Cadence

Designing a product-service for repair & maintenance of medical imaging equipment in Africa
"Designing a product-service for repair & maintenance of medical imaging equipment in Africa"

Grace Kane 4405390  
Master’s Thesis  
Integrated Product Design (Medisign)  

Faculty of Industrial Design Engineering  
Delft University of Technology  
December, 2016

Supervisory team  
Chair: Dr. ir. C.A. Bakker  
Mentor: Prof. dr. A.R. Balkenende (Ruud)  

Company team  
Company: Philips  
Karthik Govindarajan  
Maarten van Herpen
Thanks & Acknowledgements

This project would not have been possible without the many generous people who were willing to take time from their busy and important work to help me understand it.

Many thanks to Jim Loeffler, Angela Garcia, Oluwasoga Oni, Maurice Pagé, Sheila, Jospeh Tumwesigye, Bill Gentles, Dr. Bruce Kirenga, Dr. Dale Mugisha, Sajith Kurian, Ismael Cordero, Rob Zegers, Brittany Zick, Margaux Bellier, Thomas Opsomer & Jose Gomez-Marquez.

Thank you also to:

Conny & Ruud, for their encouragement and understanding
Karthik & Maarten for their guidance and trust in the project
Maher, Basem, Tamer, Christos, Gerhard, Robert & the rest of the Teleservicing team for making me feel at home while very far away
Karthik M for the indispensable advice
Anna, Ned & Gordon, for sounding out my ideas and putting in some of their own
Mart, for innumerable morally-supportive (half) cups of coffee
My family, for the love and support
Hec, for everything

This report is dedicated to Toffee who, like me, enjoyed making circles.
# Table of Contents

Executive Summary | 1

1. Introduction | 3

2. Literature Research: Repair & Maintenance | 5
  2.1 Overview | 5
  2.2 Maintenance Method and Strategy | 5
  2.3 Design for Repairability | 6
  2.4 Medical Maintenance | 7

3. Scoping Research | 8
  3.1 Introduction | 8
  3.2 Methodology | 8
  3.3 Analysis | 9
  3.4 Results Research Questions 1 & 2: System & Stakeholders | 10
  3.5 Results Research Question 3: Problems of Repair & Maintenance | 15
  3.6 Vision: A Product Service System for Repair and Maintenance | 174

4. Research Plan | 19

5. Benchmarking Research | 20
  5.1 Medical Equipment Remote Servicing | 20
  5.2 Telemedicine | 20
  5.3 Existing Online Resources for Machine Repair | 20

6. User Research within Philips Remote Servicing | 22
  6.1 Summary | 22
  6.2 Study Objectives | 22
  6.3 Methods | 22
  6.4 Study Scope and Participants | 25
  6.5 Results | 27
  6.6 Design Vision & Conclusion | 38

7. User Research: Customers without Service Support | 42
  7.1 Overview | 42
  7.2 Research Scope & Participants | 42
  7.3 Results | 43
  7.4 Conclusion & Vision | 47

8. System Analysis | 49
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.</td>
<td>Concept Design</td>
<td>51</td>
</tr>
<tr>
<td>9.1</td>
<td>Introduction</td>
<td>51</td>
</tr>
<tr>
<td>9.2</td>
<td>Brainstorming</td>
<td>51</td>
</tr>
<tr>
<td>9.3</td>
<td>Evaluation Criteria</td>
<td>56</td>
</tr>
<tr>
<td>9.4</td>
<td>Development of Service Design Concepts</td>
<td>56</td>
</tr>
<tr>
<td>9.5</td>
<td>Concept Selection</td>
<td>57</td>
</tr>
<tr>
<td>9.6</td>
<td>Final Concept Solution Spaces</td>
<td>57</td>
</tr>
<tr>
<td>10.</td>
<td>Preliminary Concepts</td>
<td>60</td>
</tr>
<tr>
<td>10.1</td>
<td>Development of Concept Designs for User Feedback</td>
<td>60</td>
</tr>
<tr>
<td>10.3</td>
<td>Concept Feedback</td>
<td>68</td>
</tr>
<tr>
<td>11.</td>
<td>Final Concept Design</td>
<td>73</td>
</tr>
<tr>
<td>11.1</td>
<td>Vision: Combining the grassroots and ‘birds-eye’ views</td>
<td>73</td>
</tr>
<tr>
<td>11.2</td>
<td>Product Description</td>
<td>73</td>
</tr>
<tr>
<td>12.</td>
<td>Final Concept Embodiment</td>
<td>80</td>
</tr>
<tr>
<td>12.1</td>
<td>Final Concept Embodiment: Hospital App</td>
<td>80</td>
</tr>
<tr>
<td>12.2</td>
<td>Final Concept Embodiment: Remote Engineer Workspace</td>
<td>83</td>
</tr>
<tr>
<td>13.</td>
<td>Platform Design &amp; Evaluation</td>
<td>90</td>
</tr>
<tr>
<td>13.1</td>
<td>Using the Platform Design Tool for Evaluation</td>
<td>90</td>
</tr>
<tr>
<td>13.2</td>
<td>Guaranteeing Value</td>
<td>91</td>
</tr>
<tr>
<td>13.3</td>
<td>Challenges to Providing Value</td>
<td>93</td>
</tr>
<tr>
<td>13.4</td>
<td>Getting there: Roadmap to Cadence</td>
<td>94</td>
</tr>
<tr>
<td>13.5</td>
<td>Conclusion</td>
<td>95</td>
</tr>
<tr>
<td>14.</td>
<td>Recommendations</td>
<td>95</td>
</tr>
<tr>
<td>14.1</td>
<td>Testing the User Interface Design</td>
<td>95</td>
</tr>
<tr>
<td>14.2</td>
<td>Financing and Information Systems</td>
<td>95</td>
</tr>
<tr>
<td>14.3</td>
<td>Part Sourcing and Logistics</td>
<td>95</td>
</tr>
<tr>
<td>14.4</td>
<td>Competition to Collaboration</td>
<td>96</td>
</tr>
<tr>
<td>15.</td>
<td>Reflections</td>
<td>97</td>
</tr>
<tr>
<td>15.1</td>
<td>Reflections on Process</td>
<td>97</td>
</tr>
<tr>
<td>15.2</td>
<td>Frugal Design vs. Frugal Servicing</td>
<td>98</td>
</tr>
</tbody>
</table>
List of Appendices:

Appendix I: Scoping Research: Interview Questions
Appendix II: Scoping Research: Interview Results Summary
Appendix III: Field Research Notes: Field Service Engineer Benelux
Appendix IV: Field Research Notes: Remote Service Engineer Benelux
Appendix V: Field Research: Site Scoping & Interview Questions: Radiography
Appendix VI: Field Research: Site Scoping & Interview Questions: Ultrasound
Appendix VII: Field Research: Hospital Baseline Survey Results
Appendix VIII: Field Research: Interview Transcript Hospital 1
Appendix IX: Field Research: Interview Transcript Hospital 2
Appendix X: Field Research: Interview Transcript Hospital 3
Appendix XI: Field Research: Interview Transcript Hospital 4
Appendix XII: Field Research: Interview Transcript Hospital 5
Appendix XIII: Field Research: Interview South Africa Field Service Engineer
Appendix XIV: Field Research: Sequence Model South Africa Field Service Engineer
Appendix XV: Field Research: Sequence Model Egypt Remote Service Engineer
Appendix XVI: Field Research: Cluster Maps
Appendix XVII: Field Research: Conceptual Inquiry Workflow Models
Appendix XVIII: Transcription and Summary of Ugandan Doctor/Biomed Interviews
Appendix XX: Design Concepts User Feedback
Appendix XXI: Platform design work
Executive Summary

Medical devices are defined by the FDA as any instrument “intended for use in the diagnosis of disease or other conditions, or in the cure, mitigation, treatment, or prevention of disease” which is does not operate through “chemical action or...being metabolized”. In other words, any physical piece of equipment used in medicine which is not a drug. This covers a wide range of products in purpose and complexity, from stethoscopes to Magnetic Resonance Imaging machines. Modern medicine relies heavily on highly technically advanced equipment. Many diseases or injuries that in the past were untreatable are now treated routinely, thanks in particular to accurate diagnosis through imaging equipment and safe surgeries assisted by patient monitors, anesthesia equipment and surgical tools.

