	Attit	Self	Sense	Relat	Priva	Sync	Rep	Reach	Mont	Utilization
Fit	0.186	-0.111	-0.077	0.537	0.065	0.174	0.116	-0.027	0.380	0.799

5.2.4 Significance of Factors and Path Coefficients

Though PLS does not assume normality of data distribution, test for significance requires use of parametric tests such as Student's t-test. However, to estimate t-values, SmartPLS relies on a non-parametric procedure known as bootstrapping. Bootstrapping is an algorithm that uses one-tailed or two-tailed test to generate estimates of t-values for the indicators and

path coefficients. After running the bootstrapping algorithm on the pretest dataset, SmartPLS generated estimates of t-values at 5% significance level shown in Figure 5.6.

Significance of Factor Loadings

To obtain t-values for factor loadings, we ran bootstrapping algorithm using 5000 subsamples in SmartPLS to estimate normality of distribution of sample means. Figure 6.6 above shows highly significant factor loadings, with the minimum indicator having a t-value of 5.530 that is greater than the 5% critical value.

Significance of Path Coefficients

Similarly, we estimated t-values for the path coefficients to determine significance of path coefficients for hypothesized relationships P_1 to P_{10} as shown in Figure 5.6 below.

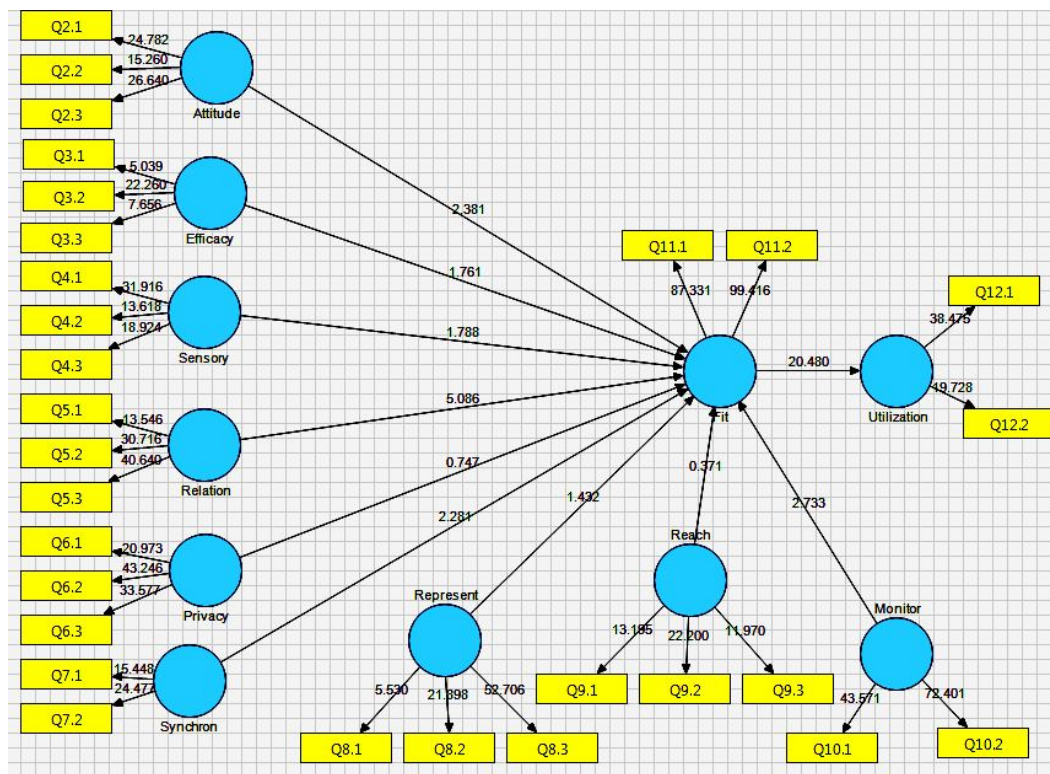


Figure 5.6: Bootstrapped predictive model

Table 5.7 shows a summary of the t-values estimated from the path coefficients with t-values marked in asterisk denoting significant relationship.

Table 5.7: Path coefficients t-test values

	Attit	Self	Sense	Relat	Priva	Sync	Rep	Reach	Monit	Utilization
Fit	2.381*	-1.761	-1.788	5.086*	0.747	2.281*	1.432	-0.371	2.733*	20.480*

5.2.5 Sobel Test for Mediation Effect of Fit

Configuration of TIPFit model shows that fit mediates the effects of individual characteristics, process requirements and technology functionality on technology utilization. However, it is important to statistically evaluate and quantify mediation effects in causal models (Preacher & Hayes 2004). To test the mediating effect of fit, we used PLS modelling to simulate direct and indirect paths between each latent construct and Technology Utilization. Once the path coefficients and standard errors were generated, the parameters were fed into Sobel test calculator to compute p-values. The following steps were followed to test mediation effect of fit on each hypothesized relationships P_1 to P_{10} :

1. Modelled a direct path between a latent construct and technology utilization as shown in Figure 5.7, and then generated path coefficients.

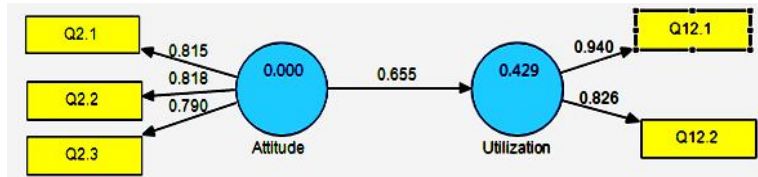


Figure 5.7: Direct effect of Attitude on Technology utilization

2. Induced fit as a mediating variable and regenerated the path coefficients. Figure 5.8 shows a big drop in the direct effect of Attitude on Technology utilization after inducing fit as a mediator.

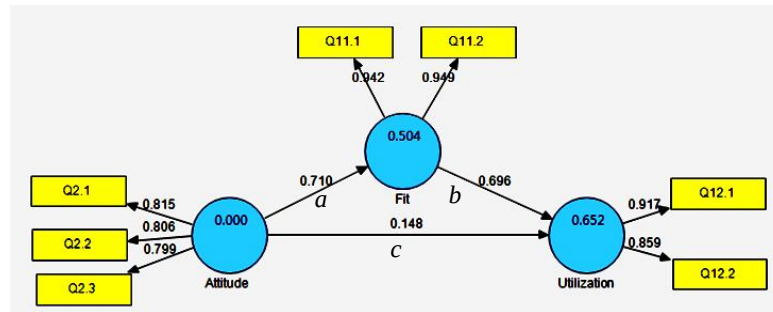


Figure 5.8: Mediated effect of fit on technology utilization

3. Generated t-values and standard errors SE_a and SE_b associated with paths a and b shown in Figure 6.9 above. These standard errors and their corresponding path coefficients were the parameters required to test for significance of mediation effect in Sobel test.
4. Keyed in the parameters β_a , β_b , SE_a and SE_b into Sobel Test calculator to compute p-values for each independent variable. For example, Figure 5.9 below shows that for a two-tailed test, fit significantly mediates synchronism with p-value < 0.001 .
5. Computed the effect size f^2 using Cohen's (1992) formula based on coefficient of determination R^2 on fit expressed as:

$$\frac{R^2_{included} - R^2_{excluded}}{1 - R^2_{included}}$$

Where $R^2_{included}$ is when the construct is not dropped while $R^2_{excluded}$ is after the construct is dropped

Sobel Test Calculator for the Significance of Mediation

This calculator uses the Sobel test to tell you whether a mediator variable significantly carries the influence of an independent variable to a dependent variable; i.e., whether the indirect effect of the independent variable on the dependent variable through the mediator variable is significant. This calculator returns the Sobel test statistic, and both one-tailed and two-tailed probability values.

Please supply the necessary parameter values, and then click 'Calculate'.

A: 0.5305
 B: 0.6319
 SE_A: 0.0819
 SE_B: 0.0680

Calculate!

Sobel test statistic: **5.31386387**
 One-tailed probability: **0.00000005**
 Two-tailed probability: **0.00000011**

Diagram: independent variable → A (SE_A) → mediator variable → B (SE_B) → dependent variable

Figure 5.9: Sobel test on mediating effect of fit

Table 5.8 shows a summary of path coefficients, p-values from Sobel test and effect size (Cohen 1992) of each independent variable on fit. Based on the pretest dataset, all the p-values were negligible demonstrating that fit significantly mediates the effect of the nine constructs.

Table 5.8: Significance of Fit as mediating variable

Construct	Path β_a	Path β_b	SE _a	SE _b	t-statistic	Effect-f ²	p-value
Attitude	0.7102	0.6956	0.0333	0.0633	2.389*	0.06	p < 0.001
Self-efficacy	0.4136	0.7708	0.0474	0.0511	1.182	0.04	
Sensory requirements	0.5936	0.7589	0.0383	0.0441	1.438	0.02	
Relationship	0.8396	0.4217	0.0278	0.0951	5.481*	0.44	
Identification & privacy	0.5689	0.7201	0.0775	0.0551	2.685*	0.01	
Synchronism	0.5305	0.6319	0.0819	0.0680	4.220*	0.06	
Representation	0.6459	0.6575	0.0696	0.0458	3.003*	0.02	
Reach	0.6472	0.6213	0.0283	0.0708	4.207*	0.00	
Monitoring capability	0.7340	0.9449	0.0686	0.1011	1.731	0.27	

Though the paths marked with asterisk are significant as shown in the t-statistic column, their direct effect is smaller compared to the sum of indirect paths β_a and β_b . Inspection on f² column shows that, other than two constructs i.e. reach, and identification and privacy that have zero and negligible effect on fit, the rest have between small (0.02), medium (0.15) and large (0.35) effect on fit.

The table shows that relationship has the largest effect on fit with 0.44 while reach, and identification and privacy constructs have negligible effect. Generally, these results demonstrate that the model with fit as a mediating variable is logically sound. This goodness of fit demonstrated using structural modelling is due to iterative refinement of the model informed by the researcher's pre-study experience and extensive consultations with health experts and professors, and scholars from Kenya, Germany, India and Portugal.

5.2.6 Summary of Pretest Results

Individual characteristics

Based on the pretest results, positive significant effect exist between attitude and fit with $t=2.381$; hence we rejected sub-hypothesis P_1 . On the other hand, a negative effect exists between Self-efficacy and Fit. However, given that its t -value of -1.761 is less than the critical value i.e. ± 1.96 , we failed to reject P_2 that postulates self-efficacy has no significant effect on fit. These findings revealed that most respondents strongly believe use of mobile phones in maternal care is useful. However, the results showed that majority of the respondents have no confidence in their ability to use most of the features and services on their mobile phones. This may be attributed to education level given that over 80% of the respondents have only basic education and limited ICT skills required for competent use of mobile device features and services.

Process requirements

The pretest findings on process requirements implied that negative nonsignificant effect exist between sensory requirement and fit with $t=-1.788 < \pm 1.96$. Relationship with $t=5.086$, synchronism ($t=5.086$), and identification and privacy ($t=0.747$) predicted positive effect on fit. Despite practical demonstrations on how to use portable biometric devices such as BP monitors, the results suggest that the respondents have reservations on ability of mobile phones and portable medical devices to satisfy sensory requirements. Most of them do not mind the cost and time of visiting hospital to seek for advice and assessment from caregivers. This may be due to a number of factors among them; education, cost of point-of-care devices and the caregiver-centred model of care in low resource settings.

However, significance of relationship and synchronism constructs indicated that most respondents believe use of mobile phones can help improve interaction with caregivers minimizing inconveniences and delays experienced with physical follow-up process. Low t -values of identification and privacy suggest that the respondents' perception on issues relating to mobile-based identification and privacy may not be a strong basis for judging fit of an mHealth artefact. Based on these inferences, we failed to reject sub-hypotheses P_3 and P_5 but rejected P_4 and P_6 .

Technology functionality

In regard to technology functionality, the pretest findings shows that representation with $t=1.432$ and reach with $t= -0.371$ are nonsignificant though they negatively affect fit.

However, monitoring is significant and positively influences fit given that $t=2.733$. This justified our failure to reject sub-hypothesis P_7 and P_8 but rejected P_9 . These findings indicate low opinion on effectiveness of mobile phones in delivery and access of maternal care services and information. These statistical inferences imply that respondents have strong feeling on suitability of mobile phone in monitoring their maternal health progress.

Fit and technology utilization

Despite mixed perceptions on fit of using mobile phones in maternal care, generally the pretest results predicted that the planned mHealth intervention was likely to be suitable, with $20.480 > 1.96$ hence predicting high probability of post-deployment acceptance and use. These findings justified rejecting the sub-hypothesis P_{10} that postulates *Fit of mHealth artefact has no significant effect on utilization in low-resource settings*. Table 5.9 gives a summary of the pretest predictions after testing significance of hypothesized relationships P_1 to P_{10} .

Table 5.9: Test outcome of hypothesized

Construct	Pi	Sub-hypothesis	Outcome
Attitude	P1	Attitude towards technology has no significant effect on fit of mHealth intervention	Reject
Self-Efficacy	P2	Self-efficacy on using mobile devices and computers has no significant effect on fit of mHealth intervention	Fail to Reject
Sensory	P3	Sensory requirements of touch, sight and aural experience have no significant effect on fit of mHealth intervention.	Fail to Reject
Relationship	P4	Relationship requirement between patient and caregiver has no significant influence on fit of mHealth intervention	Reject
Identification and Privacy	P5	Identity and privacy requirement between patient and caregiver has no significant effect on fit of mHealth intervention	Fail to Reject
Synchronism	P6	Synchronism requirement of time-constrained processes has no significant effect on fit of mHealth intervention	Reject
Representation	P7	Representation capability of mHealth artefact has no significant effect on fit	Fail to Reject
Reach	p8	Reach capability of mHealth artefact has no significant effect on fit	Fail to Reject
Monitoring	P9	Monitoring capability of mHealth artefact has no significant effect on perceived fit	Reject
Fit (Artefact)	P10	Fit of mHealth artefact has no significant effect on its utilization in low-resource settings	Reject

5.3 Discussion of Post-test1 Results

The purpose of post-test1 was to evaluate the reactions of the participants at least one month after exposure to experimental treatment. Seventy five (75) subjects who received various mobile alerts e.g. clinic reminders, danger signs, safe delivery and nutrition participated in post-test1 exercise. During the exercise, the participants filled questionnaires guided by research assistants. Each participant questionnaire was identified using a unique number such as B03 that matched the number given during the pretest.

5.3.1 Data Preparation for Analysis

Having started with 79 subjects the number dropped to 75 in post-test1 due to voluntary withdrawal. The 75 filled questionnaires were cross-checked for completeness and correctness before coding the responses. After eliminating four invalid questionnaires, the 71 responses were keyed into Excel and SPSS for further clean-up and analysis.

5.3.2 Participants' Demographic Details

Though the 71 post-test1 responses came from the same participants who were recruited to receive experimental treatment, it was necessary to review their demographic details to compare with the pretest demographics. Table 5.10 (a) and (b) below shows distribution of the subjects' education level and age. These results are almost similar to the pretest observations safe for the minor differences due to a drop in number of subjects.

Table 5.10(a): Subjects' age

	Age distribution	
	Frequency	Percent
15-19	7	10.0
20-25	35	50.0
26-30	16	22.9
31-35	10	14.3
Above 35	2	2.9
Total	71	100.0

Table 5.10(b): Subjects' education

Education level		
Frequency		Percent
Primary	25	35.8
Secondary	32	45.7
College	11	15.7
University	2	2.9
None	-	
	100.0	98.6 (+1.4 missing)

Apart from ownership of mobile phone, additional responses on gravida and number of children were taken. Table 5.11(a) and (b) indicates summary of other demographic details of post-test1 subjects. These results indicate that demographics of post-test1 participants had no major differences with those of the pretest. The differences in frequencies and percentages were mainly because of the drop in number of subjects.

Table 5.11(a): Participants' gravida

Codebook Index	Gravida	
	Frequency	Percentage (%)
1	39	54.9*
2	16	22.5
3	12	16.9
4	2	2.8
5	2	2.8

Table 5.11(b): Participants' no. of children

Codebook Index	No. of Children	
	Frequency	Frequency
1	60.6	60.6
2	26.8	26.8
3	8.5	8.5
4	4.2	4.2

5.3.3 Reliability and validity Analysis

To assess the reliability and validity of the post-test data collection instrument, we used the same procedure applied on pre-test data. This is by analyzing the dataset for internal consistency, convergent validity and discriminant validity.

Reliability Analysis

After running the PLS algorithm, Figure 5.10 (a) and (b) shows graphical illustrations of composite reliability and Cronbach's alpha of the pos-test1 dataset. The graph on the right shows that synchronism is the only construct that scored an alpha slightly below 0.7 threshold. See Table 5.12 for more details on composite and Cronbach's alphas.

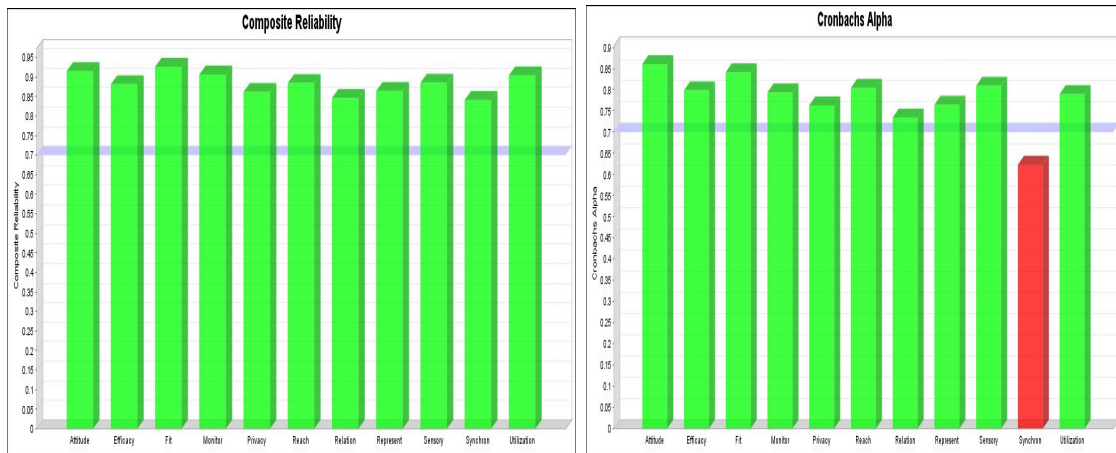


Figure 5.10: Post-test1 reliability analysis

Table 5.12 also shows that post-test1 dataset demonstrated high internal consistency with all constructs scoring composite reliability coefficients above 0.80. This was also confirmed by alpha coefficients shown in the last column. The table indicates synchronism is the only construct that scored an alpha value of 0.62, slightly lower than 0.70.

Convergent Validity

Checking on convergent validity in Figure 5.11, it is evident that all the eleven constructs scored AVEs coefficients above 0.50. These results indicate that post-test measurement indicators highly converged to the latent variables they are intended to measure.

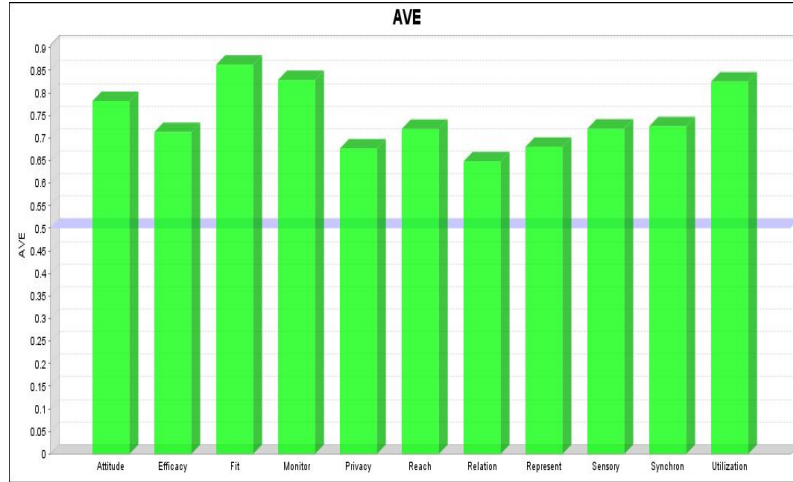


Figure 5.11: Post-test1 AVE coefficients

Table 5.12 shows a summary of AVEs, internal consistency, convergent validity and R^2 indicating high level reliability and validity of post-test1 measurement instrument.

Table 5.12: Post-test1 reliability and validity tests

	AVE	Composite Reliability	R Square	Cronbachs Alpha
Attitude	0.781989	0.914932		0.860675
Efficacy	0.713150	0.881369		0.798571
Fit	0.862376	0.926090	0.691367	0.841520
Monitor	0.828601	0.906253		0.793930
Privacy	0.676766	0.861815		0.763042
Reach	0.720254	0.884453		0.804426
Relation	0.648296	0.846037		0.734345
Represent	0.680390	0.864460		0.764827
Sensory	0.720908	0.885295		0.809661
Synchron	0.726079	0.841281		0.623136
Utilization	0.825055	0.904105	0.505197	0.789932

Discriminant Validity

To demonstrate discriminant validity, we created Table 5.13 below in which calculated square roots of AVEs are written diagonally. The model demonstrates good discriminant validity because the square root of AVE for each construct being singled out is higher than correlations against other latent constructs.

Table 5.13: Post-test1 discriminant validity

	Attitu	Self	Sense	Relat	Priva	Sync	Repre	Reach	Mont	Fit	Use
Attitu	0.8843										
Self	0.7182	0.8445									
Sense	0.2897	0.3618	0.8491								
Relat	0.5168	0.5455	0.6070	0.8052							
Priva	0.5164	0.5829	0.3709	0.6589	0.8227						
Sync	0.6050	0.5877	0.3642	0.60430	0.6384	0.8521					
Repre	0.5725	0.6187	0.3167	0.6474	0.6275	0.7535	0.8249				
Reach	0.3622	0.4135	0.5325	0.4190	0.3741	0.4944	0.4696	0.8487			
Mont	0.4864	0.4971	0.4161	0.6262	0.5245	0.5756	0.5099	0.5151	0.9103		
Fit	0.6191	0.5741	0.2899	0.5867	0.6495	0.7077	0.7430	0.5390	0.5425	0.9286	
Use	0.3899	0.4483	0.3272	0.4281	0.5030	0.5364	0.6664	0.6227	0.4893	0.7108	0.9083

5.3.4 Path modelling and Analysis

To analyze respondent's feedback on suitability of *mamacare* services in maternal care, we modelled the dataset taken at least a month after exposure to experimental treatment. After creating the model, PLS algorithm was used to generate factor loadings for the measurement model and path coefficients of the structural model as shown in Figure 5.12.

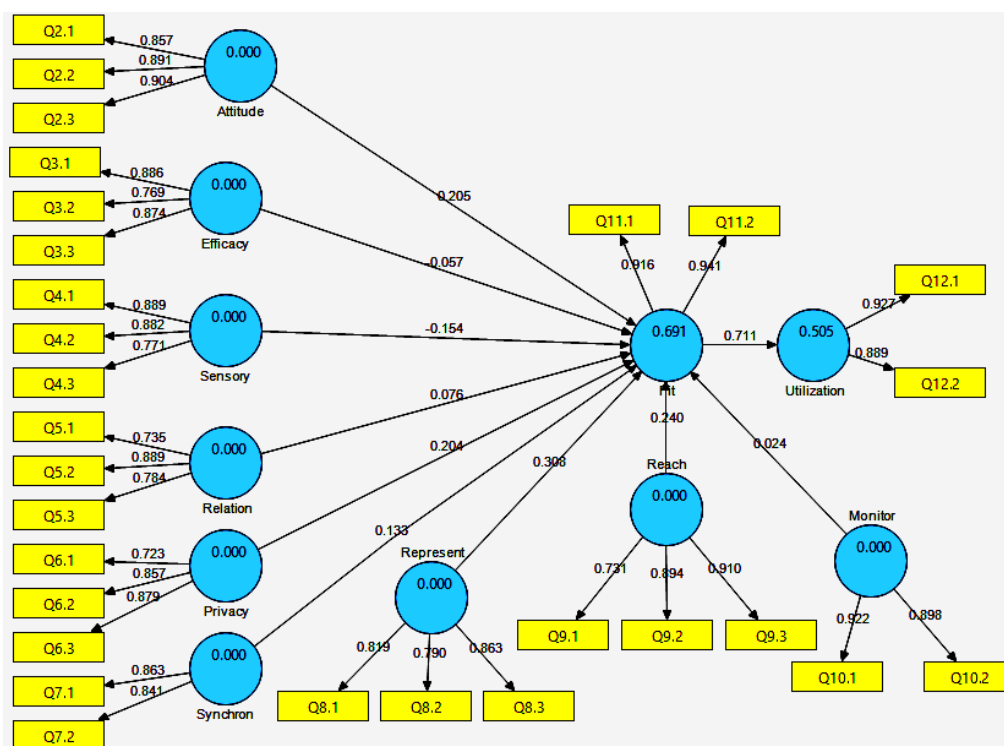


Figure 5.12: Post-test1 indicators and path coefficients

Factor Loadings

The figure above shows that the post-test measurement indicators cleanly loaded onto latent constructs they were intended to measure with most items scoring coefficients above 0.80 as shown in Table 5.14 below.

Table 5.14: Post-test1 indicators loadings

Factor	Attit	Effic	Sense	Relat	Priva	Sync	Rep	Reach	Monit	Fit	Utiliz.
Factor1	0.8569	0.8856	0.8891	0.7355	0.7226	0.8633	0.8194	0.7313	0.9220	0.9161	0.9270
Factor2	0.8912	0.7688	0.8816	0.8886	0.8575	0.8408	0.7899	0.8937	0.8984	0.9410	0.8892
Factor3	0.9041	0.8741	0.7714	0.7838	0.8792		0.8635	0.9095			

Path Coefficients and R²

Figure 6.10 above shows that post-test1 data fitted the model by about 70% variance on fit, while fit explains technology utilization by about 51%. In terms of predictive modelling, user evaluation on fit was quite good with 70% approval and approx. 51% actual utilization. Inference on self-efficacy and sensory requirements indicates negative influence on fit, while the other constructs have positive impact as shown in Table 5.15.

Table 5.15: Post-test1 path coefficients

	Attit	Self	Sense	Relat	Priv	Sync	Rep	Reach	Mont	Tech util.
Fit	0.205	-0.057	-0.154	0.076	0.204	0.133	0.308	0.240	0.024	0.711

5.3.5 Significance of Factors and Path Coefficients

To evaluate significance of the path coefficients, we ran bootstrapping algorithm to estimate t-values shown in Figure 5.13. Visual inspection shows that all the measurement indicators were significant with t-values ranging between 10.383 and 94.56.

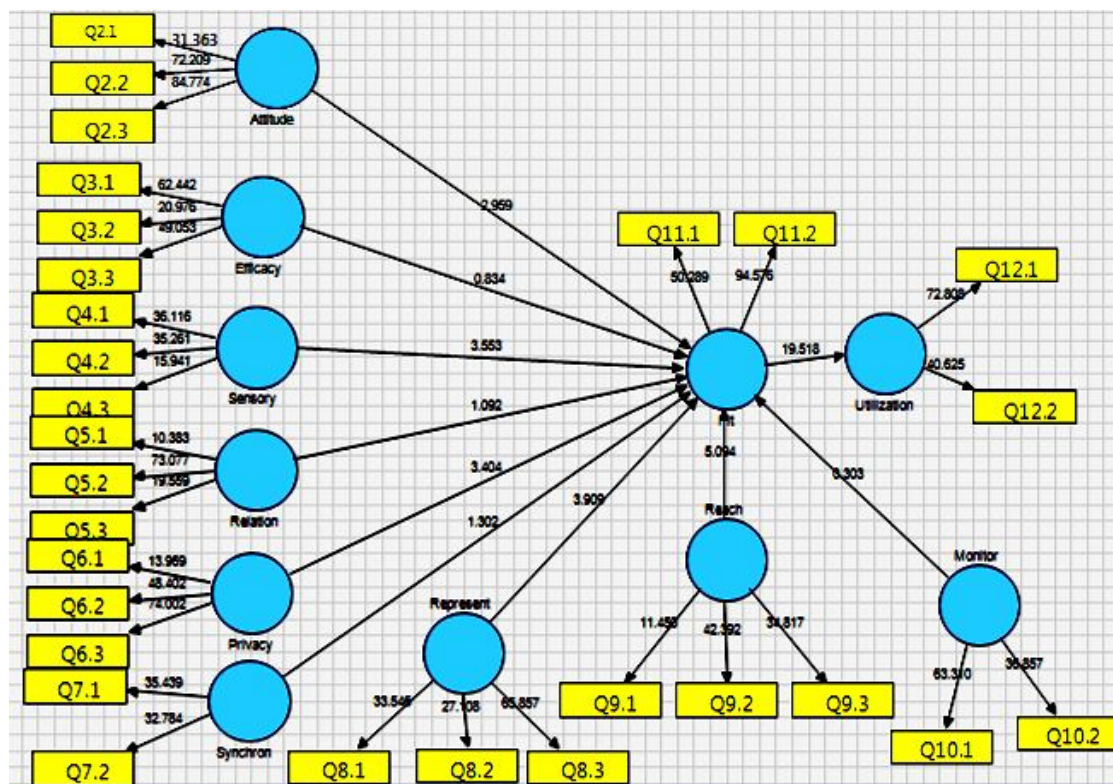


Figure 5.13: Post-test1 bootstrapped model

Given that our interest was to predict effect of independent variables on fit and subsequent utilization of maternal care mHealth artefacts after treatment, Table 5.16 gives a summary of significance of the path coefficients.

Table 5.16: Post-test1 path coefficients significance test

	Attit	Self	Sense	Relat	Priv	Sync	Rep	Reach	Monit	Tech util.
Post-test1	2.959*	-0.834	-3.553*	1.092	3.404*	1.302	3.909*	5.094*	0.303	19.518*

5.3.6 Summary of Post-test1 Results

Individual characteristics

Based on post-test1 results, positive significant effect exist between attitude and fit with $t=2.959$. On the other hand, a relatively lower negative nonsignificant effect exists between self-efficacy and fit given that $t= -0.834$. However, it is important to note that, though not significant, there was a marginal increase in participants' experience on self-efficacy after exposure to experimental treatment. Therefore, basing our inference on post-test1, we rejected sub-hypothesis P_1 but failed to reject sub-hypothesis P_2 .

Process requirements

A sneak preview into the pretest observations showed consistency of sensory requirements in the two tests. Post-test1 confirmed the pretest observation that sensory requirements negative effect on fit is significant with $t = -3.553$. The results also demonstrate that relationship and synchronism constructs are nonsignificant with t -values of 1.092 and 1.302 respectively. Therefore, based on post-test1 statistical inference, we failed to reject sub-hypotheses P_4 and P_6 but rejected P_3 and P_5 .

Technology functionality

Significance test of technology functionality after treatment revealed that representation ($t=3.909$), and reach ($t=5.094$) significantly influences fit while monitoring was nonsignificant with t -value $=0.303$. These observations differ from pretest results hence need for further observations in order to draw reliable conclusions. But based on post-test1 inference, we rejected sub-hypothesis P_7 and P_8 but failed to reject P_9 .

Fit and technology utilization

Consistent with pretest findings, Post-test1 results confirmed that fit has strong effect on technology utilization as demonstrated by t -statistic of 19.518. This justified rejecting sub-hypothesis P_{10} . Table 5.17 gives a summary of the inference on the ten sub-hypotheses tested based on post-test1 results.

Table 5.17: Pretest and post-test1 sub-hypothesis

Concept	Pi	Sub-hypothesis	Outcome
Attitude	P1	Attitude towards technology has no significant effect on fit of mHealth intervention	Reject
Self-Efficacy	P2	Self-efficacy on using mobile devices and computers has no significant effect on fit of mHealth intervention	Fail to Reject
Sensory	P3	Sensory requirements of touch, sight and aural experience have no significant effect on fit of mHealth intervention.	Reject
Relationship	P4	Relationship requirement between patient and caregiver has no significant influence on fit of mHealth intervention	Fail to Reject
Identification and Privacy	P5	Identity and privacy requirement between patient and caregiver has no significant effect on fit of mHealth intervention	Reject
Synchronism	P6	Synchronism requirement of time-constrained processes has no significant effect on fit of mHealth intervention	Fail to Reject
Representation	P7	Representation capability of mHealth artefact has no significant effect on fit	Reject
Reach	P8	Reach capability of mHealth artefact has no significant effect on fit	Reject
Monitoring	P9	Monitoring capability of mHealth artefact has no significant effect on perceived fit	Fail to Reject
Fit (Artefact)	P10	Fit of mHealth artefact has no significant effect on its utilization in low-resource settings	Reject

5.4 Discussion of Post-test2 Results

The purpose of the second post-test at least a month after post-test1 was to confirm whether post-test1 observations were as a result of random variation or effect of treatment. Moreover, this follow-up test was necessary to clarify the inconsistent observations between pretest and post-test1.

5.4.1 Data Preparation for Analysis

The same procedures used to cross-check and clean-up the pretest and post-test1 datasets were applied. This involved checking the questionnaires for completeness and correctness. Out of 73 participants, 70 valid responses were processed manually for further statistical clean-up. Using SPSS and SmartPLS validator, the dataset was inspected for outliers and any inconsistencies corrected before subjecting it to modelling and statistical analysis.

5.4.2 Participants' Demographic Details

In post-test2, after eliminating invalid questionnaires the remaining 70 responses were subjected to descriptive analysis. The purpose was to confirm whether participants' demographics were difference from the previous tests. Table 5.18 (a) and (b) shows the frequencies of education level and age of the 70 subjects. The table revealed that the results had no major differences with those of the pretest and post-test1 observations.

Table 5.18(a): Subjects' age

Age group	Age distribution	
	Frequency	Percent
15-19	15-19	7
20-25	20-25	35
26-30	26-30	16
31-35	31-35	10
Above 35	Above 35	2
Total	Total	70

Table 5.18(b): Subjects' education

Education level		
Level	Frequency	Percent
Primary	25	35.7
Secondary	32	45.7
College	11	15.7
University	02	2.9
None	00	00
	100.0	100

Table 5.19 (a) and (b) gives a summary of other demographic details that were relevant in understanding post-test2 respondents. These are gravida and the number of children. No major differences were noted between post-test1 and post-test2 demographics.

Table 5.19(a): Subjects' gravida

Codebook Index	Gravida	
	Frequency	Percentage (%)
1	38	54.3*
2	15	21.4
3	12	17.1
4	2	2.9
5	2	2.9

Table 5.19(b): No. of children

Codebook Index	No. of Children	
	Frequency	Frequency
1	41	58.6*
2	18	25.7
3	6	8.6
4	3	4.3

5.4.3 Reliability and Validity Analysis

Given that data collection instrument used in Post-test2 was the same used in post-test1, results on reliability and validity were relatively consistent. Figure 5.14 (a) and (b) shows the composite reliability and Cronbach's alpha. Only sensory scored an alpha below the 0.7.

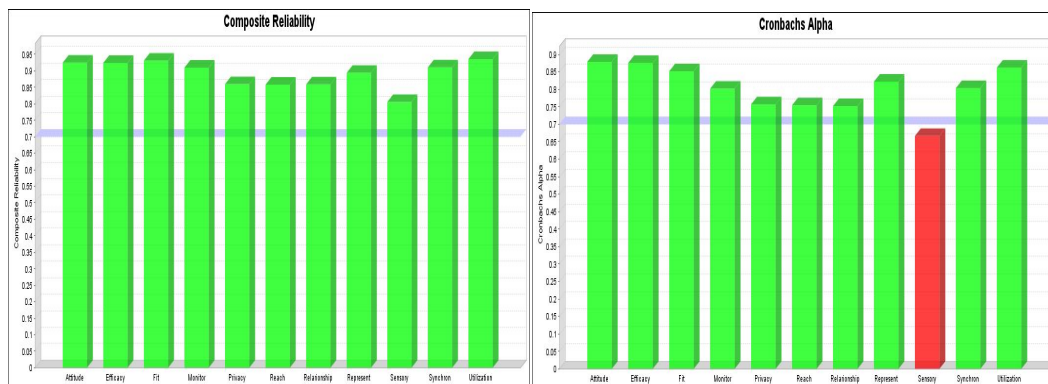


Figure 5.14: Post-test2 reliability analysis

Convergent Validity

To test post-test2 instrument on convergent validity, we used the AVE coefficients. The AVEs in Figure 5.15 indicates good convergent validity with coefficients above 0.50.

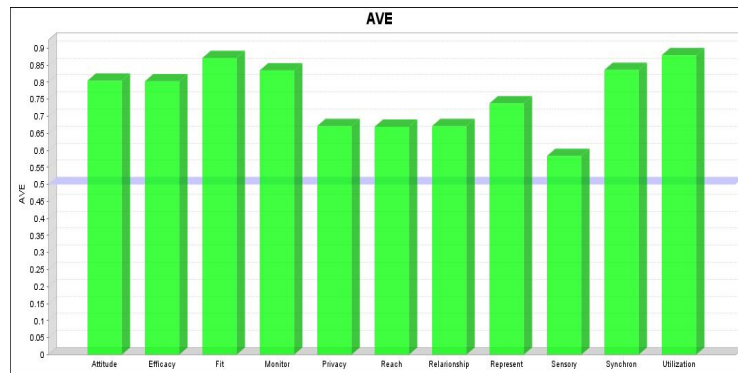


Figure 5.15: Post-test2 AVE coefficients

Table 5.20 shows a summary of AVEs, internal consistency, convergent validity and R^2 indicating high level reliability and validity of post-test2 measurement instrument.

Table 5.20: PLS Post-test2 reliability and validity tests

	AVE	Composite Reliability	R Square	Cronbachs Alpha
Attitude	0.804266	0.924927		0.878902
Efficacy	0.802623	0.924099		0.875936
Fit	0.870883	0.930985	0.603076	0.851827
Monitor	0.834660	0.909877		0.802051
Privacy	0.671063	0.859523		0.757476
Reach	0.669285	0.858083		0.754543
Relationship	0.671098	0.858716		0.752436
Represent	0.737711	0.893955		0.822383
Sensory	0.583225	0.805327		0.666868
Synchron	0.835926	0.910630		0.803818
Utilization	0.879067	0.935642	0.537310	0.862436

Discriminant Validity

To assess discriminant validity using post-test2 dataset, we created Table 5.21 below with calculated square roots of AVEs. The results indicate good discriminant validity because no value exceeds the square root of AVE of the construct being singled out.