In hospitals in the developed world, such equipment is now commonplace. However, studies of medical equipment in the developing world showed that despite the grave need for it, a large proportion of the equipment there is effectively unusable. The WHO estimated that up to 50-80% of medical devices in the developing world are broken (World Health Organization 2003), and an extensive study of inventory reports in 16 developing countries reported 40% (Perry and Malkin 2011). By comparison, in high economic-index countries only 1% of equipment is out of commission at any given time (The Imperial College London/ Lancet Commission 2012).

Studies by the WHO and Tropical Health & Education trust, among others, have shown that a major reason for this lack of functioning equipment is the inadequacy of repair and maintenance in low-resource clinics. In the developed world, repair & maintenance are performed on medical equipment as a matter of course. However, in much of the developing world, preventative maintenance is not performed or even budgeted for, and repair is hampered by the lack of skilled technicians and difficulty of accessing spare parts (THET 2003).

This project began with a broad ‘fuzzy front end’ in the research phase, where the very broad topic of repair and maintenance of medical equipment developing world was explored to find a narrower scope. Literature research was performed on the specific issue of repair & maintenance in the developing world, and “scope-finding” interviews were held (Saffer 2010) with key stakeholders from this field. The purpose of this research was to find the underlying causes of this lack of repair and maintenance, and to create a system description of medical equipment in the developing world, identifying different stakeholders, environments and types of equipment.

This scoping research resulted firstly in the narrowing of the project scope. Medical imaging equipment (X-rays, ultrasound machines etc.) was chosen as an equipment-specific focus, and Africa was also chosen as a (still broad) geographical focus, because of the acute difficulties of repair there and the interests of the project partner (Philips) in this market. The second outcome was the definition of the project goal: “To design a product-service system to allow effective, remote-assisted repair & maintenance of medical imaging devices for any user in the African market”. It was found firstly that it is currently not affordable for many clinics to budget for sporadic repair and maintenance if quality cannot be guaranteed, making a regular and reliable service system essential. Secondly, it was found that one of the main barriers to repair is not the lack of skills to fix a machine problem, but the lack of expertise to diagnose the problem and prescribe a solution. Therefore, system is needed to bring this remote expertise together with local resources to perform quality repair & maintenance.
More detailed research was then performed on existing methods of remote repair servicing within the project partner, Philips. Two sets of field studies were performed in which service engineers and customer users of medical imaging equipment were shadowed and interviewed. The first section of this research was performed in the Netherlands for engineers servicing the Benelux area, and a second with engineers and customers within the target market, in Egypt and South Africa. The goal of this research was to find out the current practices and problems present in remote servicing, and to see what particular barriers were present to its expansion in the African market.

This research led to a set of design requirements and vision for an ideal remote servicing tool was created. Product ideas were generated through brainstorming, and refined using a customized service journey design tool (the ‘Troubleshooting Timeline’) created for this project. Further details of the development of this tool can be found in the supplementary document to this thesis: “Development of a Design for Troubleshooting Method”. Demonstration storyboards were made of these concepts and sent to users for feedback to further refine the design. This resulted in a design concept for a remote service tool consisting of a digital workspace for a remote support engineer which was optimized for troubleshooting task flow, and a web-to-mobile communication app which connects hospital end users to this workspace with a highly visual communication channel.

The project goal, however, was not simply to improve existing remote service systems but to expand them to customers who are currently unable to access and afford them. To that end, several additional in-depth user interviews were performed with medics and biomedical technicians in Uganda, working in hospitals without service support. From this a similar design vision was created for a mobile workspace for biomedical engineers, which provided not only access to remote communication but also a means to manage inventory in their hospitals.

A further insight from both research studies was on a systems level – it was found that the current world of remote servicing in Africa is split into two distinct and separate spheres – a small one of ‘official’ service contracts, which are too expensive and rigid for most users to afford, and a far larger informal sphere in which grassroots methods of equipment support, such as local knowledge networks, were employed. From this insight, the final design concept was created.

Cadence is a platform tool designed to connect different stakeholders involved in medical equipment repair support in Africa, and to enable a diverse range of contracts, transactions and information sharing between them. The building blocks it uses to do this are two basic software tools. Cadence has two user environments – one for remote support engineers and one for hospital end-users – which are specifically designed to support the workflow of medical equipment service and repair. Highly visual communication channels between these environments enable remote service support.

Cadence allows for flexible interactions between manufacturers, distributors and customers – not only service contracts but one-off service requests, part shipments and the licensing of support materials, allowing manufacturers to get many small revenue streams from customers that would have previously not been cost-effective to reach. Cadence also encourages information exchange between manufacturers and end users – manufacturers release basic repair guides for their products, but reap the benefits in the visibility they now have of new customers and the product feedback data they get from open forum discussions of machine errors. The key goal of Cadence is to move away from today’s situation, in which a service support system developed for US and Europe is trying – and failing – to be applied in Africa. Instead, a more agile, “frugal” system of service is proposed.
I. Introduction: Medical Equipment in the Developing World and the Need for Repair & Maintenance

The seeds of this project idea came about several years ago, when I made a trip to Nicaragua with a design team trying to build a low-wattage nebulizer for drug delivery in rural areas. Our team had gone there hoping to create a design which could make a difference to these clinics. However, something else we saw there shocked us: outside almost every hospital there was a cordoned-off area where piles of broken medical equipment had been dumped. This equipment, mostly donated from well-meaning hospitals in wealthier countries, had at some point stopped working, was unable to be fixed, and had been left there to rust. At the same time, the hospitals still had severe equipment shortages and were still eager to receive new donated equipment, even though that equipment would presumably meet the same fate as its predecessor.

I discovered that this phenomenon was not limited to Nicaragua, but was in fact a global problem, one referred to as the problem of ‘equipment graveyards’. The largest evidence-based study determining its scope was one performed by Duke University, which estimated that up to 40% of equipment physically in the possession of low-resource hospitals all over the world is not usable (Perry and Malkin 2011). Other, even higher estimates (such as the WHO’s stated 50-80%) exist, but these are not supported by the same breadth of data (World Health Organization 2003).

Despite its scope, this problem has attracted little academic interest thus far. No large-scale study has been performed on the root causes of this issue, but evidence can be gleaned from case studies performed on individual hospitals, and from guidelines written by large international organizations experienced in medical care in the developing world. In all these case studies and guidelines the root causes can be broadly divided into two types: either the equipment is inappropriate for the setting to begin with, or the repair and maintenance services required to keep it running are inadequate.

Figure 1 - Medical equipment graveyard in Roosevelt Hospital, Guatemala. (Kvcs 15)
A report into the failure of a large donation of oxygen concentrators to a hospital in the Gambia, for example (Howie, et al. 2008), found both that the concentrators were rated incorrectly for the local power supply and that there was inadequate transferal of information about maintenance requirements from the donor to the recipient, resulting in the concentrators wearing out very quickly.

THET, a UK-based healthcare development NGO, elaborates on these two reasons for equipment failure in its guideline ‘Making it Work’. Poor procurement practices, poor legal and regulatory frameworks, and equipment that in its design is inherently unsuitable for a low-resource environment leads to unsuitable equipment being bought or received by hospitals (THET 2003). Once equipment is installed a lack of trained technical staff to maintain it, difficulty of obtaining spare parts & consumables, lack of repair equipment & service manuals, and inadequate budgeting for use and service mean that once broken, the machine is very difficult to get back into operation again.

The key point made by THET is that even if the equipment is appropriate, if it is not able to be properly maintained it will still fail. Another case-study report which followed a Canadian NGO’s equipment donation to a Ghanaian hospital showed that even when due diligence was performed on the equipment’s appropriateness for the setting, 12 months later only 40% of the equipment was still in use, due to lack of maintenance (Adjabu, Gentles and Bradley 2014).

Thus improving repair & maintenance of medical equipment in low-resource settings was identified as the most important area to target within this larger problem, and was chosen as the starting-point for this graduation project.

---

Figure 2 – Developing World Medical Equipment Life Cycle
2. Literature Research: Repair & Maintenance

2.1 Overview

Before going into the specific study of repair & maintenance of medical equipment in the developing world, a literature study was performed on repair and maintenance in general, to see what exactly these terms mean and how they are performed in other industries.

Repair and maintenance is generally defined as all the activities - technical and organizational - during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform its required function (CEN 2005). The main distinction in this definition is between “retaining” and “restoring”, activities commonly referred to as preventative and corrective maintenance respectively.

Traditionally, preventative maintenance is an activity performed with a fixed frequency based on a machine’s expected “mean time to failure” under the working conditions it operates in. It can range from simple activities performed on a daily basis by a non-expert user (such as cleaning or changing a filter) to yearly servicing by skilled technicians in which major components are replaced or recalibrated.

Corrective maintenance, by contrast, is a sporadic activity undertaken in response to a machine unexpectedly losing performance, usually as a result of some non-standard error or event. Depending on the complexity of the machine, the problem and solution may be obvious, or may require an expert to diagnose, troubleshoot and find an appropriate fixing method.

The types of errors addressed by maintenance can also be broadly divided into two types: ‘hard’ and ‘soft’ errors. (Meeker W 1998) Soft errors are those which do not render the machine unusable, but which slowly degrade its performance, and are a result of constant environmental factors such as wear and tear from use, exposure to temperature, dust or humidity. Hard errors are those which significantly affect the machine’s performance and are usually caused by random, unpredictable events (such as physical shocks or power surges), or by the degradation caused by accumulated soft errors reaching a critical point. The purpose of preventative maintenance is to address the ‘soft’ errors before they lead to a ‘hard’ error. Corrective maintenance is almost always in response to a ‘hard’ error (Taghipour, Banjevic and Jardine 2010).

2.2 Maintenance Method and Strategy

The goal of most organizations involved in repair and maintenance of complex devices is to guarantee the maximum machine performance for the minimum cost. Since its beginning at Bell Laboratories in the 1930s, the field of Reliability Engineering has developed strategies towards this goal based on statistical modelling & prediction, experimental testing and methods of organizational structure (Saleh and Marais 2006).

Because this field was developed out of high-risk industries (military and aviation), it is focused on preventative maintenance and how to schedule it in order to minimize unplanned ‘hard errors’. It firstly uses statistical methods to predict the time taken for systems or components to degrade (‘soft errors’) and schedules preventative maintenance accordingly, and secondly identifies risk factors (potential ‘hard errors’) and minimizes them by focusing preventative maintenance on those risky aspects (Moubray 1997). This way maintenance can be performed ‘just enough’ (i.e. at the minimal cost) to keep the machine constantly running.
The ideal goal of maintenance strategy is to be able to predict exactly when a failure will occur, and replace it just in time – known as “predictive maintenance”. This idea has existed since the early days of reliability engineering, but has become more and more difficult to achieve as machines become more and more complex (Saleh and Marais 2006).

However, recent advances in technology have made failure prediction of complex systems easier. Sensing technology embedded in devices can send a warning when a critical threshold is reached – such as the engine overheating in an aircraft engine. For very complex systems, ‘Big Data’ and networked sensors (the “Internet of Things”) can be used to gather data on failures from multiple devices, and use this to discover root causes and prediction factors, resulting in very accurate failure prediction (Dunn n.d.). The Philips RADAR system, which enables remote monitoring of medical imaging devices, is an example of this technology use (Philips 2013).

A parallel development is that of improved service delivery to deal with ‘hard’ errors and corrective maintenance. This has mostly occurred in the field of consumer products, as a means of providing service easily to an increasingly large, globally distributed network of customers.

The service delivery approach focuses on troubleshooting, diagnosing and fixing a problem with the minimum involvement of expensive specialists and tools, often remotely over telephone or internet. A typical consumer product service structure includes some form of self-help troubleshooting by the customer, followed by a conversation with a non-expert who advises a set series of actions to screen or ‘triage’ the problem, and finally involvement from an expert if the issue is not solved (Galdes and Ericson 1998).

Advances in sensors and networking have also improved corrective maintenance in consumer products. Car manufacturers, for example, have begun to introduce diagnostic tools which allow a customer or non-authorized mechanic to self-test and find an error using a simple handheld device or smartphone (Eastin 2016). The development of Virtual Private Networks (VPN) allows experts to remotely access another networked computer, allowing them to fix software errors or customer difficulties from afar. Philips employs this strategy to remotely service its networked medical devices (Philips 2014).

2.3 Design for Repairability

A complimentary approach to maintenance strategy is to design “repairability” into the product itself, to make the product by its design as easy as possible to repair. As opposed to developments in maintenance strategy, which involve high-level prediction of the failure of existing machines, design for repairability focuses on machine design and how this facilitates the interaction between the machine and the person fixing it during the repair itself. Figure 3 shows a selection of design guidelines for repairability recommended in the literature (Mulder 2012).
Certain recent products, such as the FairPhone, have put an extreme emphasis on component design for repairability – their phone is designed such that an unskilled user can replace major parts without even the need for tools (Fairphone 2016).

2.4 Medical Maintenance

Repair and maintenance of medical devices has several factors which distinguish it. Firstly is the criticality of uptime and performance – patients may be hurt if equipment is unavailable or not functioning correctly. Secondly, there is the complexity of the systems, which makes both the prediction and the diagnosis of errors difficult. Thirdly, there is the wide variety of manufacturers (meaning a wide variety of machine models and thus more complexity) and intense competition between them, leading to a level of IP protection higher than in many other fields (Wang 2016). Thus some manufacturers are unwilling to allow customers or third-party technicians the ability to diagnose and fix devices.

Medical equipment also involves, more so than many devices, the confluence of many different types of engineering design. A given medical device might contain high-voltage power, complex microelectronics, software systems, moving mechanical parts, motors, fluid piping, radioactive material or pressurized gas. It will also interact with patients and have physical effects on their bodies in specific ways. Because of the complexity involved, the field of Biomedical Engineering & Technology has arisen. Education in this field trains people to design (engineers) or repair & maintain (technicians) a wide range of biomedical equipment. In most high-income and middle income, and some low-income, countries in the world, industry organizations of biomedical technicians and engineers exist to provide staff with this expertise.

<table>
<thead>
<tr>
<th>Standardization</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Use standard, universally applicable components (widely available and understood by technicians/users)</td>
</tr>
<tr>
<td>- Use standard interfaces to enable quick subsystem connection.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ergonomics</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Provide sufficient space around maintenance points for ergonomically safe repair</td>
</tr>
<tr>
<td>- Make regularly-replaced components easy to access and hand</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Use fasteners that facilitate quick removal and replacement with minimum tools</td>
</tr>
<tr>
<td>- Design cues guide user to repair the machine in the ‘right’ way</td>
</tr>
</tbody>
</table>

Figure 3 - Aspects of design for repairability (Adapted from source: Mulder et al (2012))
3. Scoping Research

3.1 Introduction

As outlined in the introduction, guidelines such as those made by THET have described possible root causes of medical equipment failure, including those related to repair & maintenance. However, because of the limited amount of academic available information on the topic, further scoping research was performed to gain a better understanding of the particular problems of biomedical repair and maintenance in a developing-world context. The research question proposed were as follows:

1. What stakeholders and systems are involved in provision, repair and deposition of medical devices to the developing world?
2. How are different types of equipment and different stakeholders affected by lack of repair & maintenance?
3. What barriers exist which prevent repair and maintenance in the developing world?

The purpose of these research questions was firstly to narrow the scope by determining which types of equipment and users were particularly affected by the problem, and secondly to identify any additional barriers to repair & maintenance that were not evident from general literature on developing world medical device failure.