Table 5.21: Post-test2 discriminant validity

	Attitu	Self	Sense	Relat	Priva	Sync	Repr	Reach	Mont	Fit	Utiliz.
Attitu	0.8968										
Self	0.5238	0.8959									
Sense	0.5230	0.2599	0.7637								
Relat	0.5701	0.3933	0.4808	0.8192							
Priva	0.6055	0.6912	0.3929	0.6408	0.8192						
Sync	0.5588	0.6512	0.3352	0.6269	0.7580	0.9143					
Repre	0.5134	0.6559	0.3659	0.5066	0.6648	0.7586	0.8589				
Reach	0.4870	0.4612	0.5623	0.7206	0.5999	0.5783	0.6005	0.8181			
Montr	0.4466	0.4295	0.4002	0.6265	0.5662	0.5943	0.5596	0.6511	0.9136		
Fit	0.5436	0.5224	0.2910	0.5591	0.6537	0.6027	0.6144	0.6333	0.6348	0.9332	
Use	0.4957	0.4870	0.2627	0.5418	0.5762	0.5098	0.4528	0.6267	0.5665	0.7330	0.9376

5.4.4 Path modelling and Analysis

To analyze participants' evaluation on the experimental treatment one month after a similar post-test evaluation, we used PLS algorithm to generate indicator loadings and path coefficients as shown in Figure 5.16 below.

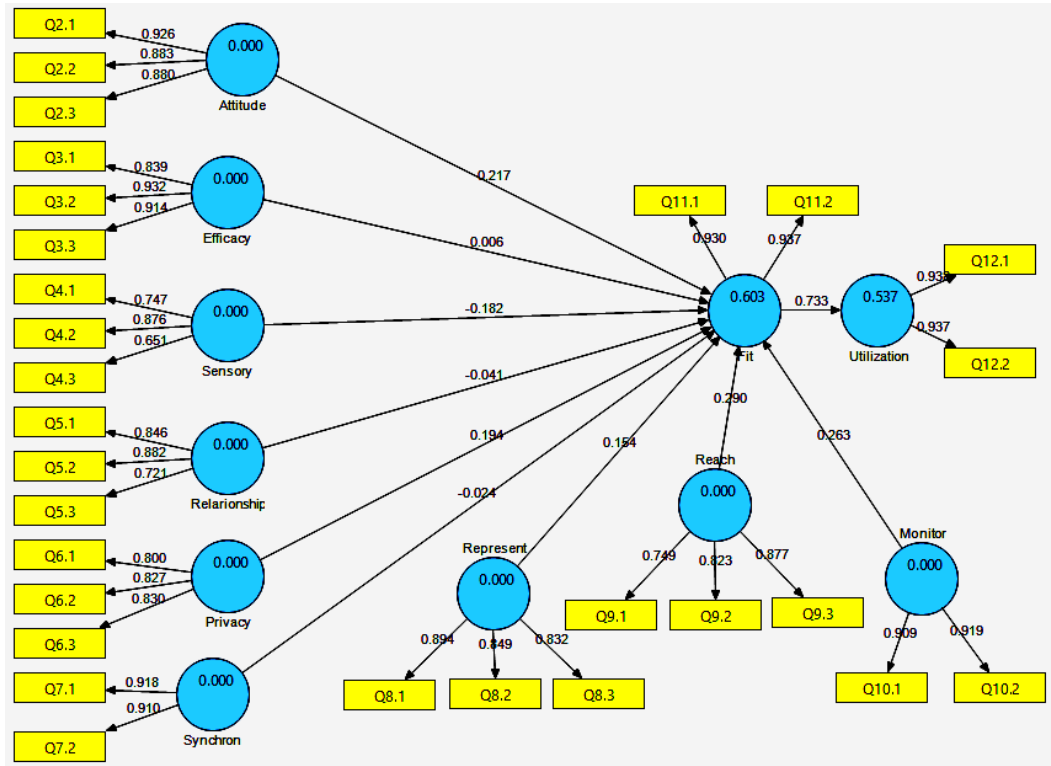


Figure 5.16: Post-test2 indicators and path coefficients

Factor Loadings

A visual inspection of the model demonstrates that most of the factors loaded with coefficients above 0.80 summarized in Table 5.22 below.

Table 5.22: Post-test2 factor loadings

Factor	Attit	Effic	Sense	Relat	Priva	Sync	Rep	Reach	Mont.	Fit	Utiliz.
Factor1	0.9259	0.8394	0.7473	0.8463	0.7999	0.9183	0.8941	0.7492	0.9086	0.9298	0.9385
Factor2	0.8834	0.9319	0.8761	0.8816	0.8271	0.9102	0.8493	0.8227	0.9186	0.9366	0.9367
Factor3	0.8805	0.9137	0.6509	0.7210	0.8302		0.8322	0.8772			

Path Coefficients and R²

Visual inspection of Figure 5.16 above shows that post-test2 data explains the model by 60.3% of variance on fit while fit as a mediator variable explains technology utilization by 53.7%. These R² coefficients indicate a drop in judgement of fit but marginal improvement on utilization of mamacare. Table 5.23 shows a summary of path coefficients of hypothesized causal-effect three months into the experiment.

Table 5.23: Post-test2 path coefficients

	Attit	Self	Sense	Relat	Priv	Sync	Rep	Reach	Mont	Fit-> Util.
Post-test2	0.217	0.006	-0.182	-0.041	0.194	-0.024	0.154	0.290	0.263	0.733

The table above shows that sensory, relationship and synchronism requirements negatively affect fit while the other six constructs i.e. attitude, self-efficacy, identification and privacy, representation, reach, and monitoring positively influences fit. Consistent with the pretest and post-test1 findings, the results shows that fit strongly influences technology utilization.

5.4.5 Significance of Factors and Path Coefficients

To evaluate impact of the treatment three months into the experiment, post-test2 indicators and path coefficients were subjected to bootstrapping algorithm to generate t-values. Statistical inference using generated t-values demonstrate that all the indicators were significant with t-values ranging between 10.917 and 85.010. This inference allowed us to analyze significance of path coefficients. Table 5.24 shows t-values of path coefficients generated from post-test2 dataset with significant paths marked in asterisk.

Table 5.24: Post-test2 inner model t-test values

	Attit	Self	Sense	Relat	Priv	Sync	Rep	Reach	Monit	Utiliz.
Post-test2	3.161*	0.075	-3.649*	-0.587	2.141*	-0.252	1.944*	3.643*	3.862*	20.395*

5.4.6 Summary of Post-test2 Results

Individual characteristics

The results of post-test2 observations confirmed the previous two tests that attitude effect on fit is positive and significant with $t = 3.161$. The results also showed that though self-efficacy has improved over time, its effect on fit is nonsignificant with a t-value of 0.075. Therefore, based on post-test2 inference it was justified to reject sub-hypothesis P_1 but there was no enough ground to reject P_2 .

Process requirements

Regarding use of mobile phones in maternal care, post-test2 results of process requirements confirmed that sensory requirements negative effect significantly influences fit of an mHealth artefact with t-value $= -3.649$. The findings also showed that “identification and privacy” with $t = 2.141$ has positive significant effect on fit. However, relationship with $t = -0.587$ and synchronism requirements with $t = -0.252$ registered nonsignificant effect. This justified rejecting sub-hypotheses P_3 and P_5 while failing to reject sub-hypotheses P_4 and P_6 .

Technology functionality

Results of post-test2 showed that reach with $t = 3.643$ and monitoring with a t -value of 3.862 have positive significant effect on fit. Unlike in post-test1, representation fell short of the critical value with $t = 1.944$, slightly less than the critical value of 1.96. A sneak preview of pretest and post-test1 reveals some inconsistencies in representation. Therefore, using our discretion and nearest neighbour policy (P_8 and P_9), we judged it as significant subject to further statistical tests to draw reliable inference. Therefore, based on post-test2 results we rejected the three technology functionality sub-hypotheses P_7 , P_8 and P_9 .

Fit and technology utilization

The empirical findings of post-test2 confirmed that indeed fit has strong significant effect on technology utilization with t -value = 20.395. Therefore, this inference gave us a strong reason to reject P_{10} . Table 5.25 gives a summary of the outcome of sub-hypotheses testing based on post-test2 statistical inference.

Table 5.25: Post-test2 sub-hypothesis test outcome

Concept	Pi	Sub-hypothesis	Outcome
Attitude	P1	Attitude towards technology has no significant effect on fit of mHealth intervention	Reject
Self-Efficacy	P2	Self-efficacy on using mobile devices and computers has no significant effect on fit of mHealth intervention	Fail to Reject
Sensory	P3	Sensory requirements of touch, sight and aural experience have no significant effect on fit of mHealth intervention.	Reject
Relationship	P4	Relationship requirement between patient and caregiver has no significant influence on fit of mHealth intervention	Fail to Reject
Identification and Privacy	P5	Identity and privacy requirement between patient and caregiver has no significant effect on fit of mHealth intervention	Reject
Synchronism	P6	Synchronism requirement of time-constrained processes has no significant effect on fit of mHealth intervention	Fail to Reject
Representation	P7	Representation capability of mHealth artefact has no significant effect on fit	Reject
Reach	P8	Reach capability of mHealth artefact has no significant effect on fit	Reject
Monitoring	P9	Monitoring capability of mHealth artefact has no significant effect on perceived fit	Reject
Fit	P10	Fit of mHealth artefact has no significant effect on its utilization in low-resource settings	Reject

5.5 Data Triangulation and Discussion of Results

Triangulation of data collected in longitudinal or repeated measures experimental designs attempts to determine diachronic reliability and stability of observations taken at different points in time (Cohen, Manion & Morrison 2007). Therefore, triangulation of data taken at different conditions or time points may be necessary for two reasons:

- When a more holistic view such as effectiveness of an intervention or experimental treatment is required.
- When data collection method used such as repeated measures results to inconsistent results that require further clarification.

Given that our experiment employed within-subjects repeated measures, triangulation of data from the three measures taken at different time points was necessary to establish effect of treatment as well as clarify on inconsistent observations before drawing inference on the null hypothesis. In this section, we discuss how observations from the three datasets were triangulated to investigate the overall effect of the treatment.

5.5.1 Within-Subjects Effect on Treatment

To investigate the overall effect of experimental treatment, we consolidated pretest and post-test datasets for each construct. Table 5.26 shows combined overview of path coefficients from the three observations. It is evident from the table that, whereas some constructs such as attitude showed consistent improvement over time, others like relationship dropped. The table also shows inconsistencies in representation and monitoring constructs.

Table 5.26: Comparison of pretest and post-tests path coefficients

	Attit	Self	Sense	Relat	Priv	Sync	Rep	Reach	Mont	Tech Utiliz.
Pre-test	0.186	-0.111	-0.077	0.537	0.065	0.174	0.116	-0.027	0.380	0.799
Post-test1	0.205	-0.057	-0.154	0.076	0.204	0.133	0.308	0.240	0.024	0.711
Post-test2	0.217	0.006	-0.182	-0.041	0.194	-0.024	0.154	0.290	0.263	0.733

Further, we evaluated significance of path coefficients based on each dataset. Table 5.27 below shows summarized t-values from the pretest, and the two post-tests with significant values marked in asterisk.

Table 5.27: Significance of pretest and post-tests path coefficients

	Attit	Self	Sense	Relat	Priv	Sync	Rep	Reach	Monit	Utiliz.
Pre-test	2.381*	-1.761	-1.788	5.086*	0.747	2.281*	1.432	-0.371	2.733*	20.480*
Post-test1	2.959*	-0.834	-3.553*	1.092	3.404*	1.302	3.909*	5.094*	0.303	19.518*
Post-test2	3.161*	0.075	-3.649*	-0.587	2.141*	-0.252	1.944*	3.643*	3.862*	20.395*

5.5.2 Treatment Effect on Individual characteristics

The results revealed interesting trends in attitude and self-efficacy before and after exposing the subjects to experimental treatment. This pattern motivated us to carry out more statistical inferences to validate the results. Inference on attitude showed some consistency with similar findings on attitude by Ajzen (1991), Ingram et al. (2000), Armitage & Conner (2001) and Hagger et al. (2002).

On the other hand, nonsignificance of self-efficacy was surprising because unlike other studies involving use of computers, we expected the subjects to be competent in using mobile phones (Goodhue & Thompson 1995; Strong, Dishaw & Bandy 2006; Overby and Konsynski 2010). Nevertheless, our observations on self-efficacy are consistent with studies such as that conducted by Strong, Dishaw and Bandy (2006) using extended Task-Technology Fit model. For example, using computer literacy as a dimension of individual behaviour, Goodhue and Thompson (1995) found it nonsignificant hence it was not included in their final TTF model. Later, Goodhue's findings were confirmed by Strong, Dishaw and Bandy (2006) using Computer Self-Efficacy. This is the same pattern revealed by three observations using repeated measures experiment. This suggests that self-efficacy has minimal impact on fit of a technology artefact because benefits accrued motivate people to learn how to use it.

5.5.3 Treatment Effect on Process requirements

This study used within-subjects design in a clinical environment to test propositions of Overby's (2008) relatively new theory. To the best of our knowledge, this kind of approach is one of its kind in health informatics research. According to a research commentary by Overby, Slaughter and Konsynski (2010), there is insufficient data on effectiveness of telemedicine in medical processes that require frequent monitoring! Therefore, this experiment was deliberately meant to identify factors that would accelerate integration of mHealth innovations in healthcare ecosystem (Davis & Venkatesh 2004; Strong, Dishaw & Bandy 2006; Overby, Slaughter & Konsynski 2010).

Results from the three datasets revealed that sensory requirement was consistently negative supporting Overby's (2008) process virtualization theory (PVT) propositions that sensory requirements negatively affects virtualization of a physical process. However, observations on the other three process requirement constructs showed mixed outcomes which required more inference to get a clear picture.

5.5.4 Treatment Effect on Technology Functionality

Overby posited that, IT capabilities of representation, reach and monitoring capability positively moderate negative process requirements. However, our model considered information technology as first-order independent variables same level as individual characteristics and process requirements. This is partly because mobile technology is one of the key drivers to successful deployment of mHealth interventions.

In this study, findings from the experiments indicate that representations and reach have positive effect on fit before and after intervention. Although, prediction on reach was negative prior to intervention there was great improvement after treatment. However, to clarify on other observed inconsistencies, it was necessary to use alternative statistical tests.

5.5.5 Effect of Time on Fit and Technology Utilization

The empirical findings in pretest, post-test1 and post-test2 showed consistent path coefficient between fit and technology utilization with t-values 20.480, 19.518 and 20.395 respectively. This confirms *predicting fit and utilization prior to implementation and deployment reduces the gap between design and reality thus high probability of acceptance and use*. In summary, Table 5.28 shows the outcome of sub-hypotheses testing that formed the basis for more inferences to clarify on inconsistent observations.

Table 5.28: Summary of Pretest and Post-tests sub-hypotheses testing

Concept	Pi	Sub-hypothesis	Pretest	Post-test1	Post-test2
Attitude	P1	Attitude towards technology has no significant effect on fit of mHealth intervention	Reject	Reject	Reject
Self-Efficacy	p2	Self-efficacy on using mobile devices and computers has no significant effect on fit of mHealth intervention	Fail to Reject	Fail to Reject	Fail to Reject
Sensory	p3	Sensory requirements of touch, sight and aural experience have no significant effect on fit of mHealth intervention.	Fail to Reject	Reject	Reject
Relationship	p4	Relationship requirement between patient and caregiver has no significant influence on fit of mHealth intervention	Reject	Fail to Reject	Fail to Reject
Identification and Privacy	p5	Identity and privacy requirement between patient and caregiver has no significant effect on fit of mHealth intervention	Fail to Reject	Reject	Fail to Reject

Synchronism	P6	Synchronism requirement of time-constrained processes has no significant effect on fit of mHealth intervention	Reject	Fail to Reject	Fail to Reject
Representation	P7	Representation capability of mHealth artefact has no significant effect on fit	Fail to Reject	Reject	Reject
Reach	P8	Reach capability of mHealth artefact has no significant effect on fit	Fail to Reject	Reject	Reject
Monitoring	P9	Monitoring capability of mHealth artefact has no significant effect on perceived fit	Reject	Fail to Reject	Reject
Fit	P10	Fit of mHealth artefact has no significant effect on its utilization in low-resource settings	Reject	Reject	Reject

The table shows that before and after treatment; attitude, self-efficacy and fit remained consistent. The table further shows that, while some cause-effect relationships were stable after the treatment, others dropped making it difficult to draw valid conclusions based on such observations. To evaluate the overall effect of treatment, we used repeated measures ANOVA followed by Bonferroni post-hoc test of differences between means. This approach is similar to that employed by Davis and Venkatesh (2004) to predict usefulness of information systems.

5.5.6 Composite Predictive Model

Davis and Venkatesh (2004) argue that usefulness of a system artefact can be predicted prior to its implementation. To investigate this assertion, we conducted a pretest to determine the predictive power of the model prior to exposing the subjects to an mHealth intervention. This is because it is important to understand stakeholder's behaviour that informs on their future acceptance of a planned intervention. Based on individual characteristics, process requirements and technology functionality, Figure 5.17 below shows that composite model predicted fit of about 67% and about 61% utilization.

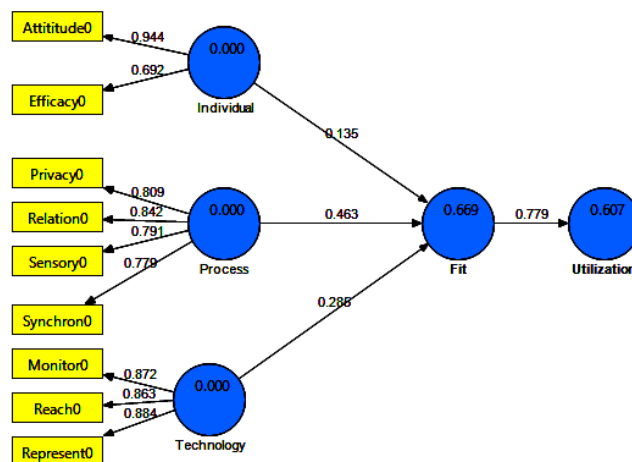


Figure 5.17: Composite TIPFit predictive model

To generate the composite model, we calculated the average data point from indicators of each construct. For example to generate a path coefficient between attitude and fit, we summed up the raw scores of indicators 2.1+2.2+2.3 then divided the total by 3. Table 5.29 gives a summary of statistical inferences on the three main constructs that influence fit and subsequent utilization of a planned mHealth intervention.

Table 5.29: Summary of composite predictive model coefficients

Construct	Path β	t-value	Effect- f^2	p-value	Remarks
Individual Characteristics	0.135	2.053	0.024	0.0439	Small significant effect
Process Requirements	0.463	3.007	0.233	$p < 0.001$	Large significant effect
Technology Functionality	0.285	2.695	0.073	0.008	Small significant effect
Fit ->Tech. utilization	0.779	20.297		$p < 0.001$	Large significant effect

5.5.7 Composite Evaluation model

After intervention, we evaluated user's satisfaction on intervention, similar to approach used by Goodhue (1998), and Davis and Venkatesh (2004). The rationale behind post-deployment evaluation was to compare predictions outcome with actual experience after exposure to an intervention. This approach is fundamental in predictive modelling to bridge the gap between design of mHealth artefacts and reality on the ground (Beale & Heard, 2007; Davis and Venkatesh, 2004). Figure 5.18 shows user's evaluation on fit and utilization of mamacare.