3.2 Methodology

In order to answer these, two approaches were used; first a specific literature research was performed on repair & maintenance of medical equipment in developing countries specifically. Secondly a broad range of stakeholders involved in developing world healthcare were approached and interviewed. These stakeholders are from a range of for-profit, non-profit and academic settings, and are described below:

Table 1 - Scoping research interview participants

<table>
<thead>
<tr>
<th>Organization/Individual</th>
<th>Sector</th>
<th>Specialization</th>
<th>Region/Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Links</td>
<td>Non-profit</td>
<td>Donation of medical equipment</td>
<td>Central America, Caribbean</td>
</tr>
<tr>
<td>International Aid</td>
<td>Non-profit</td>
<td>Subsidized sale of donated medical equipment</td>
<td>Sub-Saharan Africa</td>
</tr>
<tr>
<td>MDaaS</td>
<td>For-profit</td>
<td>Sale and servicing of medical equipment</td>
<td>Nigeria</td>
</tr>
<tr>
<td>Gradian Health Systems</td>
<td>For-profit</td>
<td>Sale of “appropriate medical technology” anesthesia machine designed for a developing-world environment</td>
<td>Sub-Saharan Africa</td>
</tr>
<tr>
<td>Ana Laura Santos (TU Delft)</td>
<td>Academic</td>
<td>User interaction and usability of medical technology in humanitarian contexts</td>
<td>Global humanitarian emergencies</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------</td>
<td>-------------------------------------------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Jose Gomez-Marquez (MIT)</td>
<td>Academic</td>
<td>Design of appropriate medical technology for developing-world contexts</td>
<td>Global</td>
</tr>
<tr>
<td>Bill Gentles (Canadian Medical and Biological Engineering Society)</td>
<td>Industry organization</td>
<td>Donation policy and best practices</td>
<td>Canada, West Africa</td>
</tr>
<tr>
<td>Sajith Kurian (Philips)</td>
<td>Equipment Manufacturer</td>
<td>Customer service support</td>
<td>Africa</td>
</tr>
</tbody>
</table>

A 30-45 minute interview was performed with 6 of the stakeholders, and 1 stakeholder (Bill Gentles) was interviewed over email. The interviews were performed as guided interviews based around a set of pre-prepared questions, but allowing for elaboration if additional areas for exploration were revealed. These questions were based on the three research objectives described above, but were tailored to the areas of expertise of each stakeholder. The sets of questions used to guide each interview are referred to in the Appendix I, and transcripts or notes in Appendix II. Interviews were recorded when agreed upon with the interviewee, and when not possible detailed notes were taken during the interview.

### 3.3 Analysis

The interview transcriptions were analyzed and the individual points and facts were divided and written on separate cards. The same was done with individual points found on the literature research. These cards were clustered in three ways; first by general association, to identify general themes and problems. Next, in order to address the research questions 1 and 2, they were clustered along two frameworks – one to create a stakeholder map, and the second to find any difference in different types of medical equipment and how they were affected by repair and maintenance.
3.4 Results Research Questions 1 & 2: System & Stakeholders

3.4.1 Stakeholders and Systems

The results from the interviews were first clustered with the intention of creating a map of the stakeholders and the flows between them in order to answer Research Question 1 “What stakeholders and systems are involved in provision, repair and deposition of medical devices to the Developing world?

The simplified map resulting from this clustering is shown below:

Figure 4 - Stakeholder Map
3.4.2 Equipment Divisions

Previously, this report has talked about “medical equipment” in general. However, the interviews clarified important differences between types of medical equipment and the sources of medical equipment. The table below show the differences in types of equipment donated and purchased:

Table 2 - Types of medical equipment

<table>
<thead>
<tr>
<th></th>
<th>Consumables</th>
<th>Furnitures/accessories</th>
<th>Complex long-lived devices</th>
<th>Medium-complexity devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td>Syringes, catheters, bandages</td>
<td>Radiotherapy chair, gurney, surgical lights</td>
<td>Medical imaging (X-ray, ultrasound), surgical (anesthesia machine, patient monitor)</td>
<td>Fetal Doppler, pulse oximeter</td>
</tr>
<tr>
<td>Cost</td>
<td>low</td>
<td>medium</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>User requirements</td>
<td>Basic medical training</td>
<td>Knowledge of procedure, basic training on equipment</td>
<td>Specialist knowledge of equipment, extensive training</td>
<td>Stable power, humidity &amp; temperature control, clean environment, enough space for operation</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Biomedical waste disposal</td>
<td>Enough space and correct power supply for operation</td>
<td>Stable power, humidity &amp; temperature control, clean environment, enough space for operation, consumables</td>
<td>None</td>
</tr>
<tr>
<td>Repair requirements</td>
<td>None</td>
<td>Infrequent, occasional part replacement (e.g. lightbulb)</td>
<td>Preventative servicing, cleaning and calibration, part replacement, software patching/troubleshooting by technical with specialist knowledge</td>
<td>Batteries changed, basic cleaning</td>
</tr>
</tbody>
</table>

Most of the problems with donation come from equipment in the “complex, long-lived devices” category. This equipment is the most expensive, so hospitals are more likely to rely on donations or low-cost purchases to acquire it. It also requires the most skilled operators and maintenance, leaving it victim to many of the problems mentioned previously on repair quality and training.
Particularly relevant the complex, long-lived devices category (though this also applies to the “Furniture/accessories” and “Medium complexity devices”) is the division in the sources of the equipment, listed below:

1. New “high-quality” equipment

Equipment manufactured by high-end suppliers (e.g. Philips, Siemens, GE), the most expensive to procure. Usually sold with service contract or warranty. Occasionally manufacturers donate directly to donation NGOs, in which case no warranty is provided.

2. Second-hand “High-quality” equipment, non-refurbished

Donated equipment originally manufactured by high-end suppliers (e.g. Philips, Siemens, GE) and retired from hospitals after upgrade or obsolescence. May arrive non-functional or missing spare parts/instruction manuals.

2. Second-hand “High-quality” equipment, refurbished

Donated, resold or returned equipment which has been refurbished by either the original manufacturer, a 3rd-party broker, or an NGO. Refurbishment entails replacing almost worn-out parts, recalibration and sourcing of instruction manuals. Can last for 5-10 years if properly maintained, though if replacement parts may be difficult to source.

3. New “low-quality” equipment

New ‘budget’ equipment usually manufactured in China or India. Much cheaper than new high-quality equipment, and sometimes cheaper than refurbished. Short lifespan (1-2 years) and sometimes difficult to repair as manufacturer may not stock individual parts, and does not come with warranty. Purchased either directly by hospitals or by donation NGOs who give to hospitals for free

3.4.3 Hospital Division

The stakeholder map in Figure 4 - Stakeholder MapFigure 4 shows how these different categories of equipment are spread across different types of hospitals in developing countries. Only the best funded central teaching hospitals can afford to buy high-quality equipment directly. Slightly less wealthy city hospitals or hospitals funded by NGOs or religious organizations choose to buy second-hand, or to buy new cheap Asian-made equipment. These options are affordable, but do not usually guarantee spare parts, consumables or service, so though these hospitals can be assured the equipment will work initially, they are taking a gamble on its longevity. The poorest hospitals rely on donations. The varying quality of donation NGOs means that it is not guaranteed for how long a donated machine will work, if at all.

The way hospitals are distributed across these three categories varies by country. Kenya, a middle-income country, recently signed a contract for new, fully-serviced radiology equipment from GE for 98 of its district hospitals (GE Healthcare 2015), whereas the Gambia still relies on donated equipment in its largest teaching hospital (Howie, et al. 2008).
3.5 Results Research Question 3: Problems of Repair & Maintenance

3.5.1 Confirmation of Repair & Maintenance as a problem

A key finding in the interviews was just how crucial repair and maintenance was, particularly for complex medical devices. International Aid described how oxygen concentrators, for example, had a lifetime of 10 or 15 years if their filters were changed, and only 1-3 months if they were not. The two interviewees who sold refurbished medical equipment (MDaaS and Global Links) indicated that the fact that equipment was 2nd-hand was not necessarily in itself a problem, since many first-world hospitals replaced equipment because of policy changes rather than because the equipment was broken. What was a problem was the fact that 2nd-hand equipment does not come with a service contract, and if no longer manufactured by the company, was difficult to find spare parts for.

Four of the interviewees mentioned the lack of a “maintenance culture” – preventative maintenance was not often performed and corrective maintenance would only be performed if the machine was completely unusable (not, for example, if it was behaving unusually but still functioning). It is as yet unclear whether this lack of motivation to hire maintenance service is due to lack of knowledge or particular work cultures, or whether it actually arises in response to the lack of quality repair services, as will be explained below.

3.5.2 Financing Repair & Maintenance

A problem that appeared throughout literature and interviews was the difficulty of budgeting for repair & maintenance, particularly corrective maintenance in response to machine breakdown. The WHO and THET warn donation organizations and hospitals of the "hidden costs" of medical equipment, including repair and maintenance, and warn against only accounting for the upfront 'sticker price' of the machine. The implication is that these costs are not accounted for due to oversight or lack of knowledge from the hospitals; an opinion supported by one of the donation organizations interviewed (Global Links).

However, some other interviewees (Gradian Health, MDaaS, Philips, Gomez-Marquez) gave a different view; that budgeting for maintenance was often, from a hospital manager’s perspective, actually a bad financial decision.