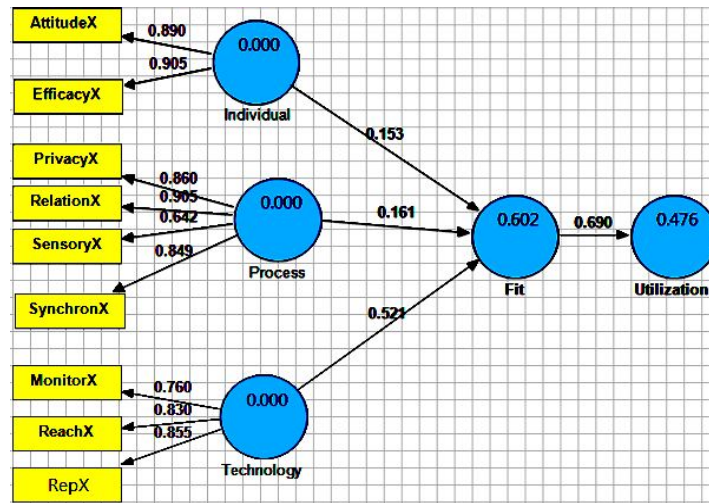


Figure 5.18: Composite utilization model

Based on individual characteristics, process requirements and technology functionality, about 60% felt mamacare is suitable with actual utilization of 48%. This is quite encouraging given the challenges in the context of this study. Table 5.30 shows a summary of statistical inferences on user's evaluation on the three main constructs that influence fit and persistent utilization of mamacare mHealth prototype.

Table 5.30: Summary of composite post-test model coefficients

Construct	Path β	t-value	Effect-f ²	p-value	Remarks
Individual Characteristics	0.153	2.828	0.025	0.006	Small significant effect
Process Requirements	0.161	2.776	0.020	0.007	Small significant effect
Technology Functionality	0.523	10.041	0.236	p< 0.001	large significant effect
Fit ->Tech. utilization	0.690	16.396		p< 0.001	Large significant effect

Though the two models are sufficient to draw inference on the main hypothesis (H_0), we also used alternative statistical methods to enhance reliability of our conclusions. This is by using parametric tests such as repeated measures ANOVA and Bonferroni post hoc test of differences between sample means. In the following section, we demonstrate parametric tests that were used as confirmation on findings from PLS-SEM.

5.5.8 Comparison between Sample Means

Due to some inconsistencies from the three repeated measures observations, it is reasonable to use parametric tests that draws inference from population means (μ) and variances (δ^2). In this study, we explored on use of parametric tests e.g. ANOVA against their non-parametric equivalents such as Friedman test. Given that parametric tests are more powerful, we subjected the three datasets to the following requirements for use of repeated measures ANOVA:

- *No extreme outliers*: there should be no significant outliers in the three levels of within-subjects factor
- *Assumption of normality*: The Central Limit Theorem states that: if $\bar{x}$ is a sample mean from a population with mean μ and variance δ^2 , the sampling distribution of means approaches normal distribution as n tends to ∞ (Panneerselvam 2006).
- *Sphericity*: the differences between variances on all combinations of levels of within-subjects factors should be homogenous.

Inspection for Outliers

To test whether there were significant outliers in the three datasets, we used a boxplot shown in Figure 5.19. Visual inspection of the boxplot shows that there were few outliers marked with case numbers. However, because it's practically normal to have outliers, we ignored them because there were no extreme cases that would have affected the outcome of repeated measures ANOVA.

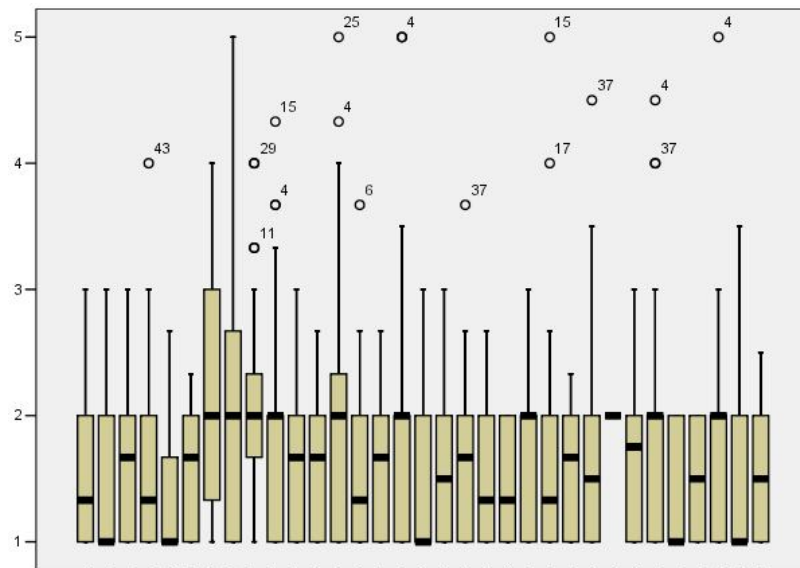


Figure 5.19: Boxplot inspection for outliers

Normality Test

To test for significance of differences between sample means in repeated measures ANOVA, the distribution of sampled means should be approximately normal. To assume normality where the population distribution is unknown, the Central Limit Theorem (CLT) states that “*distribution of sample means approaches normality as the size of n increases, regardless of the shape of the population distribution.*” Therefore, CLT can be used to assume normality of sample means for large samples. Most simulations used to determine the smallest sample size for CLT to hold states that at least 30 observations are sufficient. Using a dataset of 70 observations, we used central limit theorem to assume normality. Furthermore, repeated measures ANOVA relies on sample means, hence robust to violations of normality for large samples.

However, to statistically confirm this assumption, we used random number generator and one-sample t-test in SPSS on 10% subsamples drawn from each dataset. For example, attitude before intervention (attitude0) with a sample mean of 1.557, skewness of 0.635 and kurtosis of -0.501 was subjected to sampling distribution of mean using SPSS random seed. We then ran one-sample t-test with assumption of sample mean as the population mean. Table 5.31 (a) and (b) shows the test results for sampled distribution of attitude0 means i.e. 1.5838 and test of its difference from population mean($\bar{x} = \mu$) of 1.557.

Table 5.31 (a): Pretest subsample means for attitude

	N	Mean	Std. Deviation	Std. Error Mean
Attitude0	8	1.5838	.61186	.21632

Table 5.31 (b): Significance of difference between means

Test Value = 1.557						
	t-value	Degrees of freedom	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Attitude0	.124	7	.905	.02675	-.4848	.5383

The nonsignificance of distribution of sample means indicates that, as long as the dataset does not deviate extremely from normal distribution with skewness and kurtosis above ± 1.96 , the central limit theorem holds. Therefore, it was theoretically and statistically safe to assume normality of the three datasets to allow us to use parametric tests.

Sphericity Test

Sphericity is an assumption that, the differences between variances in repeated measures are almost equal. If assumption of sphericity is not violated, the variances and correlations among measurements are the same. Violation of sphericity is considered serious in RM-ANOVA because the computed F-ratio may be too low leading to high likelihood of committing Type I error. However, there are correction procedures such as *Greenhouse-Geisser* and *Huynh-Feldt* used to produce more valid F-ratios. To assess repeated measures dataset for sphericity, Mauchly's test evaluates a null hypothesis that assumes differences between variances for three 3 levels of measurements are the same. If the test is statistically significant ($p < 0.05$), we reject the null hypothesis that the differences are not equal. This implies that assumption of sphericity has been violated. For example, Mauchly's test for Attitude shown in Table 5.32 indicates that assumption of sphericity was not violated because inference on p-value of 0.766 was nonsignificant.

Table 5.32: Mauchly's test of sphericity

Factor level	Mauchly's W	Approx. Chi-Square	Degrees of freedom	Sig.	Epsilon(a)		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	0.992	0.534	2	0.766	0.992	1.000	0.500

Therefore, after testing the three datasets for outliers, normality and sphericity, the results showed that there were no significant outliers, and the assumptions of normality and sphericity were satisfied to justify use of parametric tests.

Test for Overall Treatment Effect

To evaluate the overall effect of experimental treatment, we considered one-way Repeated Measures ANOVA (RM-ANOVA) appropriate. For example, Table 5.33 shows that, after

testing *attitude* for sphericity which returned $\chi^2(2) = 4.412$ and $p = 0.110$, we used the first row to interpret the results. ANOVA results under *Sphericity Assumed* with $F(138, 2) = 2.473$ and $p = 0.088$ confirmed results from PLS modelling that indeed there was no significant change in attitude. This demonstrates that even after exposing the subjects to experimental treatment, participants had formed judgement on fit thus confirming TIPFit predictive power.

Table 5.33: Tests of Within-subjects effects

Source		Type III Sum of Squares	Degrees of freedom	Mean Square	F	Sig.	Partial Eta Squared
time	Sphericity Assumed	1.419	2	.710	2.473	.088	.035
	Greenhouse-Geisser	1.419	1.882	.754	2.473	.092	.035
	Huynh-Feldt	1.419	1.933	.734	2.473	.090	.035
	Lower-bound	1.419	1.000	1.419	2.473	.120	.035
Error(time)	Sphericity Assumed	39.585	138	.287			
	Greenhouse-Geisser	39.585	129.843	.305			
	Huynh-Feldt	39.585	133.362	.297			
	Lower-bound	39.585	69.000	.574			

In summary, Table 5.34 shows the outcome of repeated measures ANOVA inferences on the eleven TIPFit constructs. In the remarks column, the highlighted comments stating *G-G used* indicates that sphericity was violated. This means that the degrees of freedom used to compute the reported p-values were adjusted using the Greenhouse-Geisser epsilon (ϵ).

Table 5.34: Summary of Repeated Measures ANOVA

Construct	Sphericity: χ^2 & p		ANOVA: F & p		Effect Size	Remarks
	χ^2	p-value	F-ratio	p-value	Partial Eta ²	
Attitude	0.534	0.766	2.595	0.078	0.036	Not significant
Self-Efficacy	3.432	0.180	3.258	0.041	0.045	Significant
Sensory requirements	5.109	0.078	1.233	0.295	0.018	Not significant
Relationship	22.076	$p < 0.001^*$	4.038	0.029	0.055	G-G used: Significant
Identification and Privacy	9.980	0.007*	7.462	0.001	0.098	G-G used: Significant
Synchronism	13.683	0.001*	8.022	0.001	0.104	G-G used: Significant
Representation*	10.664	0.005	2.373	0.105	0.033	G-G used: Not significant
Reach	5.034	0.081	1.117	0.330	0.016	Not significant
Monitoring capability	20.082	$p < 0.001^*$	13.384	$p < 0.001$	0.162	G-G used: Significant
Fit	8.516	0.014*	10.144	$P < 0.001$	0.128	G-G used: Significant
Technology utilization	1.350	0.509	4.152	0.018	0.057	Significant

The table above shows that prediction before intervention and evaluation after treatment did not change the participants' standpoint on *attitude*, *sensory requirements*, *representation* and *reach*. In the table above, the ANOVA inferences also helped in disambiguating inconsistencies of representation observed in the three repeated measures PLS models.

Pairwise Differences between Means

To compare differences between the pretest and post-test observations, we employed *Bonferroni post-hoc* analysis holding the familywise error at 0.05. Table 5.35 shows the summary of differences between the three dataset means. The differences that are statistically significant are marked with asterisk.

Table 5.35: Bonferroni differences between sample means

Model Construct	Pretest		Post-test1		Post-test2		Mean differences		
	$\bar{x} = \mu$	SE	$\bar{x} = \mu$	SE	$\bar{x} = \mu$	SE	$T_0 - T_1$	$T_1 - T_2$	$T_0 - T_2$
Attitude	1.557	0.065	1.390	0.059	1.543	0.062	0.110	0.171	0.998
Efficacy	1.547	0.072	1.352	0.057	1.552	0.058	0.103	0.042*	1.000
Sensory	2.229	0.117	1.976	0.124	2.109	0.085	0.049*	0.208	0.388
Relationship	1.814	0.088	1.533	0.060	1.657	0.058	0.110	0.171	0.998
ID & Privacy	1.888	0.099	1.514	0.068	1.576	0.056	0.008*	0.859	0.008*
Synchronism	1.843	0.100	1.436	0.067	1.607	0.063	0.002*	0.092	0.094
Representation	1.634	0.067	1.471	0.055	1.519	0.052	0.113	0.834	0.481
Reach	1.743	0.071	1.595	0.084	1.648	0.055	0.472	0.933	0.641
Monitoring	1.657	0.082	2.000	0.000	1.600	0.064	0.000*	0.000*	0.922
Fit	1.771	0.088	1.357	0.055	1.536	0.056	0.000*	0.058	0.061
Utilization	1.686	0.082	1.429	0.065	1.507	0.058	0.023*	0.735	0.184

The table shows that there were significant differences between pretest and post-test1 in 6 out of 11 constructs. Between post-test1 and post-test2, only self-efficacy and monitoring had significant differences. Though we expected significance difference between the pretest and post-test2, the results showed that the only difference between the pretest and post-test2 was in identification and privacy. Therefore, to investigate on this unexpected pattern, we recommend similar experiments be replicated in a similar or different context to compare the findings.

5.5.9 Inference on Null Hypothesis

To draw inference on the the null hypothesis formulated for this study, we used the inferences from PLS-SEM together with repeated measures ANOVA and Bonferroni tests. This study set out to test a null hypothesis that states:

Fit of mHealth artefact has no significant effect on utilization in low-resource settings

To draw inference on null hypothesis, we first used the concrete models shown earlier in Figures 5.17 and 5.18, followed by RM-ANOVA and Bonferroni post hoc tests. Table 5.36 gives a recap of the concrete predictive and evaluation models showing effect of each of the

three main constructs (i.e. individual characteristics, process requirements and technology functionality) on fit and technology utilization.

Table 5.36: Summary of pretest and post-test statistical inference

Constructs	Pretest model				Post-test model			
	Path β	t-value	p-value	Effect	Path β	t-value	p-value	Effect
Individual Characteristics	0.135	2.053	0.0439	0.024	0.153	2.828	0.006	0.025
Process Requirements	0.463	4.736	p<0.001	0.233	0.161	2.776	0.007	0.020
Technology Functionality	0.285	2.695	0.008	0.073	0.523	10.041	p<0.001	0.236
Fit ->Tech. utilization	0.779	20.297	p<0.001		0.690	16.396	p<0.001	

The table shows that, though prediction on individual characteristics construct was significant before intervention, it greatly improved after the treatment. The same pattern was observed on technology functionality though it was equally significant before and after treatment. However, process requirements construct was significance before intervention but slightly dropped from 0.001 to 0.007 after exposing the cohort to prolonged maternal care intervention through mamacare prototype. Inference on the concrete models shows that, before exposure to treatment, process requirements construct had the highest effect on fit while individual characteristics had the least. However, after exposure to treatment, technology functionality returned the highest effect but individual characteristics remained relatively constant. Based on concrete predictive and evaluation models and statistical tests using repeated measure ANOVA and Bonferroni post hoc analysis, *we are 95% safe from committing Type I error*. Therefore, we **reject the null hypothesis (H_0)** in favour of the alternative hypothesis (H_1) that states:

*Fit of mHealth artefact in terms of individual, process and technology factors **has significant effect** on utilization*

“Scientific research requires application of the highest potentials of science and appropriate technologies to the intentional advancement of wellbeing and standard of living for all”

CHAPTER 6

Conclusion and Recommendations

6.1 Introduction

This study advances research in the area of technology adoption by identifying social-technical factors that influence acceptance and use of information technology artefacts with particular emphasis on mHealth interventions. Having set the context of the study which falls in health informatics research stream, we started off with ethnographic pre-study and review of relevant literature. Motivation from the pre-study engagements and insight from related work informed on our research problem, objectives, research questions and a null hypothesis in chapter one. Subsequent chapters have addressed how to solve the problem through socio-technical approach.

This chapter summarizes the study by reviewing the research process that gave birth to a predictive model for design of mHealth solutions fit for the context of use. The chapter also discusses the achievements and implications for practice informed by inferences drawn from the research findings. Finally, the chapter concludes by providing suggestions on further research to evaluate the validity and utility of the proposed model in different contexts.

6.2 Research Objectives Achievement

The purpose was to provide a holistic approach to scale-up utilization of mHealth interventions in low-resource settings. To realize this goal, we formulated three objectives whose achievements required answering three questions. Table 6.1 below restates the three objectives and questions raised in chapter one.

Table 6.1: Summary of research objectives and questions

#	Objective	Question
1	Identify key factors that influence deployment and effective utilization of mHealth interventions in low-resource settings	Which factors influence deployment and utilization of mHealth interventions in low resource settings?
2	Based on existing models and the key factors, derive a model that serves as a blueprint for design and deployment of mHealth solutions suitable for low-resource settings	How can a predictive model be used to bridge the gap between design and reality in order to scale-up utilization of mHealth in low-resource settings?
3	Develop a prototype to validate the model using a practical scenario in maternal and childcare services	How can such model be validated in terms of practical utility in a maternal care scenario?

6.2.1 Research Objective #1

To address the first objective, we sought to answer the question concerning “*factors that influence deployment and utilization of mHealth interventions*”. To answer this question, we embarked on a pre-study by visiting several hospitals among them Kenyatta National Hospital, Karen Hospital, Ruiru Sub-district hospital, Kiambu Hospital and Kimbimbi Sub-district Hospital. During these fieldwork visits, we met with patients and caregivers whom we discussed on health challenges, healthcare priorities, and strategies to improve access to healthcare in underserved areas.

From our fieldwork experience, conferences, and review of studies focusing on ICT innovations, we identified key factors that influence deployment and utilization of mHealth. These factors relate to people, healthcare processes and technology whose pointers are socio-technical issues such as infrastructure, technical expertise, professional qualifications, ethics, economic capacity and legal framework. This list of pointers is not exhaustive but limited to the context of technology deployment (Yu et al. 2006; Grameen Foundations 2011; Mechael et al. 2010; WHO 2011; Beale & Heard 2007; Vital Wave Consulting 2009; ITU 2010). By identifying these the key factors based on context, it is possible to align available technologies to people and process to maximize on acceptance and cost-effective utilization. In this view, we answered the first question to achieve our first objective.

6.2.2 Research Objective #2

Having identified key factors that influence integration of mHealth innovations into healthcare system, we dug deeper into literature to find out whether there are architectural models and theoretical frameworks that can answer our second question. In our literature review, we analyzed several models identifying their strengths, gaps and suggestions for further research. The main models that were considered relevant to this study include:

- *Technology Acceptance Model (Davis 1989)*: Contributed to attitude and self-efficacy concepts as pointers to prediction on attitude and ability to use technology.
- *Information System Success (DeLone & McLean 1995)*: Contributed to use of *attitude* as a generic replacement of “intention and perception”. Attitude is a widely researched concept in behavioural science studies such as that of conducted by Ajzen (1991) using Theory of Planned Behaviour (TPB). A meta-analysis by Armitage and Conner (2001) as well as that conducted by Hagger et al. (2002) confirmed that attitude has strong effect on “intention to” behaviour or action.

- *Task-Technology Fit (Goodhue & Thomson 1995)*: This model has been widely researched in the field of information systems research on technology utilization. Because the main goal of this study is to motivate utilization of mHealth solutions, we considered this model as the backbone of our study by adapting Task, Technology, Fit and technology use constructs into our research model.
- *Process Virtualization Theory (Overby 2008)*: Contributed to process requirements and information technology constructs adapted to replace generic task and technology characteristics of Task-Technology Fit model.

These four models were fundamental in configuring and operationalizing the proposed TIPFit model, similar to approach taken by Strong, Dishaw and Bandy (2006) and Overby and Konsynski (2010). This is because review of existing models proved none of the stand-alone models fitted exactly to the context of this study. The integrated predictive model based on a multi-linear regression was the answer to our second research question hence making it possible to realize the second objective.

6.2.3 Research Objective #3

Providing an answer to the third question was the most demanding undertaking in this study in terms of time and cost! While most researchers use technology adoption models in surveys, we believe in *design science philosophy* that emphasizes on “*demonstrating tangible results through the reduction of design concepts into actual practice*”. To be true to this philosophy, through iterative user-centred design, we developed an mHealth prototype for maternal care named *mamacare*. Mamacare is a context-aware application whose design and implementation was guided by a matrix that mapped identified key factors that influence fit and utilization of mHealth artefact onto design and implementation specifications. The maternal care prototype and data collection instruments derived from the model were used to investigate utility of the model in a clinical environment. Therefore, to realize the third objective, a repeated measures experiment was conducted during which the following three observations were recorded and analyzed:

- *Pretest*: This was the initial test taken before exposing the subjects to experimental treatment. Data collected was modelled using PLS and statistically analyzed using SPSS to predict fit and utilization of mHealth interventions.
- *Post-test1*: This measurement was taken midway within the experiment period to get feedback on effect of the treatment on the dependent variable. Data was modelled and statistically analyzed for comparison with the pretest findings.

- *Post-test2*: This was a follow-up test after three months of exposure to experimental treatment to compare with the pretest and post-test1 findings. This is why the same instrument used in post-test1 was used.

To determine the predictive power of TIPFit model, we triangulated datasets for modelling using PLS-SEM. To ensure reliability of our conclusions, the consolidated datasets were further subjected to parametric tests using repeated measures ANOVA and Bonferroni post-hoc analysis. The results from PLS-SEM and the two parametric tests justified rejection of the null hypothesis based on inference on the pre-intervention and post-intervention outcomes.

6.3 Benchmarking the Study

To benchmark our research findings with related studies, we reviewed empirical findings from related studies that informed this study. One of such studies is by Davis and Venkatesh (2004) pre-prototyping approach using TAM to predict usefulness and ease of use of a system prior to implementation in workplace. Although our study contexts are different, the experimental designs, predictive modelling and parametric analyses strategies used in both studies are similar. The outcome of this study confirms predictive ability of the proposed model hence confirming Davis and Venkatesh assertion that *evaluating user's perceptions on usefulness or fit of a system prior to implementation can be used to predict post-deployment acceptance and use*.

Another similarity between the two studies is observed inconsistencies in repeated measures experimental designs. While in our study there were inconsistencies for example in representation, we also observe the same in Davis and Venkatesh's outcome on perceived usefulness. We assume that such inconsistencies are inevitable in longitudinal experiments involving human subjects due to maturation or stable judgement after prolonged exposure to treatment. This implies that in longitudinal studies involving repeated observations, it is possible to determine whether mHealth interventions fulfil stakeholders' needs and expectations.

To further benchmark our findings, we analyzed Overby and Konsynski's (2010) survey on online purchase of used vehicles. To some extent, their findings depict similar trends to our findings. For example, there is similarity on inferences drawn concerning negative effect of sensory requirements on perceived fit. Similar patterns are also evident in perceived relationship, computer anxiety (our similar concept is self-efficacy) and the strong effect of

fit on technology utilization. However, given that the two studies used different research designs, these comparisons are not based on one-to-one mapping but overall pattern observed. More comparisons between our empirical findings and those of Strong, Dishaw and Bandy (2006) indicate similarities in nonsignificant outcome of self-efficacy. Therefore, without fear of contradiction, we are 95% confident that *“predicting fit of mHealth design concept prior to actual implementation is crucial to its post-deployment utilization.”* Furthermore, our research findings are in tandem with other empirical findings on acceptance and use of information technology by Davis (1989); Davis and Venkatesh (2004); Goodhue and Thompson (1995); Goodhue (1998); Ingram et al. (2000); Strong, Dishaw and Bandy (2006); and Overby and Konsynski (2010).

6.4 Implication for Practice

In this study, iterative user-centred design through predictive modelling technique was instrumental in design, implementation and deployment of an mHealth artefact for the people and by the people! This was achieved by involving patients and caregivers right from conceptualization throughout to design, implementation and deployment of mamacare prototype. To demonstrate tangible results through the reduction of design concepts into actual practice, this study contributes to healthcare transformation agenda for developing countries by recommending the following:

- There are simple but effective eHealth solutions that can be deployed on existing limited infrastructure to provide equitable access to healthcare. For example in Kenya, tremendous achievement in financial inclusion has been realized through Safaricom’s mPesa. Though mPesa is a simple SMS-based mobile payment system, its success has revolutionized even the banking section. Why can’t such success be replicated in health?
- Mobile phones however simple can enhance access to healthcare and coordinate a broad range of home-based and routine ambulatory care beyond the hospital walls. Using mamacare mHealth prototype, we demonstrated how mobile phones can be used to support maternal care patients even in absence of biometric sensors.
- Mobile phones can indirectly contribute to patient health outcome, improved patient monitoring as well as overall wellness of the society through public health education and awareness on disease outbreaks.
- Through a sector-wide approach, identify other factors that limit successful integration of mHealth into healthcare. This will help in development of comprehensive guidelines

that regulates use of mobile phones and biometric devices in patient monitoring and home-based care.

The results of this study demonstrate that mobile phones are not only a reserve for the financial sector but can also transform how we manage patients' health. This will contribute to enhanced access to healthcare services and information regardless of our demographic differences. In addition, the research gives a practical insight into hardware resources and *open source technologies* that may be considered in deploying cost-effective mHealth solutions that do not have to cost thousands or millions to acquire or maintain!

6.5 Research Contributions

In any research, it is important for a study not only to broaden theoretical foundation by investigating individual theories, but also to deepen the foundation by extending or integrating them where applicable. In view of this, this study contributes to the body of knowledge in four areas:

- **Technical:** In system development domain, the predictive model is intended to be used as a tool to support ISO/IEC/IEEE 29148:2011 standard for requirements engineering and ISO/IEC 25010:2011 standard for evaluation of systems and software quality. Through user-centred design approach, the proposed model indicators and evaluation metrics were guided by these standards in order to identify key requirements in order to transform conceptual designs into mHealth artefacts suitable for the context of use.
- **Theoretical:** Through predictive modelling, this study contributes to the enhancement of widely used information systems models such as Technology Acceptance Model, Task-Technology Fit model and Information Systems Success model. Above all, this study went beyond these widely used models to evaluate practical utility of the relatively new Process Virtualization Theory.
- **Structural Equation Modelling:** This study contributes to use of relatively new variance-based Structural Equation Modelling known as Partial Least Squares. By employing repeated measures experiment, we demonstrated that, PLS-SEM can be used to predict outcome or future behaviour provided the researcher employs sound methodologies in predictive modelling.
- **Health informatics:** In this study, we used repeated measures experimental design to validate practical utility of a theoretical model in a clinical environment. This approach

is unique in health informatics because it helped in revealing key factors and challenges that strongly influence virtualization of clinical processes in low-resource settings.

6.6 Conclusion

This study highlighted the importance of using socio-technical approach to predict user utilization of mHealth interventions prior to design and deployment. It is evident from the empirical findings that, mobile phones have the potential to address health challenges faced by communities in low-income countries. However, to better understand the underlying intrinsic and extrinsic issues, strategies used to deploy mHealth interventions should be realistic and appropriate to the needs and expectations of the intended users.

6.7 Future Research

This study focused on maternal care to predict fit and post-deployment utilization of mHealth artefacts. As a result, the empirical findings from this study may not generalize to other domains. Therefore, to further evaluate practical utility of the proposed model in other contexts, we recommend further research be conducted with emphasis on the following:

- Extend this study to test utility of the model on different clinical processes such as diagnosis, treatment and patient monitoring using wireless sensors. This is because accumulation of empirical findings will contribute to more explanatory power of process requirements in Overby's (2008) process virtualization theory.
- Though we used mamacare prototype to demonstrate how mHealth may be used in maternal care, the prototype is an open source artefact that researchers or system developers can re-configure or extend to support other healthcare processes.
- Future research based on predictive modelling may also involve adapting or extending TIPFit model for use in other domains such marketing, education, economics, agriculture and financial sector to test propositions of individual characteristics, process requirements and technology functionality in different contexts.
- Expand the nomological network by studying propositions of process requirements and information technology as originally proposed by Overby (2008) in Process Virtualization Theory and impact of IT (PVT).
- To take care of illiteracy level that makes it difficult to deploy meaningful mHealth innovations, we recommend further research be conducted to come up with better strategies in design of mHealth artefacts that fulfils needs and expectations of even the least educated members of the society.

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APPENDICES

Appendix 1: TIPFit Operationalization Definitions

Table A.1 below gives operations definition of each dimension used to measure latent construct of TIPFit in maternal care context.

Individual Characteristics
Attitude
• <i>Usefulness</i>: Degree to which an individual believes that using system artefact is valuable in realizing set goals • <i>Beliefs</i>: Individual's viewpoints, values and perceptions that influence his/her choice of behavioural actions such as value of using mobile phones manage health • <i>Effectiveness</i>: Degree to which set objectives or targets are achieved in solving a problem regardless of cost.
Self-Efficacy
• <i>Literacy</i>: Measure of individual's academic ability to read and write; or proficiency in using IT devices • <i>Ease of use</i>: Degree to which an individual believes that using an artefact is free of cognitive and physical effort • <i>Competence</i>: Individuals procession of required knowledge, skills, qualification and capacity to use system artefact or perform a task
Process Requirements
Sensory requirements
• <i>See</i>: Human being faculty of vision or perceiving objects using eyes • <i>Touch</i>: Human sense of feeling that results from the activation of neural receptors on primarily by contact • <i>Hear</i>: Human being aural sense of perceiving sound using ears -
Relationship requirements
• <i>Accessibility</i>: Degree to which one can obtain something; remotely or physically reach or approach somebody • <i>Rapport</i>: Close relationship in which two people understand each other's feelings and ideas • <i>Harmony</i>: Refers to the degree to which two parties are in agreement in terms of action, opinion and feeling.
Identification and privacy
• <i>Authenticity</i>: Degree to which the identity of a subject can be proved to be the one claimed • <i>Trust</i>: Degree to which a user or patients and caregivers believes that use of a system artefact cannot compromise privacy • <i>Consent</i>: Individual's verbal or written approval or permission to participate in a study, or treatment conditions • <i>Confidentiality</i>: Degree to which a system artefact ensures that data is only accessible to authorized users
Synchronism requirements
• <i>Availability</i> : Degree to which a service or information is accessible when required for use

• <i>Responsiveness</i>: Degree of efficiency with which a system can respond to user's request against time constraint
Technology Functionality
Representation
• <i>Format</i>: The way something is arranged, presented or stored • <i>Content</i>: Refers to information that is expressed using physical, electronic media, writing, sound or art • <i>Workflow</i>: Sequence of processes or tasks through which a piece of work passes from initiation to completion
Reach
• <i>Availability</i>: Degree to which something is present and ready for use or acquisition • <i>Convenience</i>: Degree to which something is well suited to one's purpose, comfort or needs • <i>Reliability</i>: Capability of a system or device to perform required functions under stated conditions without fail
Monitoring
• <i>Sufficient and quality data</i>: Degree to which a patient monitoring intervention provides relevant data in sufficient quality and quantity for necessary action to be taken • <i>Timeliness</i>: Degree to which an intervention delivers required output or feedback with minimal delay
Intervening and Dependent Variables
Fit
• <i>Expectations</i>: Individuals belief that certain behaviour or action will lead to successful outcomes or benefits • <i>Suitability</i>: Individual's judgement of worthiness or relevance of an artefact to realistic needs
Technology Utilization (mHealth)
• <i>Utilization</i>: Make practical, worthwhile or profitable use of a tool or system artefact • <i>Satisfaction</i>: Degree of fulfilment of one's objectives, target or desire against perceived constraint

Appendix 2: Sample Pretest Questionnaires

CLIENTS' OPINION ON USE OF MOBILE PHONES IN ANTENATAL AND POSTNATAL CARE

TIME _____

DATE _____

INSTRUCTIONS

1. This Form consists of 12 **Parts**. Kindly answer All or ask for help if the question is not clear
2. Please **DO NOT** write your Name
3. For Questions based on 5 Options, Please Select **ONLY ONE OPTION** if you **Strongly Agree, Agree, Not Sure, Disagree** or **Strongly Disagree**

1. Personal Details (This is for analysis only)

1.1. Age (Years)	1.2. Education	1.3. Pregnancies	1.4. Children	1.5. Own a Mobile?
☐ 15 – 19	☐ Primary	☐ 1	☐ 0	☐ Yes
☐ 20 – 25	☐ Secondary	☐ 2	☐ 1	☐ No
☐ 26 – 30	☐ College	☐ 3	☐ 2	
☐ 31 – 35	☐ University	☐ 4	☐ 3	
☐ Above 35	☐ None Above	☐ Above 4	☐ 4 and Above	

Personal Opinion

Please give us your opinion on use of mobile phones in Maternal and Child Healthcare (MCH)

- 2.1 In my opinion, use of mobile phone services in antenatal and postnatal care can be useful to me
☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
- 2.2 I believe use of mobile phone can make MCH improve service delivery to clients and patients
☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
- 2.3 Use of mobile phone services in maternal care can help me adhere to clinic follow-up schedule
☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

2. Mobile Phone Use

This section aims at getting information on your literacy and ability to use mobile phones

- 3.1 Because of my level of education, I easily learn how to use a mobile phone
☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
- 3.2 I have necessary skills in using a mobile phone to read, write and send sms messages
☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
- 3.2 I'm comfortable using a mobile phone to access services e.g. mobile money transfer (m-Pesa®)
☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Follow-up Clinics Please give us your views on whether use of mobile phone can minimize need of going to hospital 4.1 I believe good use of mobile phone can minimize need of going to hospital to see a doctor/nurse ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 4.2 I would be interested in checking my body condition e.g. BP and send observations to hospital via mobile phone for advice on any danger signs ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 4.3 Getting preventive care advice via mobile phone is better than going to ask from a doctor/nurse ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
Relationship with Medical Staff Please indicate your opinion on use of mobile phone in enhancing relationship with medical staff I believe use of mobile phone services can improve my relationship with medical staff in MCH ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree In case of health-related issues, I have no problem medical staff contacting me via mobile phone ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree I expect use of mobile phone to help in updating doctor/nurse on my own/baby's health status ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
Personal Privacy To what extent do you agree with the following statements regarding privacy of your health status? I easily distinguish between genuine sms/calls and those received from unknown sources ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree If my health record is to be stored in a computer, it should be available only to people I trust ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree I would like to be consulted if MCH section decides to be sending clinic sms messages to me ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
Timeliness To what extent do you agree with the following regarding timeliness of received sms reminders? I would like to be receiving clinic reminders via sms in good time so that I prepare for the visit ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree I would appreciate getting timely information e.g. danger signs and vaccination via my phone ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Clinic SMS Messages

If you would like to be receiving sms reminders, indicate your preference in regard to its content

8.1 If I'm to receive clinic sms reminders, the messages should be in my preferred language

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

8.2. The content of sms messages addressed to me should be short and easy to understand

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

8.3. I would like to get clinic sms messages that are relevant to my clinic follow-up programme

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Maternal Care Access

Please help us know how mobile phone can improve access to antenatal and postnatal care

9.1 If MCH decides to provide maternal care via phone, the service should always be available

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

9.2 I believe use of mobile phone services in MCH can improve access to antenatal/postnatal care

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

9.3 MCH should make it possible to access vital clinic follow-up information on mobile phone

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Health Monitoring

Please indicate extent to which mobile phones can help in monitoring you or your child's health

10.1 I believe adequate use of mobile phone can help in preparation for safe delivery/motherhood

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

10.2 Maternal care services via mobile phone should help in monitoring my own/baby's progress

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Expectations

Overall, indicate extent to which use of mobile services can meet your needs and expectations

11.1 I hope use of mobile phones to provide maternal care services will be suitable to my needs

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

11.2 I believe use of mobile phone services in antenatal/postnatal care will meet my expectations

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

General Remarks

Generally, comment on how we can make use of available technologies to improve maternal care

12.1 Generally, I like the idea of using mobile phones to provide better maternal care services

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

12.2 If provided by MCH, I would like to be getting information and services via mobile phone

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

12.3 If you agree with (12.2) above, please write the services you would LIKE to be provided through your mobile phone (see sample services below)

(Safe delivery, danger signs, medication adherence, vaccination, lab test results, nutrition, preventive care, family planning, education on HIV/Aids etc.)