Lower-income hospitals in receipt of donations could easily wait on the next donation if a machine broke, rather than pay for it to be repaired (Gomez-Marquez). Higher income hospitals could make a decision between a one-time purchase of an expensive, high-quality refurbished machine with additional maintenance costs over a lifetime of 5-10 years, and a low-cost Chinese-manufactured machine which would need to be replaced every 1-2 years, which may be cheaper in the long term (see Figure 5).
Budgeting for repair fares even worse in this calculation when one considers the fact that in the developing world, unlike in developed-world hospitals, paying for maintenance does not necessarily mean actually getting the machine repaired.

Mechanics may be improperly trained – over 85% of African hospitals surveyed by THET reported difficulty finding trained biomedical technicians (THET, 2003). The breadth of medical equipment present (particularly when donations are collected from all over the world) means that even well-educated mechanics may be inexperienced with the particular type of equipment being repaired (Gentles). Hospitals see even less point of budgeting for repair and maintenance if they also do not trust the quality of the repair and maintenance available.

In the developed world there are few ‘freelance’ biomedical engineers; equipment manufacturers maintain repair quality by selling servicing contracts which guarantee the customer’s access to their own, in-house biomedical engineers, highly-trained on the specific equipment sold by that company. According to the interviewee from Philips, however, these service contracts are difficult to sell in the developing world, particularly Africa, since few customers can afford them. When they are sold, it is difficult for Philips to maintain a profit margin on them because providing service in Africa is so expensive; quality service engineers can only be found in a few locations (e.g. Kenya, Ghana, South Africa) and so have to travel great distances to repair machines elsewhere on the continent.
3.5.3 Lack of Diagnosis Expertise

Most of the interviewees and literature cited a lack of skilled biomedical technicians. However, only one study has actually examined the skills which are required by a technician to repair machine breakdowns in the developing world.

An extensive field study performed by Duke University in 2010 examined 2,849 medical repair requests in resource-poor hospitals across 11 countries. For each case, an engineer or engineering student was sent to diagnose and repair the device, and report on what actions, parts and tools were required to put the device back into service (Malking and Keane 2010). A crucial detail is that though the students were
only allowed to use locally available parts and tools, they had access to online manual resources and the ability to call an expert engineer in the US to help them diagnose and solve problems.

It was found that 66% of the equipment could be put back into service using only basic levels of knowledge in six domains (see Figure 6), far below the skill level of a trained biomedical technician.

![Pie chart showing knowledge required to fix medical equipment in low-resource hospitals](Image)

*Figure 6 - Knowledge required to fix medical equipment in low-resource hospitals (Data Source: Malkin & Keane 2010)*

It was also found that 72% of the equipment was able to be put back in service without the use of imported spare parts – i.e. with no spare part or with locally-procurable standardized parts such as washers or cables.

This study was particularly interesting for this project because it implies that a large percentage of machine breakdowns are actually physically capable of being repaired locally. In 66% of cases, what was missing was not specific tools or parts, but the knowledge required to know firstly what the issue was and secondly the approach required to fix it. The key missing factor the students had that local biomedical technicians did not was the connection to an expert engineer who knew what simple fixes they should perform.

This problem was confirmed in the interview of by Bill Gentles, an academic who studied device donation in Ghana. He said that though Ghanaian engineers were generally well-educated, they often did not have specific knowledge of how to approach diagnosing a particular model of machine. This is especially prevalent with donated equipment, since a single hospital could have donations from various different suppliers and of varying ages, and an engineer may not build up enough experience on specific devices.

This indicates that there is a “diagnosis gap” in repair and maintenance of medical equipment in the developing world, where equipment which is technical fixable does not reach the point of repair as there is no expert diagnosis available. This is something that remote repair services could potentially help.
3.6 Vision: A Product Service System for Repair and Maintenance

The problems found in the interview research indicate two things; firstly that there is a need for a viable, affordable product-service system for repair and maintenance in the developing world, which can guarantee quality maintenance. Secondly it indicates that this product-service system must be based on some sort of remote expert support to assist with machine diagnosis.

Interviews and literature research indicate that inadequate local support for repair is available, and that providing quality expert technicians in person is too expensive for equipment providers and customers. The study by Duke University however, shows that expertise can be decoupled from basic technical skills; the expertise required to diagnose a problem could be provided remotely, over phone or internet, and the actual physical repair could performed by a local technician or the user themselves.

This type of remote support service is already provided by some companies and organizations (such as interviewees Philips and International Aid). However, as the interviewee from International Aid stated, simple phone-based support services can currently “only do so much” – good communication can be difficult and they are not a complete solution for repair & maintenance support.

Improving this remote support within a complete product service system could therefore make a huge impact within this space. As seen in the equipment provision analysis in the box “Existing Strategies for Equipment Provision” on the next page, currently providers of medical equipment must make trade-offs between providing repair & maintenance services and other factors such as affordability, quality and scope of their equipment.

The product focus of medical imaging equipment was chosen because (as shown in Table 2), this type of equipment falls into the category which faces the greatest challenges in repair and maintenance. Medical imaging equipment (radiography and ultrasound) is commonly used worldwide in all levels of healthcare from primary care and diagnosis to complex surgical procedures. Africa was chosen as the continent of focus because it has a high incidence of broken medical equipment (Perry and Malkin 2011) and a low-incidence of biomedical engineering services (THET 2003), making it a potential high-impact region for a product-service system.

This assignment therefore has two objectives: requirements for the design of a circular medical imagining device and requirements for the service system around it. Since these aspects are closely interlinked, they will be developed and iterated simultaneously, as will the concept designs which result from them.

“To design a product-service system to allow effective, remote-assisted repair & maintenance of medical imaging devices for any user in the African market”
Existing strategies for equipment provision

As well as the general questions posed to all interviewees, the four interviewees who were active providers of medical equipment were asked about their strategies for successful handover of medical equipment.

From these interviews, five “trade-off” factors were identified, that the interviewees described having to balance in order to be able to function successfully.

1. Machine affordability (for the end customer)
2. Machine quality
3. Scope of customer needs met (i.e. how many requested equipment types and models can be provided)
4. Provision of repair and maintenance
5. Scale of operation

Each provider was then rated on a qualitative scale of 1-5 according to how much they focused on this need in their operations. As can be seen below, all four adopt tactics that exclude some of the factors to focus on others. Global Links, for instance, limit the scope of the countries they operate in so that they can minimize overheads, and limit the range of products they donate to exclude “Complex long-lived devices” (see Table 2) and thus reduce maintenance and training costs. This allows them to ensure high-quality donations free of charge for their recipients. International Aid, by contrast, charges customers for their equipment, allowing them to cover the costs for wider distribution and basic over-the-phone maintenance support. Gradian Health Systems has focused on the machine quality and the appropriateness of their design (their anesthesia machine is designed withstand hot, humid environments and power cuts, and uses standardized parts), making their equipment less likely to break down and able to be repaired without specialist knowledge, though they do not themselves provide repair support. MDaaS is able to provide extensive repair and maintenance support for refurbished equipment by limiting its reach to a small geographical area (southern Nigeria).

Figure 7 - Strategies for Developing-World Medical Equipment Provision
4. Research Plan

As already hinted at during the scoping research, there are many different factors involved in the provision of remote servicing. These factors require different methods of investigation from a product design perspective.

Firstly, remote servicing can be viewed as a particular interaction problem – two users have to collaborate and communicate effectively, mediated by technology, in order to solve a potentially complex problem. This interaction, like any other, will have its own unique features and challenges. In order to investigate this, user observational studies and interviews were performed with users who are already involved in remote repair of medical equipment. This research was performed with engineers from and customers of Philips Healthcare, at their service support offices in Eindhoven (Netherlands), Cairo (Egypt) and Johannesburg (South Africa). This research was analyzed to create a vision and set of requirements for the ideal remote service interaction.

Secondly, since remote interaction is a technology-dependent interaction, a short benchmarking investigation was performed into existing technologies and trends for remote servicing.

Thirdly, the proposition implied in the research question to expand the scope of remote servicing in Africa beyond those who already have it requires an understanding of the situation and work practices of users who currently do not have service contracts. For this, in-depth interviews were performed with biomedical engineers and medics working in non-serviced hospitals in Uganda. This research was used to create user requirements for what features a product assisting these users in their work would need to have.