Appendix 3: Sample Post-test Questionnaire

SUITABILITY OF MOBILE PHONES USE IN ANTENATAL AND POSTNATAL CARE

TIME _____ DATE _____

INSTRUCTIONS			
<i>This Form consists of 12 Parts. Kindly answer All or ask for help if the question is not clear</i> <i>Please DO NOT write your Name</i> <i>For Questions based on 5 Options, Please Select ONLY ONE OPTION if you Strongly Agree, Agree, Not Sure, Disagree or Strongly Disagree</i>			
Personal Details (This is for analysis only)			
1.1. Age (Years) ☐ 15 – 19 ☐ 20 – 25 ☐ 26 – 30 ☐ 31 – 35 ☐ Above 35	1.2. Education Level ☐ Primary ☐ Secondary ☐ College ☐ University ☐ None Above	1.3. No. of Pregnancies ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ Above 4	1.4. No. of Children ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 and Above
Personal Opinion			
Please give us your opinion on use of mobile phones in Maternal and Child Healthcare (MCH) 2.1 Based on my experience, use of mobile phone services in antenatal and postnatal care is useful ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 2.2 Use of mobile phone is a good idea for improving service delivery in maternal healthcare ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 2.3 Clinic sms reminders I receive from MCH has helped me adhere to clinic follow-up schedule ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree			
Ease of Using Mobile Phone			
This section aims at getting information on your literacy and ability to use mobile phones 1.1 Because of my level of education, I easily learned how to use my mobile phone ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 3.2 I have necessary skills in using a mobile phone to read, write and send sms messages ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 1.2 I'm comfortable using a mobile phone to read sms messages sent to me from MCH section ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree			
Follow-up Clinics			

Please give us your views on whether use of mobile phone minimizes need of going to hospital 4.1 I believe good use of mobile phone minimizes need of going to hospital to see a doctor/nurse ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 4.2 I'm interested in checking my body condition e.g. BP and send observations via mobile phone to hospital for advice on any danger signs ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 4.3 Getting preventive care advice via mobile phone is better than going to ask from a doctor/nurse ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
Relationship with Medical Staff Please indicate your opinion on use of mobile phone in enhancing relationship with medical staff I believe use of mobile phone has improved my relationship with medical staff in MCH section ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree In case of health-related issues, a medical staff can easily contact me through mobile phone ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree I believe use of mobile phone helps in updating doctor/nurse on my own/baby's health progress ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
Personal Privacy To what extent do you agree with the following statements regarding identification and privacy? I easily identify sms/calls received from MCH section and those from unknown sources ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree I would like MCH to handle my records stored in the computer as private and confidential ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree I'm comfortable receiving sms reminders from MCH section because I was informed about it ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
Timeliness To what extent do you agree with the following regarding timeliness of received sms messages? I receive clinic sms reminder in time which helps me remember to prepare for scheduled visit ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree I appreciate getting timely information e.g. danger signs and preventive care via mobile phone ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Clinic SMS Messages

Please indicate your opinion on content and format of sms messages received from MCH section

8.1 Clinic sms messages I receive addresses me by name, with content that is easy to understand

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

8.2. I like the idea of choosing my preferred language for receiving clinic sms messages from MCH

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

8.3. Clinic sms messages I receive are in line with my current antenatal/postnatal clinic follow-up

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Maternal Care Access

Please help us know how mobile phone can improve access to maternal care services

9.1 Since I was registered for mobile phone services, I always get/got clinic visit messages via sms

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

9.2 Use of mobile phone services in MCH section provides better access to antenatal/postnatal care

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

9.3 MCH makes it possible to get antenatal and postnatal care information through mobile phone

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Health Monitoring

Please indicate extent to which mobile phone helps in monitoring your own/child health status

10.1 I believe adequate and timely calls/sms helps in preparation for safe delivery/motherhood

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

10.2 I believe good use of mobile phone services helps in monitoring of my own/baby's progress

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Suitability

Overall, indicate whether sms messages you have been receiving from MCH section are suitable

11.1 Based on my experience, clinic sms reminders I receive from MCH section are important

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

11.2 I would recommend use of mobile phone services be offered to all antenatal/postnatal clients

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

General Remarks

Generally, indicate whether you are satisfied with current mobile phone services provided by MCH

12.1 Generally, I'm satisfied with the current clinic reminders sent via sms to me by MCH section

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

12.2 So long as I'm in antenatal/postnatal care, I would like to be getting services via mobile phone

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

12.3 If you agree with (12.2) above, please list maternal care services you would LIKE to be provided through your mobile phone. (For ease of listing, see sample services below)

(Safe delivery, danger signs, medication adherence, vaccination, lab test results, nutrition, preventive care, family planning, education on HIV/Aids etc.)

Appendix 4: Informed Consent

Consent for participation in a study to evaluate suitability of mHealth solutions in Low-resource setting in Kenya

Why are you being given this form?

The reason we are giving you this form is for you to understand about our study particularly your rights, risks and benefits. Once you have understood the content, you can decide if you wish to participate. After all, you can also decide to voluntarily withdraw from the study any time you feel deemed fit.

Who is doing this study?

My name is Stephen N. Mburu. Undertaking my doctorate studies (PhD) at the University of Nairobi. My research interest is use of Information technologies to enhance access to healthcare services and information particularly in underserved areas in Kenya. My supervisors Professor Okelo-Odongo and Dr. Robert Oboko are lectures in the School of Computing and Informatics, University of Nairobi.

What is the purpose of this study?

Given that mHealth is relatively new, the complexity of implementing solutions suitable for realistic healthcare needs is evident in failed attempts to integrate it into healthcare system. Therefore, the purpose of this study is to evaluate suitability of mHealth interventions in accessing care services and information in maternal health. The findings from this study will be used as a guide for mHealth innovators and policy makers in healthcare sector to manage deployment of mHealth interventions.

Risks and discomforts

Though there are no known risks and discomfort before the commencement of the study, necessary measures will be undertaken if encountered. In case any issue crops up during the study, we will assist you as a participant to seek for further clarifications from the principal researcher and hospital administration.

What are the benefits to being in this study?

Because participation is voluntary, the participant will not receive any participation payment, gifts or rewards. However, if necessary, we will offer technological support and resources that may be needed to run the project.

What are the possible costs to participating?

Participant will not incur any financial cost other than the time required for participating in this research study.

Confidentiality:

The information provided in this study will be treated as confidential hence it will not be used for any other purpose other than for this study. In case as a participant you wouldn't want your identity disclosed, we shall not disclose it in whichever form or media.

Compensation for Research Related Injury:

This research is voluntary and non-intrusive hence no research related risks are anticipated. As a participant you have the rights to participate, not participate, or withdraw from the study at any time. In case any physical, physiological or psychological harm occurs during the study that may affect your participation, necessary steps will be taken to mitigate the risk, injury or harm.

CONSENT FORM

I (full name of participant) have read the above information / the above information has been explained to me by (full name of person taking consent), and I have fully understood the information. I have had opportunity to ask questions, and all my questions have been answered to my satisfaction. I understand that I may at any time during the study revoke my consent without any loss or penalty. I consent to be enrolled in the study.

Signature.....
(Participant)

Signature.....
(Person taking consent)

Signature.....Name (Print).....
(Witness)

Date.....

In case you require any further information or clarifications, please contact the principal investigator using the contact details below:

Stephen N. Mburu
Tutorial Fellow, School of Computing and Informatics,
University of Nairobi.
Mobile: +254 722 402 684; E-mail: smburu@uonbi.ac.ke

Appendix 5: Cover Letter

Stephen N. Mburu
School of Computing and Informatics
University of Nairobi
P. O. Box 30197 – 00100 GPO
NAIROBI

Date.....

Dear Respondent,

RE: VOLUNTARY PARTICIPATION IN FIELD STUDY

My name is Stephen N. Mburu, a PhD student of Computer Science in the School of Computing and Informatics, University of Nairobi. My research interest is use of Information technologies to enhance access to healthcare particularly in underserved areas in Kenya.

The purpose of this study is to demonstrate how to evaluate suitability of mHealth interventions prior to actual deployment. The findings from the study will be used as a blueprint for system developers and policy makers in healthcare sector to manage deployment of mHealth interventions suitable for intended use.

To achieve this objective, we invite your voluntary participation in our field experiment. As a participant you have the rights to participate, or withdraw from the study at any time. In case any physical or physiological harm that may affect your participation occurs during the study, necessary steps will be undertaken to mitigate the risk or injury. To safeguard your privacy, the information you provide during the study will be treated as confidential and will only be used for the purpose of this study. We appreciate your sacrifice to making this study a success.

Thank you.

Stephen N. Mburu, University of Nairobi.
Mobile: +254 722 402 684;
E-mail: *smburu@uonbi.ac.ke*

Appendix 6: KNH/UoN-ERC Research Approval



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P O BOX 19676 Code 00202
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(254-020) 2726300 Ext 44355



KNH/UON-ERC
Email: uonknh_erc@uonbi.ac.ke
Website: www.uonbi.ac.ke



KENYATTA NATIONAL HOSPITAL
P O BOX 20723 Code 00202
Tel: 726300-9
Fax: 725272
Telegrams: MEDSUP, Nairobi

Ref: KNH-ERC/A/375 Link: www.uonbi.ac.ke/activities/KNHUoN 26th November 2013

Stephen N. Mburu
School of Computing and Informatics
University of Nairobi

Dear Stephen

Research Proposal: A Model for Deployment of mHealth Solutions for Developing Countries (P511/10/2013)

This is to inform you that the KNH/UoN-Ethics & Research Committee (KNH/UoN-ERC) has reviewed and approved your above proposal. The approval periods are 26th November 2013 to 25th November 2014.

This approval is subject to compliance with the following requirements:

- Only approved documents (informed consents, study instruments, advertising materials etc) will be used.
- All changes (amendments, deviations, violations etc) are submitted for review and approval by KNH/UoN ERC before implementation.
- Death and life threatening problems and severe adverse events (SAEs) or unexpected adverse events whether related or unrelated to the study must be reported to the KNH/UoN ERC within 72 hours of notification.
- Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to KNH/UoN ERC within 72 hours.
- Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. (*Attach a comprehensive progress report to support the renewal*).
- Clearance for export of biological specimens must be obtained from KNH/UoN-Ethics & Research Committee for each batch of shipment.
- Submission of an *executive summary* report within 90 days upon completion of the study. This information will form part of the data base that will be consulted in future when processing related research studies so as to minimize chances of study duplication and/or plagiarism.

For more details consult the KNH/UoN ERC website www.uonbi.ac.ke/activities/KNHUoN.

Yours sincerely

PROF. M.L. CHINDIA
SECRETARY, KNH/UON-ERC

c c Prof. A.N. Guantai, Chairperson, KNH/UoN-ERC
 The Deputy Director CS, KNH
 The Principal, College of Health Sciences, UoN
 AD-Health Information, KNH
 Supervisor: Prof. Okello-Odongo

Appendix 7: Ministry of Health Research Approval


MINISTRY OF HEALTH
OFFICE OF THE DIRECTOR OF MEDICAL SERVICES

Telegram: "MINHEALTH", Nairobi
Telephone: Nairobi 254-20-2717077
Fax: 254 – 20- 2713750
When replying please quote

AFYA HOUSE
CATHEDRAL ROAD
P.O. BOX 30016
NAIROBI

Ref: MOH/REP/3/1/55

25th July, 2014

Mr. Stephen N. Mburu
School of Computing and Informatics
University of Nairobi

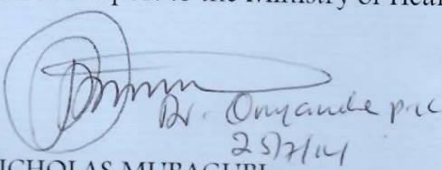
RE: REQUEST FOR AUTHORITY TO CONDUCT RESEARCH ON mHEALTH
INTERVENTION IN MATERNAL AND CHILD HEALTHCARE

Your letter dated 23rd July, 2014 on the above subject refers.

This is to acknowledge receipt of your PhD Research Project Proposal titled:
A Model for Deployment of mHealth Solutions for Developing Countries.

We have reviewed your documents and it is noted that you intend to conduct
the field experiment in Kiambu and Kirinyaga Counties.

The purpose of this communication is to inform you that authority has been
granted. On conclusion of the exercise you are expected to hand in a copy of
the research report to the Ministry of Health.


25/7/14

For: DR. NICHOLAS MURAGURI
DIRECTOR OF MEDICAL SERVICES

Figure A7: Copy of Ministry of Health Research Approval

Appendix 8: Mamacare Prototype Development

This appendix consists of important details used in conceptualization, and development of an mHealth prototype named *mamacare* that we used in our experiment. The system is hosted in one of the university of Nairobi servers under URL: www.mamacare.uonbi.ac.ke. The appendix is divided into the following six sub-sections:

- Appendix 8A: Pre-study questionnaire – This was the first questionnaire that was administered online on doctors who some of whom participated throughout this study. The responses from the respondents are discussed in chapter 5 under pre-study section.
- Appendix 8B: Prototyping questionnaire – This questionnaire was administered to 29 antenatal, maternity and postnatal clients during prototype design. Observations were factored into design of mamacare prototype.
- Appendix 8C: Evaluation of user satisfaction – This questionnaire was a follow-up to questionnaire 8A that was administered on eight caregivers to evaluate suitability of mamacare prototype before deployment.
- Appendix 8D: Mamacare user interface screenshots – These are illustrations of mamacare user interface on desktop computers and mobile phones.
- Appendix 8E: Database schema – This is mamacare database schema that was designed in MySQL Workbench and forward engineered to MySQL relational database management system.
- Appendix 8F: Mamacare sample code – These are selected HTML5, PHP, JavaScript, bash scripts and SMS Tools gateway configuration script used to implement mamacare system.

For more details on the system, you may contact the principal developer for a guest account using email address: smburu.uonbi.ac.ke.

Appendix 8A: Sample Pre-Study Questionnaire

A5. Review of mHealth in Healthcare Services

The aim of this study is to determine how mobile phones can be used to enhance the quantity and quality of healthcare in areas characterized by low income and physically hard to access in Kenya. Please fill free to express your opinion in this Questionnaire. For confidentiality reasons, Your response will only be used for the purpose of this study.

* Required

1. Which of the following healthcare Services do you think are being provided using mobile phones in Kenya *

(Response may be based on information from media)

- ☐ Mobile Call Help Centre
☐ Community Mobilization and Awareness
☐ Mobile Telemedicine [Diagnosis and Treatment]
☐ Emergency Services
☐ Surveillance and Data Collection
☐ Other:

2. From (1) above, if NONE of the services is offered, Suggest Why Mobile use in healthcare is INSIGNIFICANT:
 (This is your opinion based on experience in medical domain)

3. From your Opinion, Which of the following challenges need to be addressed if mHealth is to be SIGNIFICANT?
 (These challenges are basically drawn from mHealth model provided in my Research for FIT)

- ☐ Individual's Attitude [Medical Professionals and Patients]
☐ mHealth Usefulness [Cost-effective and User Needs]
☐ Clinical Examination [Due to Demand for Touch, Hear, See, Smell, Taste]
☐ Security [Trust and Data privacy]
☐ Infrastructure [healthcare Resources, Telecommunication]
☐ Other:

4. Indicate the LEVEL of Importance in changing Healthcare Professional's ATTITUDE to SEE VALUE in mHealth *
 (Opinion on what can make mHealth be of value to you as a Doctor)

- 1 2 3 4 5
 Least ☐ ☐ ☐ ☐ ☐ Most

5. Please score mHealth USEFULNESS in terms of COST-BENEFITS Value to both the Hospital and Patients : *
 (Opinion on what can make mHealth be of value to you as a Doctor)

- 1 2 3 4 5
 Least ☐ ☐ ☐ ☐ ☐ Most

6. Please Indicate HOW MUCH Mobile phones can be used to Perform Clinical Diagnosis/Examinations: *
 (Opinion on whether it is possible to diagnosis voice call, internet, SMS, etc)

- 1 2 3 4 5
 Least Important ☐ ☐ ☐ ☐ ☐ Most Important

7. How much do you think use of phones would compromise Medical Ethics issues Related to Trust and Privacy of Medical data? *
 (Opinion on what can make mHealth be of value to you as a Doctor)

- 1 2 3 4 5
 Least ☐ ☐ ☐ ☐ ☐ Most

8. Please Indicate the LEVEL you think phones can be used to enhance access to quality medical care security issues are addressed *
 (General Opinion on whether mHealth be of value to you as a Doctor)

- 1 2 3 4 5
 Least ☐ ☐ ☐ ☐ ☐ Most

9. If mHealth issues stated above were resolved, Which is the MOST Important healthcare area would mHealth be SUITABLE *
 (Choose or List only ONE)

- ☐ Maternal Care
☐ HealthCare: Children < 5 Years
☐ Patient Monitoring: Chronic Diseases
☐ Health Education and Awareness
☐ Emergency Alerts
☐ Diagnosis and Treatment
☐ Professional Consultations
☐ Other:

10. General Remarks

(Your opinion regarding mHealth initiatives Locally or Globally)

Submit

Appendix 8B: Sample Pre-prototyping Questionnaire

A: INVESTIGATING SUITABILITY OF MOBILE PHONES IN MATERNAL CARE

SERIAL NO _____

Time interview started HH MM		Time interview ended HH MM	
Date of interview DD MM YY			
INSTRUCTIONS 1. This Questionnaire consists of 12 Parts. Please answer all questions in each section 2. Do not indicate your Name on the questionnaire 3. Make sure that you tick within the box. 4. In the sections based on 5 options, give your opinion whereby 1 Strongly Disagree, 2 means Not Sure and 5 means you Strongly Agree			
3. Personal Details (This is for analysis only)			
1.1. Home Village/Estate _____		1.2. Age	
		☐ 15 – 19 Years ☐ 20 – 25 Years ☐ 26 – 30 Years ☐ 31 – 35 Years ☐ Above 35	
1.3. Education Level	1.4. Gestation (Weeks)	1.5. Number of Kids	
☐ Below Primary ☐ Primary ☐ Secondary ☐ College ☐ University	☐ 01 – 12 (Trimester 1) ☐ 13 - 28 (Trimester 2) ☐ 29 – 40 (Trimester 3)	☐ 0 ☐ 1 - 2 ☐ Above 2	
4. Mobile Use			
<i>If you have a mobile phone, this section aims at getting general information on how you normally use the phone</i>			
2.1. Do you have your own mobile phone?			
☐ Yes. ☐ No.			

2.2. Which of the following services does your mobile phone support? (*you can select one or more*)

- ☐ Calls
- ☐ SMS
- ☐ Internet

2.3. Using my mobile phone, I can easily make and answer calls (*Tick yes or no*)

- ☐ Yes.
- ☐ No

2.4. Using my mobile phone, I can easily send and receive sms messages

- ☐ Yes
- ☐ No

2.5. How many times do you receive or make phone call daily? (*Select calling and receiving rates*)

	0 - 5	6 - 10	Over 10
Calling			
Receiving			

(*Just rough estimate*)

2.6. How many times do you receive or send SMS daily? (*Select sending and receiving sms rates*)

	0 - 5	6 - 10	Over 10
Sending			
Receiving			

2.7. What problems you experience with use of your mobile phone? (*state one or more*)

5. Personal Opinion

Personal opinion refers to your view on importance of mobile phones in maternal care (tick yes/no)

3.1. Use mobile phones to provide maternal and child healthcare services is a noble idea

- ☐ Yes
- ☐ No.

3.2. I would be interested in getting maternal and child health alerts on my mobile phone

- ☐ Yes
- ☐ No

3.3. Instead of waiting for test results in hospital, I would wish to get through mobile phone

- ☐ Yes.
- ☐ No

6. Sensory Requirements

Sensory requirements refer to senses such sight, smell, hearing, taste and smell required in diagnosis and treatment

4.1. During clinic visits, I must see or talk to the doctor or nurse to have my health problems

☐ Yes.

☐ No

4.2. If a mobile phone can help get services, I would choose to use it to save time and cost of going to hospital

☐ Yes.

☐ No

7. Relationship with Doctors or Nurses

Your view on social need to meet and interact with other patients and caregivers Tick ✓ only one

5.1. During clinic regular visits, I enjoy meeting and sharing my status with my friends

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

5.2. During clinics, I like meeting and sharing my progress with nurses/doctors

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

5.3. If a phone help get information I need from the hospital, I would like to use it

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

8. Identity and Privacy

To what extent do you agree with the following regarding your privacy? Tick ✓ only one

6.1. I would only like to receive health information through a mobile number I know

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

6.2. I have **no problem** sharing my health status with doctor/nurse through my phone

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

6.3. I **believe** that service provider (e.g. Safaricom) is capable of protecting calls and sms

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

6.4. I have **no problem** receiving reminders and lab tests from hospital through phone

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

9. Efficiency and Convenience

To what extent do you agree with the following regarding efficiency and convenience?