Finally, as has already been identified in the scoping research, the field of medical equipment repair in the developing world is a complex global system, involving many different stakeholders. Thus the data gathered in the user studies was used to create an analysis of problems and opportunities in the current system.
After the focus on remote-assisted servicing was chosen, a short benchmarking study was performed of remote servicing assistance technologies already in existence, using internet searches and information from experts within Philips. The most relevant results are summarized below.

5.1 Medical Equipment Remote Servicing

Remote servicing solutions are already widely in place for equipment in the developed world. These rely heavily on data, rather than user interface. The Philips RADAR system for MRI machines, for example, uses a network of sensors within the device to detect errors, in some cases being warned of them before they happen. Using this system remote engineers can log directly into a user environment and interact with it. High connectivity is required for this service, and little to no focus is placed on interaction with the customer (Philips, 2013).

In the African market, the single company involved in remote servicing technology is Look.See.Do, a South African start-up company which provides remote assisted repair using low-bandwidth video connection and augmented reality videos. This is currently a small company with no widely available products, and their focus is largely on technology (Look.See.Do, 2015).

5.2 Telemedicine

Though developments in remote repair service interaction are few, there are many case studies of remote interactions to be found in medicine itself. The field of “Telemedicine” has been growing in recent years, including in Africa (World Health Organization, 2010). This typically involves some sort of data being collected in the field in remote areas and sent to experts for diagnosis. Malawian-UK mobile app Vula-Mobile, for instance, has an interface which guides health workers through making pictures of a patient’s eye, then sends them to be diagnosed by a doctor in the UK (Vula Mobile, 2016).

![Figure 8 - Vula Mobile Diagnosis Screen](image)
5.3 Existing Online Resources for Machine Repair

Though not specifically related to remote servicing, several online resources were found designed to assist users with self-repair of devices. The most commonly used is iFixit, a site to help users self-repair consumer products by providing highly visual step-by-step guides, answers forums, and links to quickly find parts and tools (iFixit, 2010). Interestingly, two online resources were found which are specifically dedicated to helping local users repair medical equipment in the developing world. These sites, Electric Squirrel and Frank’s Hospital Workshop, were each compiled by an individual biomedical engineer with the explicit intention of assisting users in the developing world. They contain how-to-guides and user and service manuals for medical equipment. The number of comments on the site suggest they are widely used. Frank’s Hospital Workshop in particular tries to share service and user manuals, but is apparently often prevented from doing so by equipment manufacturers (Squirrel, 2014) (Frank’s Hospital Workshop, 2015) due to legal reasons.

![Download prohibited by Mindray.](image)

![Download prohibited by Philips. Support is not desired.](image)

*Figure 9 - Extract from Frank’s Hospital Workshop showing blocked downloads*

5.4 Connectivity Trends

A positive development for remote repair and maintenance is that remote connectivity in general is expanding rapidly in Africa. A report by GSMA shows that the number of mobile internet subscriptions on the continent is today 300 million, tripling since 2011, and there are a total of 226 million smartphones in use across the continent. Though most of the development is taking place in large, advanced economies such as South Africa and Nigeria, the trend is still present for the rest of the continent, albeit at a slower pace. This suggests that in the very near future some sort of internet connectivity may be assumed for a large proportion of users in Africa (GSMA, 2016).
6. User Research within Philips Remote Servicing

6.1 Summary

The goal of this section was to gain a thorough understanding of the workflow and user interactions involved in remote servicing by studying the existing methods employed by Philips. Interviews and user observations were performed with three user groups involved in the process of remote servicing of medical imaging equipment (remote service engineers, field service engineers and customers) in two markets – Benelux (Eindhoven/Den Haag) and Africa (Johannesburg/Cairo). The resulting data was analyzed using work models from the field of contextual inquiry to create a description of the work processes and interactions involved in successfully fixing a problem remotely. Challenges to achieving a successful fix - both in general and specifically in the African market - were also identified. These were then used to create a vision for the ideal remote service interaction.

6.2 Study Objectives

The primary research questions in the study were:

1. What processes are required to successfully repair a machine using remote servicing?
2. What challenges or problems do users face during this process?
3. What particular challenges are there for remote service in Africa as opposed to the European market?

6.3 Methods

Because the goal of the research is to understand details of a complex process, a ‘rich picture’ approach, where a small number of test subjects are researched in greater depth, was taken. For the RSE and FSE participants, this was in the form of full-day observation studies directly observing the process of machine repair. For the customers, since it would be difficult to time observation studies with machine errors, in-depth interviews were carried out.

All observational studies were analyzed using contextual design ‘workflow models’, and user profiles were created for all studies in the target market. Association clustering to find general problems, and modelling of the situation using a custom-developed “Troubleshooting Timeline” (see the supplement to this thesis “Developing a Design Method for Troubleshooting) were performed with all data.

After using these as an initial guide, new models were created that more specifically captured the important work practices involved in remote servicing. The complete contextual inquiry work models can be found in Appendix XVII. In this section, only the final analysis is presented in full, with some selected examples from the work models where relevant.
6.3.1 Workflow Observation

For these studies, an activity-centered design approach was chosen. Activity-centered design focuses on understanding the work practices of users and analyzing the tasks that users have to perform through observational studies and interviews (Norman 2005). This approach was chosen rather than the more common “user-centered design” approach, which focuses on the thoughts, desires and lifestyle of a particular customer. Firstly this is because both the use and repair of medical equipment by their nature require precise, complex task sequences to be performed, and the success of the technology is judged on how well it supports these tasks. Secondly, since these tasks have specific technical and medical goals, they will be relatively consistent among all users, even though those users as individuals may have vastly different cultures and lifestyles.

Data was gathered according to the Contextual Inquiry method developed by Karen Holtzblatt. This method draws on techniques from ethnography and psychology to investigate user work practices, which are defined as the behaviors, attitudes, goals and intents involved when users perform a certain task. The key feature of this method is that the customers are not asked a set of standard interview questions, nor are they merely observed passively by researchers.

Instead, researchers are asked to take on an “apprentice” role, asking the participants to explain their work as they go along as if to teach the researcher how to do it, using non-leading verbal prompts (e.g. “why are you using that?”). This leads to a richer understanding of the work involved, since often practitioners of work become only fully aware of their practices and the reasoning behind them while they are performing that work (Beyer and Holtzblatt 1998) (Polyani 1958).

Studies were performed in this manner for four service engineer participants; a field and remote service engineer in Eindhoven, the Netherlands, servicing the Beneleux area, one remote service engineer in Egypt, serving the Africa market, and two field service engineers in Pretoria, South Africa.

Each participant was observed for 4-6 hours during their normal workday, using the “apprentice” method. Handwritten notes were taken throughout, using a notebook with pages divided into one section for basic observations and one for theories or opinions of the researcher. Contextual inquiry also recommends that these opinions or theories be voiced to the test subject immediately, so that feedback can be gained from them. Photographs were taken at visually relevant moments (e.g. to capture the layout of a workspace). Notes from these studies can be found in more detail in Appendices III, IV, XIV and XV.

6.3.2 Guided Semi-Structured Interviews

Since the customer (machine user) interaction during the diagnosis and repair process was being investigated, the ideal situation would have been to observe these participants while they were dealing with a repair process and employ contextual inquiry principles as described in the section above. However, machine failures are sporadic events and any time allotted to spend shadowing the customer could not have been guaranteed to contain a machine failure.

Therefore, instead of observation studies, interviews were carried out with the participant about the process of repair. The interviews had to perform two functions; firstly to characterize the type of clinic the users worked in with regards to the specific equipment they used, their patient throughput and their experience and education level, so that it could be determined how they related to other users in the
African market. The primary function of the research, however, was of an exploratory nature, aimed at generating rather than testing theories about workflow.

Thus a combination of questionnaire and semi-structured interview was used. A questionnaire was generated covering basic facts about the clinic. Customers also were asked to rate the confidence they felt at tackling a selection of common machine errors (taken from Philips data on failure rates of DXR machines).

To gain a deeper understanding of the user, the second half of the interview was done using a semi-structured interview style, whereby a small set of questions acted as guides for the conversation, but allowed additional unexpected areas to be explored if mentioned by the user. This style of interview is widely used in design and other fields (e.g. medical research) for exploratory understanding of a topic (DiCicco-Bloom and Crabtree 2006) (Jamshed 2014). The full text of both the questionnaires and the prompt questions for the semi-structured interviews is available in Appendices V & VI.

The guiding interview questions were constructed partly using “directed storytelling” techniques (Saffer 2010), where users are asked to describe a particular incident rather than make generalizations (e.g. “What was the last time there was a machine failure, and what happened?”). These parts of the interview were performed in the medical imaging room itself with the machine close at hand, so that the customer could walk through any processes mentioned with the equipment, and refer to it in their answers. For this section of the interview, the participants were voice-recorded, with minimal handwritten notes so that attention could be focused on exploring the interview answers. Transcripts or notes of the interviews can be read in Appendices VII – XIII.

6.3.3 Workflow Analysis Methods

Models from the field of contextual inquiry were used to do a “first pass” analysis of the data. These models provided four generic descriptions of the work practices in terms of communication flow, culture, sequence model and tools, described below:

**Flow model:** Shows the communication and co-ordination patterns between different users in order to accomplish tasks

**Cultural Model:** Captures ways in which behavioural norms influence work, whether cultural (e.g. office hierarchy, taboos) or policy (e.g. adhering to Health & Safety rules)

**Sequence model:** The steps required to perform a task, the intents and goals behind them and problems that potentially block them

**Artifact model:** Shows artifacts that are used or created during the workflow
6.4 Study Scope & Participants

6.4.1 Overview of Scope and User Types

Service provision in Africa is arranged slightly differently to in Benelux, as shown in Figure 10 (below). In Benelux customers first engage with Remote Service Engineers, then Field Service Engineers are sent in-person to the hospitals if required. Both engineers are based in the Benelux area.

In Africa, customers first engage over the phone with Field Service Engineers, who are local to their country and are generalists in an equipment modality. Remote service is attempted at first, and then in person if the Field Service Engineer decides it is required. If a Field Service Engineer cannot solve the problem or they know that it lies outside the scope of their knowledge, they call or email a ‘Tier 2’ Remote Service Engineer, usually an experienced specialist at a global hub (in this case, Cairo), who assists them with the problem. Thus in Africa the line between FSEs and RSEs is more blurred.

Since the intention of the research was to capture all aspects of the repair, interviews with customers were performed, as well as observational studies with two Field Service Engineers and a Tier 2 Remote Service Engineer. This allowed both types of interaction to be captured - between customer and technical expert (FSE) and between different levels of technical expert (FSE and ‘Tier 2’).
6.4.2 List of Participants
The list of participants from both the customer and company are listed in Table 3 and Table 4. The selection of customers was somewhat constrained by the availability of participants, though all attempts were made to gather customers from a wide range of hospital types (private clinics and government hospitals) and equipment modalities. All users were gathered through Philips, either as employees or customers, and were informed that the purpose of the study was an investigation into how to improve service support. Due to the nature of the participants’ work, it was known before the study that some of the interviews might need to be cut short due to the need for participants to meet work demands. For this circumstance, a short questionnaire was used in place of the unstructured interview so that basic information could at least be captured. This was required for Hospital 4 and Hospital 6, all other participants were able to complete the full interview.

Table 3- Company Field Research Participants

<table>
<thead>
<tr>
<th>Company Participants</th>
<th>Country</th>
<th>Modality Specialism</th>
<th>Study Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Service Engineer</td>
<td>Netherlands</td>
<td>Diagnostic X-ray</td>
<td>1 x 4hr observation study</td>
</tr>
<tr>
<td>Field Service Engineer</td>
<td>Netherlands</td>
<td>Diagnostic X-ray</td>
<td>1 x 7hr observation study</td>
</tr>
<tr>
<td>Remote Service Engineer</td>
<td>Cairo</td>
<td>Diagnostic X-ray</td>
<td>1 x 6hr observation study</td>
</tr>
<tr>
<td>Field Service Engineer</td>
<td>South Africa</td>
<td>MRI</td>
<td>2 x 4hr observation study</td>
</tr>
<tr>
<td>Field Service Engineer</td>
<td>South Africa</td>
<td>MRI/Diagnostic X-ray</td>
<td>1 x 4hr observation study</td>
</tr>
</tbody>
</table>

Table 4 - Customer Field Research Participants

<table>
<thead>
<tr>
<th>Institution Type</th>
<th>Country</th>
<th>Modalities</th>
<th>Participant(s)</th>
<th>Interview type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital 1</td>
<td>Private chain hospital</td>
<td>Diagnostic X-ray, CT scan, MRI</td>
<td>Head radiographer, assistant radiographer</td>
<td>Semi-structured interview, 45 mins</td>
</tr>
<tr>
<td>Hospital 2</td>
<td>Public (government) hospital</td>
<td>MRI</td>
<td>Head radiographer</td>
<td>Semi-structured interview, 30 mins</td>
</tr>
<tr>
<td>Hospital 3</td>
<td>Private radiography centre</td>
<td>Diagnostic X-ray, CT scan</td>
<td>Head radiographer, assistant radiographers, centre manager</td>
<td>Semi-structured interview, 45 mins</td>
</tr>
<tr>
<td>Hospital 4</td>
<td>Private hospital</td>
<td>Diagnostic X-ray, CT scan</td>
<td>Centre manager</td>
<td>Checklist questionnaire</td>
</tr>
<tr>
<td>Hospital 5</td>
<td>Religious org. hospital</td>
<td>Diagnostic X-ray, CT scan</td>
<td>Head biomedical technician</td>
<td>Semi-structured interview, 30 mins</td>
</tr>
<tr>
<td>Hospital 6</td>
<td>Private obstetrics clinic</td>
<td>Ultrasound</td>
<td>Medical practitioner</td>
<td>Checklist questionnaire</td>
</tr>
</tbody>
</table>
6.5 Results

6.5.1 Work Processes within Remote Servicing

This section addressed the objective set by Research Question 1: a descriptive overview of the processes required for successful remote repair.

Actions, Observations and Decisions

Repair is often used to refer interchangeably to the act of fixing a problem, by replacing a part or by some other means. However, it was observed from these user observations that the vast amount of time spent on repair was actually spent troubleshooting, i.e. trying to find out what the problem actually is. This may be because of the complexity of the equipment. Existing studies have shown that as the number of parts in a system increases, the number of possible errors scales at least with the number of interactions between those parts (Murthy & Nguyen, 1985). Thus in complex equipment there is many more potential causes to look through before finding the real problem.

This section of repair - diagnosing a problem - was observed to involve iterative repetitions of the same three core types of user activity: observations, decisions and actions. A user would first make an observation (i.e. the radiologist seeing that the image was unclear). This observation would then be used to make some decision about a next step (e.g. after having been described the unclear image, the remote service engineer would decide that there might be a problem with the cable connection, which must be tested). Based on this decision, an action would be taken (e.g. the customer would remove and reinser the cable upon the remote engineer’s instruction). An observation would be made of the outcome of this action (e.g. the image is still unclear), leading to another decision, another action and so on until either an action was taken that fixed the machine, or a decision was made on the definite cause of the error. This pattern can be seen on a short section of the sequence model created for the Benelux engineers in Figure 11.

Figure 11 - Excerpt from Sequence Model Showing Actions, Observations and Decisions
As can be seen, these activities do not necessarily have to be performed by the same person or even in the same geographical location. The general activity distribution in remote servicing is that the customer performs actions, observations are transmitted to the remote engineer by the customer (through descriptions, photos, file transfers etc), and decisions are made by the remote engineer.

An attempt was made to catalogue all the different types of action, observation and decision which were recorded in the sequence models of the observational studies. These are shown below in Figure 12. The orange dots represent those tasks which could only be performed by a field service engineer in person – the rest were potentially able to be transmitted remotely (observations) or remotely directed (actions).

It is notable in the “observations” section that different observations are best transmitted to the remote service engineer using different mediums – picture, sound, video, data or text might each be more suited to a particular observation.

Figure 12 - Observations, Actions and Decisions from Beleux/Africa Observation Studies
Fault Isolation & Case Tracking

The categories (Observations, Actions & Decisions) formed in the last section are deliberately broad so that a wide range of activities can be captured in three simple categories. “Decisions”, for example, can include both an engineer arriving at a conclusion based on a skilled analysis of the system, and on the other a customer “deciding” to follow the next step in an instruction manual without knowing anything about why that step is being taken.