7.1. I **would wish** to get mobile reminders and feedback any time I need

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

7.2. I **would wish** to get from hospital immediate feedback on my current health status

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

10. Communication Method
<i>If the hospital would wish to contact you through mobile, choose how you would like it done</i>
8.1. I would prefer to receive information using the following (<i>choose one or more</i>) ☐ Calls ☐ SMS ☐ Internet ☐ Any Other_____
8.2. I would prefer to receive feedback or reminders in: (<i>choose one or more</i>): ☐ English ☐ Kiswahili ☐ Kikuyu ☐ Any Other _____
11. Reach (Access)
<i>Reach refers to ease of accessing maternal care services and information. <u>Tick✓only one</u></i>
9.1. Mobile phone should allow me to easily get information I need from hospital ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
9.2. Where necessary, a mobile phone should lower the cost of going to hospital ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
12. Monitoring
<i>To what extent do you agree with the following regarding monitoring? <u>Tick✓only one</u></i>
10.1. I believe the hospital and service provider are capable of protecting my privacy ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
10.2. Using technology, I believe the hospital is capable of monitoring on my progress ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
13. Suitability
<i>Generally, indicate how suitable use of mobile is in maternal care <u>Tick✓ only one</u></i>
11.1. If maternal services are provided through mobile, I would like to use it ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree
11.2. In this digital age, I believe use of mobile phones in maternal care is a good idea ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

Appendix 8B: Sample Pre-prototyping Questionnaire

B: SPSS CODEBOOK FOR INVESTIGATING SUITABILITY OF MOBILE PHONES IN MATERNAL CARE

	Name	Type	Width	Decimals	Label	Values	Missing
1	pid	Numeric	8	0		None	None
2	bhome	Numeric	8	0		None	9
3	bage	Numeric	8	0		{1, 15-25 Year	9
4	beduc	Numeric	8	0		{1, Primary}...	9
5	bpgs	Numeric	8	0		{1, 1 Pregnan	9
6	bbirths	Numeric	8	0		{1, 0-1 Births}	9
7	mown	Numeric	8	0		{1, Yes}...	9
8	muse	Numeric	8	0		{1, Call}...	9
9	mdcalls	Numeric	8	0		{1, 0-5 Calls}...	9
10	mdreceive	Numeric	8	0		{1, 0-5 Calls}...	9
11	mdsmsend	Numeric	8	0		{1, 0-5 Msgs}...	9
12	mdsmrecv	Numeric	8	0		{1, 0-5 Msgs}...	9
13	mdproble	Numeric	8	0		{1, Network}...	9
14	attest	Numeric	8	0		{1, Yes}...	9
15	aalert	Numeric	8	0		{1, Yes}...	9
16	aprivacy	Numeric	8	0		{1, Yes}...	9
17	esms	Numeric	8	0		{1, Yes}...	9
18	elearn	Numeric	8	0		{1, Yes}...	9
19	esmtyp	Numeric	8	0		{1, Yes}...	9
20	xconsult	Numeric	8	0		{1, Yes}...	9
21	xmonitor	Numeric	8	0		{1, Yes}...	9
22	raccess	Numeric	8	0		{1, Strongly A	9
23	rlanguage	Numeric	8	0		{1, English}...	9
24	pproblem	Numeric	8	0		{1, Strongly A	9
25	ptrust	Numeric	8	0		{1, Strongly A	9
26	premind	Numeric	8	0		{1, Strongly A	9
27	falertok	Numeric	8	0		{1, Strongly A	9
28	ffidbakok	Numeric	8	0		{1, Strongly A	9
29	kstatus	Numeric	8	0		{1, Calls}...	9
30	ksee	Numeric	8	0		{1, Strongly A	9
31	tinfo	Numeric	8	0		{1, Strongly A	9
32	tcost	Numeric	8	0		{1, Strongly A	9
33	vatitude	Numeric	8	0		{1, Strongly A	9
34	vupdate	Numeric	8	0		{1, Strongly A	9
35	zuse	Numeric	8	0		{1, Strongly A	9
36	zoption	Numeric	8	0		{1, Strongly A	9

Appendix 8C: Sample Prototyping Questionnaires

A: SATISFACTION OF CAREGIVERS – MAMACARE PROTOTYPE

Time interview started HH MM 	Time interview ended HH MM
Date of interview DD MM YY 	
INSTRUCTIONS	
1. This Questionnaire consists of 7 Parts . Please answer all questions in each section 2. Do not indicate your Name on the questionnaire 3. Make sure that you tick within the box. 4. In the sections based on 5 options, indicate your opinion using the scale <i>Strongly Agree</i> to <i>Strongly Disagree</i>	
1. Personal Details (This is for analysis only)	
1.1 Designation _____	1.2. Age ☐ 20 – 30 Years ☐ 31 – 40 Years ☐ 41 – 50 Years ☐ Above 50
2. System Accuracy	
<i>State your observation concerning the accuracy of the system</i> 2.1 The system provides accurate reports ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 2.2 I'm satisfied with the accuracy of the system? ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree	
3. Content	
<i>To what extent do you agree with the following regarding recording and reporting</i> 3.1 The system provides precise information I need for reporting purpose ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 3.2 The system provide all reports that seems to be exactly what I need for reporting ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree 3.3 The system provides sufficient entry forms for most of the manual records used ☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree	
4. Ease of Use	

To what extent do you agree with the following regarding user-friendliness of the system

4.1 The system is user-friendly

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

4.2 The system is easy to use

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

4.3 The system looks nice and attractive

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

5. Output Format

To what extent do you agree with the following regarding reports and data forms

5.1. The system reports are presented in a nice format

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

5.2. The reports and data forms are clear and readable

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

6. Timeliness

To what extent do you agree with the following regarding monitoring? Tick ~~only~~ one

6.1. The system provides reports and information needed in time

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

6.2. The system provides up-to-date information

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

7. General Remarks

6.1. Generally the system is important and useful

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

6.2. Generally, I am satisfied with the system

☐ Strongly Agree ☐ Agree ☐ Not Sure ☐ Disagree ☐ Strongly Disagree

6.3 But I would recommend the following issues to be addressed or features improved

Appendix 8C: Sample Prototyping Questionnaires

B: SATISFACTION OF PATIENTS – MAMACARE PROTOTYPE

USEFULNESS OF MOBILE PHONES IN MATERNAL CARE

We are seeking your views on how well the new system will help deliver services tailored to your needs.

Date of interview [DD MM YYY]	
Time interview started [HH:MM]	Time interview ended [HH:MM]
INSTRUCTIONS	
4. Do not indicate your Name on the guide 5. Make sure that you tick within the box ☒	
14. Personal Details	
1.1 Category of care ☐ Antenatal (ANC) ☐ Postnatal	1.2. Age ☐ 15 – 19 Years ☐ 20 – 25 Years ☐ 26 – 29 Years ☐ 30 – 35 Years ☐ Above 35
Barriers to Healthcare Access	
1. Do you experience any difficulties when coming for ANC clinics, delivery or postnatal care? ☐ Yes ☐ No 2. If Yes , which? _____	
Relationship with Caregiver	
3. During ANC or postnatal visits, do you feel free when sharing any health problem with a caregiver? ☐ Yes ☐ No 4. Would you be comfortable sharing some of the problems with the caregiver through your phone? ☐ Yes ☐ No. Why? _____ 5. Would you like to use your phone to contact caregivers for advice in case of urgent need? ☐ Yes ☐ No	

Mobile Use in Maternal Healthcare
6. Do you feel valued by Kimbimbi hospital by sending sms to remind you to attend your clinic? ☐ Yes ☐ No. Why? _____ 7. Would you like to continue receiving such clinic follow-up reminders? ☐ Yes ☐ No 8. If Yes, in which language would you like to receive the messages? ☐ Englis ☐ Kiswahi ☐ Kikuyu 9. If you would like to receive other messages, which of the following would you be interested in? ☐ Medication adherence reminders ☐ HIV/Aids testing or PMTCT Advice ☐ Preparation for safe delivery ☐ Lab results e.g. blood Sugar, Hb etc. ☐ Child vaccination and postnatal clinics ☐ Others _____
Privacy
10. Do you share your phone with family members or close friends? ☐ Yes ☐ No 11. If Yes, do you trust that you can use the phone to receive confidential messages from hospital? ☐ Yes ☐ No. Why? _____ 12. Can you be able to safeguard confidential messages from being read by someone not supposed to? ☐ Yes ☐ No
Timeliness
13. In case of reminders, how many days or hours before, would you like to receive the message? ☐ Days ☐ Hours before _____ 14. Other than reminders, would you like to use your phone to request for other information at your convenience? ☐ Ye ☐ No 15. If Yes, Which information? _____

Appendix 8D: Sample Mamacare UI Screenshots

8D.1 Dashboard on Computer and Mobile

The following are sample screenshots of mamacare dashboard for the antenatal/postnatal and maternity subsystems both on a desktop computer and mobile phone.

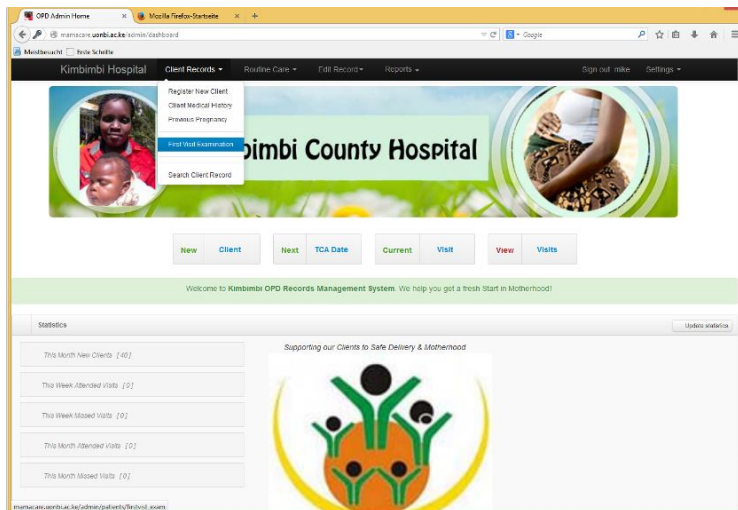


Figure A8D (a): OPD Dashboard on PC

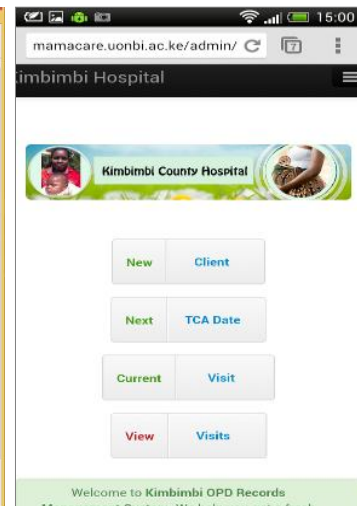


Figure A8D (b): OPD on Mobile

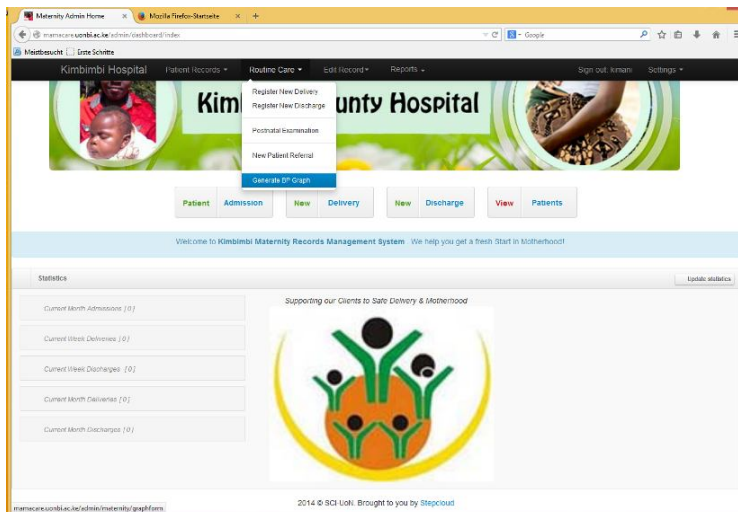


Figure A8D (c): Maternity dashboard on PC

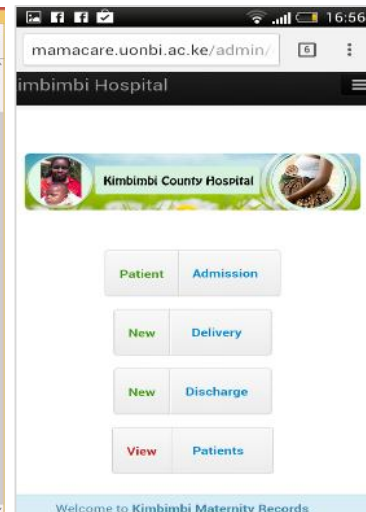


Figure A8D (d): Mobile dashboard

8D.2 Login and Cascading Menu on Mobile

The following are sample screenshots for mamacare login form and cascading dashboard menu once the system is loaded onto a mobile phone.

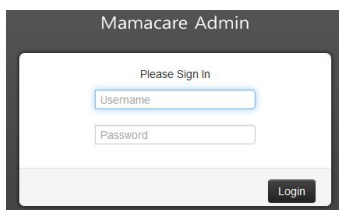


Figure 8D (e): Login screen

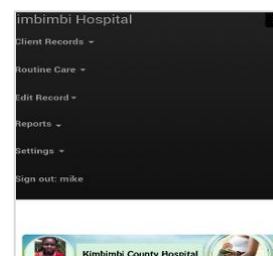


Figure 8D (f): Menu on mobile

8D.3 Mamacare Reports on Desktop PC

The following are sample clincial reports generated from antenatal/postnatal and maternity subsystems when loaded onto a desktop computer.

File Number	ANC No.	Visit No.	First Name	Middle Name	Mobile No.	Clinic Date	Message
465	268/14	726	Gladys	Waruguru	0724543853	2014-09-15 08:00:00	tafadhali kuja mapema
764	278/14	725	Josephine	Njeri	0720271663	2014-09-15 08:00:00	tafadhali kuja mapema
952	550/14	724	Caroline	Njeri	0705443294	2014-09-15 08:00:00	tafadhali kuja mapema
1027	436/14	719	Lillian	Iruha	0704040314	2014-09-15 08:00:00	tafadhali kuja mapema
1028	0317/14	720	Beatrice	Wakera	0702280381	2014-09-15 08:00:00	tafadhali kuja mapema
1029	437/14	721	Mika	Nyambura	070506238	2014-09-15 08:00:00	tafadhali kuja mapema
1030	0380/14	722	Mary	Wanjiru	071715796	2014-09-15 08:00:00	tafadhali kuja mapema
1031	430/14	723	Agnes	Wanjiru	0714440174	2014-09-15 08:00:00	tafadhali kuja mapema

Figure 8D (g): OPD Clinic follow-up schedule on PC

Serial No.	IP No.	First Name	Middle Name	Surname	delivery Date	Mode	Gestation	Outcome	Complications
947	1330/14	Pauline	Muthue	Muthama	2014-08-12 17:50:00	svd	38	Alive	none
948	1337/14	Mary	Wangeci	Muthie	2014-08-12 17:30:00	svd	39	Alive	none
949	1338/14	Lydia	Gataaka	Chomba	2014-08-13 18:30:00	CS	38	Alive	none
956	1372/14	Lucy	Njeri	Munene	2014-08-19 11:30:00	svd	38	Alive	none
957	1306/14	Harriet	Wambui	Kangangi	2014-08-23 14:20:00	svd	38	Alive	none
958	1304/14	Milcent	Wakuthi	Gitan	2014-08-23 15:00:00	svd	38	Alive	none
961	1304/14	Veronica	Wanjiru	Njuki	2014-08-09 09:00:00	svd	38	Alive	NONE
962	1377/14	Mercy	Wanjiru	Muthike	2014-08-19 22:30:00	CS	38	Alive	none
963	1376/14	Grace	Wanjiru	Munene	2014-08-21 11:30:00	svd	38	Alive	NONE
964	1346/14	shelmyth	Kamari	Kinyua	2014-08-14 18:00:00	svd	38	Alive	NONE

Figure 8D (h): Deliver Records in Maternity on PC

8D.4 Mamacare Reports on Mobile

The following are sample reports generated by mamacare system from antenatal/postnatal and maternity subsystems when loaded onto a mobile phone.

File Number	ANC No.	Visit No.	First Name	Middle Name	Mobile No.	Clinic Date	Message
465	268/14	726	Gladys	Waruguru	0724543853	2014-09-15 08:00:00	tafadhali kuja mapema
764	278/14	725	Josephine	Njeri	0720271663	2014-09-15 08:00:00	tafadhali kuja mapema
952	550/14	724	Caroline	Njeri	0705443294	2014-09-15 08:00:00	tafadhali kuja mapema

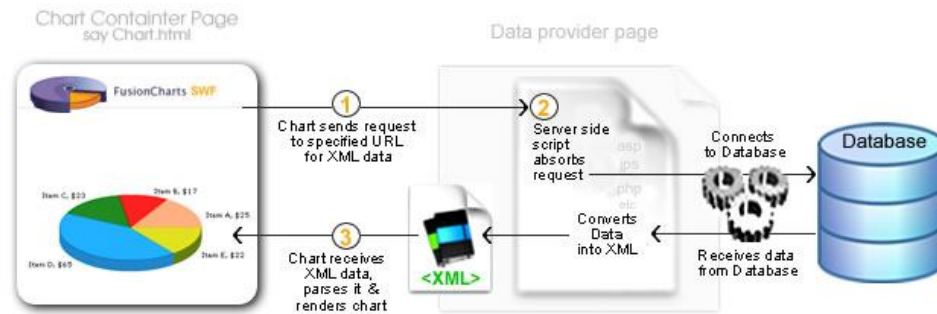
Figure 8D (i):ANC appointment

IP No.	First Name	Middle Name	Surname	delivery Date	Mode	Gestation	Outcome	Complications
76/14	Priscilla	Kasiva	Mwangangi	2014-03-04 01:25:00	svd	38	Alive	
39/14	Phillis	Waithira		2014-03-05 10:00:00	svd	38	Alive	P.v Bleeding
00/14	PAULINE	WANJIRU	KARIUKI	2014-03-08	svd	42	Alive	

Figure 8D (j): Deliveries report

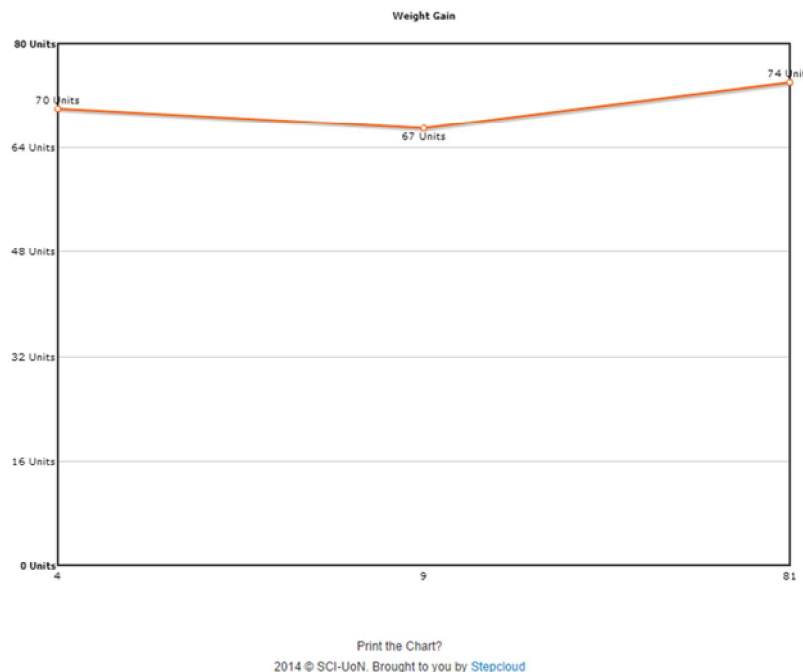
8D. 4 Dynamic Charts

Mamacare uses *FusionChart Free* to generate and render dynamic charts from the database. To create a chart, data is pulled from the database in XML format using server-side XML parser shown in the figure below. However, this functionality is only available on devices that support *Adobe Flash* SWF file format.



8D (k): Dynamic Charts client-server interaction

Once the target table values are fetched, they are passed by a PHP script to an HTML page that renders the chart using JavaScript. The figure below shows a line graph generated from three clinic follow-up observations of undisclosed antenatal client.



8D (l): Patient's weight trend after 3 clinic follow-ups

Appendix 8E: Mamacare Database Schema

Mamacare uses open source MySQL RDBMS to implement Beale and Heard (2007) Clinical Investigator Record (CIR) ontology. The CIR defines ontology for recording patient's clinical and administrative information. The database schema was designed in MySQL Workbench, and then forward engineered to MySQL relational database management system.

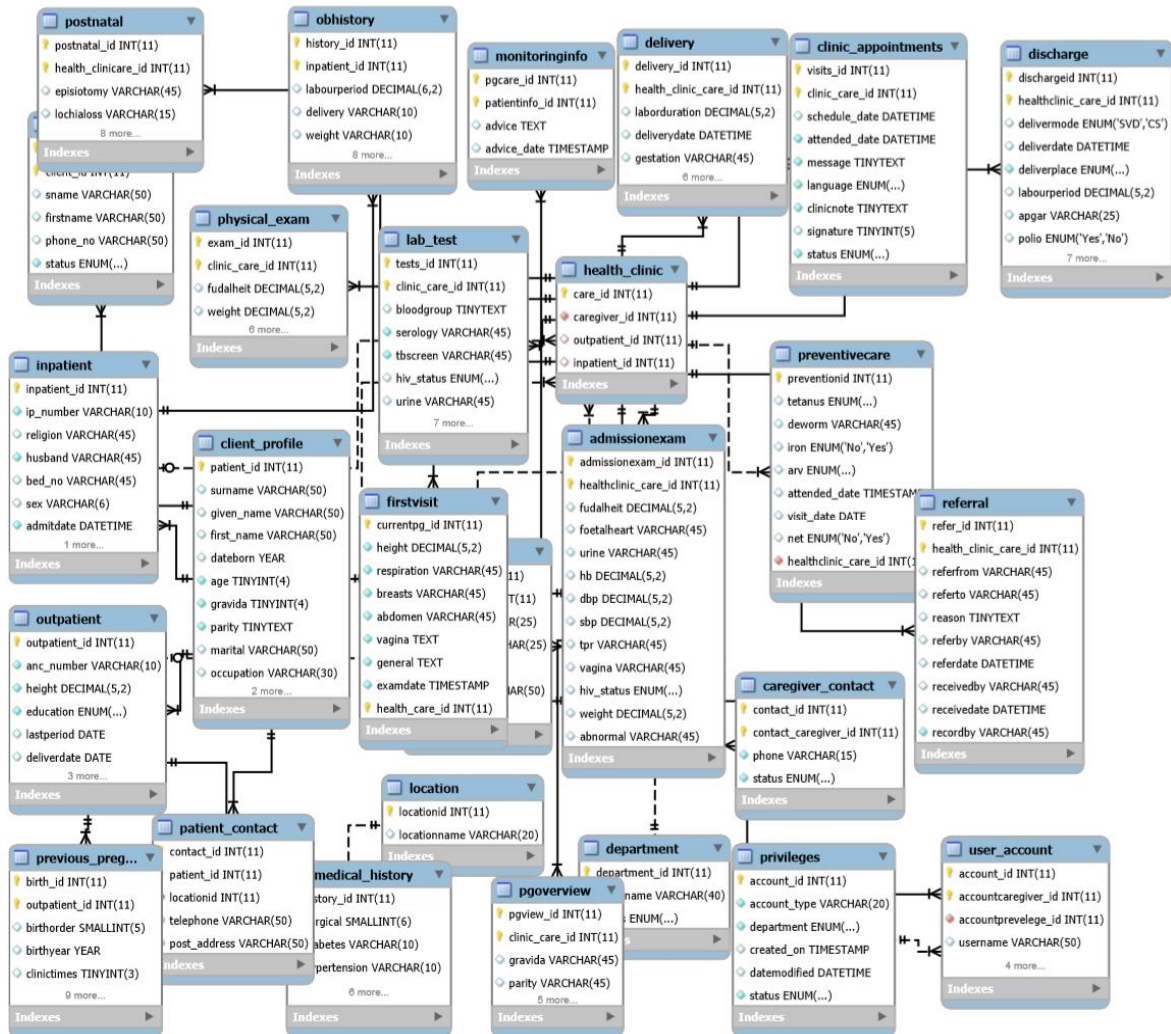


Figure A8E: Mamacare database schema

Appendix 8F: Sample Mamacare Program Codes

8F. 1 HTML5, CSS3 and Javascript

The following is a sample HTML5 script that imports several CSS3 and JavaScript files to dynamically render mamacare web pages. This code was implemented using Twitter Bootstrap framework (<http://getbootstrap.com/>).

```
</html>
<!DOCTYPE html>
<html lang="en">
<head>
  <meta http-equiv="content-type" content="text/html; charset=UTF-8">
  <meta charset="utf-8">
  <title>Records | Kimbimbi Maternity Project </title>
  <meta name="viewport" content="width=device-width, initial-scale=1.0">
  <meta name="description" content="">
  <meta name="author" content="">

  <!-- important stylesheets and inline javascript comes under here -->
  <style type="text/css">
    body {
      padding-top: 60px;
      padding-bottom: 40px;
    }
  </style>

  <!-- HTML5 shim, for IE6-8 support of HTML5 elements -->
  <!--[if lt IE 9]>
    <script src="../../assets/js/html5shiv.js"></script>
  <![endif]-->

  <script type="text/javascript">
    // < ![CDATA[
    base_url = '<?php base_url();?>'; //replaced <= with php
    //]] >
  </script>

  <link rel="stylesheet" href= "<?php echo base_url();?>site_css/boot/bootstrap.min.css" />
  <link rel="stylesheet" href="<?php echo base_url();?>site_css/boot/bootstrap-responsive.min.css" />
  <link rel="stylesheet" href="<?php echo base_url();?>site_css/boot/unicorn.main.css" />
</head>

<body>
  <div id = "wrapper">
    <div>
      <?php $this->load->view('templates/header');?>
    </div>

    <div id="main">
      <?php $this->load->view($main);?>
    </div>

    <div id= "footer">
      <?php $this->load->view('templates/footer');?>
    </div>
  </div>

  <!--important javascripts comes here -->
  <script src="<?php echo base_url();?>javascript/js/jquery-1.8.1.js"></script>
  <script src="<?php echo base_url();?>javascript/js/bootstrap.min.js"></script>
  <script src="<?php echo base_url();?>javascript/js/jquery.min.js"></script>
  <script src="<?php echo base_url();?>javascript/js/jquery-ui.custom.js"></script>
  <script src="<?php echo base_url();?>javascript/js/jquery.validate.js"></script>
  <script src="<?php echo base_url();?>javascript/js/jquery.wizard.js"></script>
  <script src="<?php echo base_url();?>javascript/js/unicorn.js"></script>
  <script src="<?php echo base_url();?>javascript/js/unicorn.wizard.js"></script>
</body>
```

8F.2 PHP for Generating SMS File

The following PHP script receives an array of values fetched from a database table to create a text file. This is because the sms gateway requires the sms message to be formatted to a text file such that the mobile number has country code and there should be a blank space between the number and the message body.

```
<?php
if ($data == null) {
    echo "Sorry No sms Message to Send\n";
    exit; //branchout if no data from the database
}

//if fetched array is not empty, create sms message files
else {
    //returned dataset need to be collapsed into string using array_map function
    $mobile = implode('|', array_map('implode', array_fill(0, count($data), ' '), $data));
    $msg = implode('|', array_map('implode', array_fill(0, count($msgdata), ' '), $msgdata));
    $msgdate = implode('|', array_map('implode', array_fill(0, count($datesms), ' '),
    $datesms));
    $splited = explode('|', $msg); //split the schedule details from appointment
    $splitdate = explode('|', $msgdate); //split the schedule details from appointment

    $fone = explode('|', $mobile); //split the phone data from appointment
    $count = sizeof($splited);

    //loop to create several contacts lists
    for ($x = 0; $x < $count; $x++){
        $text = "To: ". "+254". $fone[$x]. " " ". $splited[$x];
        echo $text. "<br />";
    }
}

//create sendsms textfile function
$f = fopen("sendsmsout", 'w'); //open file for update (append)
fseek($f, 0, SEEK_END);
if (flock($f, LOCK_EX)) {
    for ($x = 0; $x < $count; $x++){
        $text = "To: ". "+254". $fone[$x]. " "
        ". $splited[$x].", Kumbuka Kliniki Kesho $splitdate[$x] ". " $ ". " ";
        fwrite($f, $text) or die("Could not write to file");
        copy('sendsmsout', 'd:/cygwin/tmp/sendsms_XXXXX');
        flock($f, LOCK_UN);
    }
}
fclose($f);
?>
```

8F.3 PHP for Receiving Vital Signs SMS

The following PHP script reads received sms from bash script *formail* illustrated next and extracts the phone number and the message containing vital parameters such as temperature and BP. The phone number is validated against the stored patient's phone number and hospital registration ID.

```
/*-----
The following functions receives SMS messages through GSM Modem
-----*/

//receive SMS message from GSM modem event handler
public function receivesms() {

    //open the file for reading from the local folder
    $keywords = file_get_contents("../tmp/my_file"); //changed to relative path
    echo $keywords;
    $keywords = preg_split('/[\s,:]+/', $keywords);
    print_r($keywords);
    echo $keywords [0];
}
```



```

echo $keywords [1];
echo $keywords [3]." ".$keywords [4]." :".$keywords [5]." :".$keywords [6];
echo $keywords [8]." ".$keywords [9]." :".$keywords [10]." :".$keywords [11];

//variables to be used in the database
$fon = $keywords [1]; //to validated received phone number and store sent timestamp
$sent = "20".$keywords [3]." ".$keywords [4]." :".$keywords [5]." :".$keywords [6];
//store received timestamp
$received = "20".$keywords [8]." ".$keywords [9]." :".$keywords [10]." :".$keywords [11];

//write code that searches and sanitizes the content
$data = $this->clinics_model->clinic_id($fon); //store

if (! ($data['telephone'] == $fon)) {
    echo "Sorry unrecognised phone Number\n. Please try again";
}
else {
    $pid = $data['patient_id']; //grab patient id for use with haelthcare table

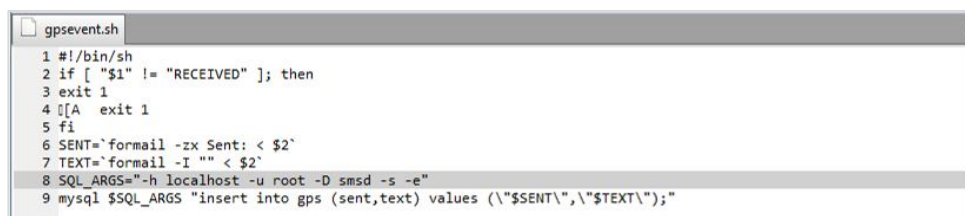
    /*this logic searches for a matching keywords in the received sms array, once
    * and avances to the next element that holds measured value */
    if (in_array("temp", $keywords)) {
        echo "Temperature ";
        $currenttemp = "temp";
        $nextkey = array_search($currenttemp, $keywords) + 1;
        if($nextkey == count($keywords)) { // reached end of array, reset
            $nextkey = 0;
        }
        $currenttemp = "8";
        $testype = $currenttemp;
        $testvalue = $keywords[$nextkey];
        echo $testvalue;

        //pass the parameters to clinics model
        $data = $this->clinics_model->vitalsigns ($pid, $testype, $testvalue, $sent,
        $received);
    }
    if (in_array("da", $keywords)) { //this logic searches for a matching pressure key value
        echo " Diastolic Pressure ";
        $currentsys = "da";
        $nextkey = array_search($currentsys, $keywords) + 1;
        if($nextkey == count($keywords)) {
            $nextkey = 0; // reached end of array, reset
        }
        $currentsys = "2";
        $testvalue = $keywords[$nextkey];
        $testype = $currentsys;
        echo $testvalue;
        //pass parameters to model
        $data = $this->clinics_model->vitalsigns ($pid, $testype, $testvalue, $sent,
        $received);
    }
    echo "<hr />";
}
} //end sms receive function

```

8F.4 Bash Script for Extracting SMS

The screenshot below shows a bash script that extracts the phone number and message body from an sms received by the sms gateway. Once the values are extracted, an eventhandler invokes the PHP script above to store the parameters into the database.



```

gpsevent.sh
1 #!/bin/sh
2 if [ "$1" != "RECEIVED" ]; then
3 exit 1
4 [[A exit 1
5 fi
6 SENT=`formail -zx Sent: < $2`
7 TEXT=`formail -I "" < $2`
8 SQL_ARGS="-h localhost -u root -D smsd -s -e"
9 mysql $SQL_ARGS "insert into gps (sent,text) values (\\"$SENT\\",\\"$TEXT\\");"

```

A8F: Bash script for extracting parameters from received sms

8F.5 PHP for Sending SMS Messages

The following are functions used to send various types of sms messages to patients and clients. The PHP script that handles messaging is triggered by a *cron daemon* to check on time-stamped events. Required values are pulled from database tables and passed to *createsms PHP script* ready for sending through the sms gateway.

```
/*This function send SMS messages through GSM modem to clients/patients */
public function dayalert() {
    $this->db->trans_start();//atomically retrieve phone numbers
    $data = $this->clinics_model->clinics(); //store
    $msgdata = $this->clinics_model->clclinicdaysms(); //store
    $datesms = $this->clinics_model->clclinicmessage(); //store
    //print_r($data); die();
    $this->db->trans_complete();//import sms textfile transaction
        include_once 'contimports/createsms.php';//create sms text file!!!!
        include_once 'contimports/sendsms.php'; //transfer the sms!!!!
    }
    // This is for retrieving hourly sms
    public function houralert() {
        //this is atomic retrieval of phone numbers and other pariticulars
        $this->db->trans_start();
        $data = $this->clinics_model->clinichrtel(); //store
        $msgdata = $this->clinics_model->clinichrsms(); //store
        $this->db->trans_complete();

        //import sms textfile create logic
        include_once 'contimports/createhrsms.php';//create sms text file!!!!
        include_once 'contimports/sendhrsms.php';//transfer the sms!!!!
    }
    //this function is used to trigger health advice messaging
    public function healthadvice() {
        $this->db->trans_start();//atomically retrieve phone numbers
        $data = $this->clinics_model->advicetel(); //store
        $msgdata = $this->clinics_model->advicesms(); //store
        $datesms = $this->clinics_model->advicemessage(); //store

        $this->db->trans_complete();//import sms textfile create logic
        include_once 'contimports/createadvicesms.php'; //create sms text file!!!!
        include_once 'contimports/sendadvicesms.php'; //transfer the sms!!!!
    }
    //this function is used to generate safe delivery message
    public function safedelivery() {
        $this->db->trans_start();//atomically retrieve phone numbers
        $data = $this->clinics_model->safesms(); //store
        $msgdata = $this->clinics_model->safenamesms(); //store
        $datesms = $this->clinics_model->safemessage(); //store

        $this->db->trans_complete(); //import sms textfile create logic
        include_once 'contimports/createssafesms.php'; //create sms text file!!!!
        include_once 'contimports/sendsafesms.php'; //transfer the sms!!!!
    }
}
```

8F.5 Semantic URL and Security Implementation

To hide mamacare implementation details, the URLs are customized so that the web pages do not show the server-side scripting language used such as *index.php*. To hide the index page, we used the following *htaccess* rule:

```
RewriteEngine On
RewriteCond $1 !^(index\.php|resources|robots\.txt)
RewriteCond %{REQUEST_FILENAME} !-f
RewriteCond %{REQUEST_FILENAME} !-d
RewriteCond %{REQUEST_URI} !(.*)/$
RewriteRule ^(.*)$ index.php/$1/ [L,QSA]
```

To enforce security of mamacare web application, access control was implemented using encryption key such as shown below (not the actual key) and the SHA256 hashing algorithm. CodeIgniter has in-built support for hashing using `do_hash()` method:

Sample encryption key:

```
$config['encryption_key'] = 'mama_XXXXXX_23x0k0!@q0l0H0g0m0_?'
```

CodeIgniter Hashing function:

```
substr(do_hash($_POST['password']),0,64)
```

To protect the site against copy-paste of the URLs on protected pages, a user must upon authentication be assigned a session key. If unauthorized user tries to enter URL directly he/she is redirected to the login page by the following global redirect statement:

```
if (!isset($_SESSION['userid'])) {  
    redirect('/mamacare/index', 'refresh');  
}
```

8F.6 Configuration of SMS Gateway

The script below was configured to support modems through which the gateway sends and receives text messages. SMS server Tools can support up to 64 redundant modems but only one HUAWEI GSM modem configuration is shown. However, more modems can be added into the script using GSM2, GSM3... GSM64 identifiers and device specifications!

```
# begin smsd configuration {  
#|-----|  
#| Main/Global modems and/or phones config|  
#|-----|  
  
devices = GSM1  
  
# folders used to store spooled sms text files  
incoming = /var/spool/sms/incoming  
outgoing = /var/spool/sms/outgoing  
checked = /var/spool/sms/checked  
failed = /var/spool/sms/failed  
sent = /var/spool/sms/sent  
stats = /var/spool/sms/stats  
  
# folder used to store log file  
logfile = /var/log/smsd.log  
loglevel = 7  
  
# additional settings for convenience  
autosplit = 3  
max_continuous_sending = 120  
  
#this is a handler for splitting multiple recipients file  
#to individual sms files
```

```

checkhandler = /usr/local/bin/split_sms.sh

# block send/receive for 1 minute
blocktime = 60

#|-----|
#| [GSM1] modems and/or phones config|
#|-----|

[GSM1]
# Huawei E1750 GSM/HSPDA Modem

# modem uses UI com12 port only
device = /dev/com9
baudrate = 19200
#make sure you disable/change pin for any line
#initialize the modem commands
memory_start = 0
init = AT^CURC=0
check_memory_method = 1

rtscts = yes
sending_disabled = no

primary_memory = "SM"

#set sms and reports priorities
incoming = yes
outgoing = yes
report = yes
decode_unicode_text = yes

#set sms event to listen to incoming mails
eventhandler = /usr/local/etc./sms/receivedsms.php
eventhandler=/usr/local/bin/samplevent.sh
# } end sms server configuration

```

More coding and configurations details used to implement mamacare cannot be exhausted in this report. What we have illustrated are few samples to be true to design science philosophy that motivated our desire to *demonstrate tangible results through the reduction of theory and design concepts into actual practice*.

***** END *****