The former – the informed decision-making of the engineers – mostly consists of a process of fault isolation. Fault isolation assumes that if the basic structure of a system is known, an error can be found by testing which parts of the system are not causing the error, thus eliminating them from suspicion and narrowing down the engineer’s search to a smaller group of components.

This means that knowing which parts of the machine are functioning is just as important as knowing which are not. In practice, engineers were observed to note down key pieces of data or facts about the error which they knew might help them with fault isolation (“case tracking”). This is especially important because not all parts of the system are capable of being individually tested, thus certain combinations of outputs may hint at certain errors or isolations.

Two excerpts from artifact models, shown below, demonstrate fault isolation and case tracking. The first is a diagram drawn by a remote service engineer in Egypt to show how he eliminate different subsystems in a diagnostic x-ray to find the problem. The second is an overview of the logbook kept by a remote service engineer in Eindhoven, which had each case noted chronologically with examples of key facts he could refer to later – especially if he was reopening the case after some time away from it.
This chronological method of reporting also offered an interesting insight on how the engineers recalled information when having to switch rapidly between many different remote service cases. There existed an official data collection system using fields where cases could be searched by certain keywords. However, both RSEs accessed information chronologically – one (who used mostly email) by looking back through his inbox, and another (who used phone calls) with his own chronological notebook, since they found the easiest way to find an old case was just to remember how long ago they had talked to the customer. In the second engineer’s own notebook he also did not record everything mentioned in the official fields, but simply the important information to that case – the rigidity of the official method, which required set types of information to be submitted, was considered both too time consuming and not flexible enough.

Networked/Outsourced Knowledge

The last important finding regarding the work processes of remote servicing was that no one engineer works from his or her own head or expertise alone. Even engineers who had a vast amount of experience and expertise on the machines “outsourced” some of the details of their knowledge to either reference material or other human experts.

For example, remote service engineers in Egypt worked with several different equipment and service manuals open at once, allowing them to read detailed information about particular subsystems as they switched focus between them during fault isolation. MRI Field Service Engineers in South Africa used a “cheat sheet” to interpret the hundreds of error codes and self-test results output by machine. The Benelux service engineer had created his own pdf with basic instructions and reminder photos, since he needed get information quicker than from the large service manual.

However, not all the knowledge required can be captured in a manual. Troubleshooting complex equipment involves a vast range of possible errors and symptoms which also grow over time – machines put into new circumstances and environments develop errors the original designers could never have
predicted. Thus as engineers gain experience in solving problems, they develop intuitive, ‘tacit’ knowledge about the type of machine errors they happen to have come across which may never have been written down in a manual and may even be unique to that single person. Remote service engineers in Benelux and Field Service Engineers in South Africa described having a ‘network’ of other engineers they could draw upon for experience – for instance, if they had isolated the problem to the power system, they would call an engineer whom they knew to have particular experience in that area, or even forward the service call onto him if they knew he would be better placed to solve it.

Official processes existed in the company organizational structure for ‘escalation’ – passing on a service case to someone known to be more expert (known as a ‘higher tier’). For instance, a call center representative might pass a call ‘up’ a tier to a remote service engineer, who would in turn pass it up to a factory or design engineer. However, the sharing of information through a lateral network of engineers on the same ‘tier’ was largely informal.

Whatever knowledge resource was used by the engineers – written or human – the remote service work process always involved an iterative task-switching between using this knowledge resource and interacting with the users. The Egyptian RSE, for instance, indicated that since he could not see the machine in front of him when guiding a remote repair, he found it helpful to have a picture reference in front of him when directing the customer or FSE, rather than try to remember the machine layout himself. He also used pictures to double-check parts with FSEs and customers – the RSE would request a picture reference of the part to be replaced and check it against the picture of the machine in the manual.

**Standard Timeline**

Though there were many more complex variations, the general timeline of the remote repair is shown in Figure 15 opposite. This gives a general overview of the types of steps involved in the repair and their rough sequence, though many steps are iterative and may repeat several times during a single repair.
Figure 15 - Remote Repair Timeline
6.5.3 Challenges in Remote Servicing

The previous section attempted to describe neutrally the work processes seen to be required for a successful service call: a sequence of observations, decisions and actions are taken (spread between the remote engineer and customer), which lead to isolation of the fault, supported by a network of knowledge resources and a method of tracking information.

However, these required processes were not always successfully completed. This section outlines some of the challenges seen in remote servicing, and distinguishes between those seen in Benelux and those which were particular to the Africa market.

Transferal of Context

As seen in the previous section, remote servicing requires accurate information to be transferred between remote service engineer and customer (or field service engineer). Sometimes this information transfer was hampered by the different backgrounds of the parties communicating – customers in South Africa described the engineers as using “technical language” that they did not understand, and so often did not feel confident that they and the engineer were referring to the same thing. Similarly, customers would describe errors in terms of their clinical processes (e.g. “cannot clearly see cardiology image”) rather than in terms of the way the machine functioned.

These problems with transferal of context in Africa are exacerbated by language barriers. Because of the relatively small install base in Africa, there are only a few remote experts assigned to the continent, each serving a large geographical area. Significant numbers of interactions take place between users who do not share a common fluent language. Since most communication is written or over the phone, there is a risk of mistranslation or misunderstanding.

Field service engineers in South Africa (who also performed remote service activities) described exchanging photos with customers over Whatsapp, an instant messaging service, to get around some of these communication barriers and more accurately transmit observations.

However, sending images still has limitations – connectivity is scarce in many areas, and also often expensive. Also, as seen from the overview of troubleshooting actions in the previous section, some observations are not best suited to transfer by image, and might need instead a video, sound recording or data file transfer, or may be able to be transmitted simply with text. This categorization is important in the African market because it shows the minimum data bandwidth required to accurately transmit certain pieces of contextual information.

Company remote service initiatives in the developed world have focused on remote network access and the transferal of direct machine data (“DICOM files”), and in some initiatives, video conferencing. However, these are all high-bandwidth, and may in fact be a data-inefficient way of transferring context.

The way that policy is structured with regards to transfer of sensitive information is also not suitable for the Africa market. Most modern machines are equipped with self-testing capabilities and the ability to generate error logs, both of which can be extremely helpful at error detection with minimum risk of further damaging the machine. They are also both only able to be performed with the permissions of a Company service engineer. In Benelux this is not a problem, since most machines are equipped with a
VPN connection through which Philips remote engineers can access the software and extract the information. However, many customers in Africa either did not have the required connectivity or were reluctant to let Philips access the network for privacy reasons, meaning these “easy” troubleshooting methods required a service engineer to physically travel to the machine.

Information Loss in Fault Isolation

As described in the previous section, fault isolation involves knowing information about the whole of the machine system’s behavior, and requires keeping track of which parts of the system have been isolated and which have not. Ideally, all information relevant to fault isolation would be captured and used toward diagnosing the problem.

However, many inefficiencies were caused in remote service due to the loss of this information. Information loss occurred at two places: between customer and remote service engineer, and between the engineers themselves.

Customers did not always know what information was relevant to tell the engineer, especially regarding parts of the machine which were not obviously displaying a problem, even though this information is also important for fault isolation. This was especially true of information about events which happened before the remote service call – customers would neglect to tell engineers about a prior incident which might have given a clue as to the error source, or troubleshooting actions they had already performed themselves (like a machine restart) which would have provided helpful fault isolation information. Thus engineers would waste time asking the customers to perform actions they had already done, or pursuing lines of enquiry which would have been ruled out if they had more complete information. This led to a long “back-and-forth” process in remote servicing which was frustrating for both engineers and customers.

Information also ‘leaked’ between the engineers. The necessity of networked knowledge means it may be necessary to pass a remote service case between several people in the course of solving it. In the observation studies it was seen that context was not always transferred effectively during these exchanges.

In several examples, field or remote engineers who had been working on a case for some time would write up lengthy descriptions of their activities in order to escalate them to an expert, but said experts would have so many different service request they would not have time to read through the text in detail, and thus would ask the engineers to repeat actions. In other cases, the original engineer on the case would neglect to pass on complete information to the new engineer. In both cases, there was a lack of a standardized means of tracking fault isolation and getting new engineers up to speed quickly on its progress.
Remote Fixing: Confidence & Trust

Remote servicing necessarily requires some actions on the part of the customers, since they are the ones who have physical access to the machine. What level of actions were taken by the customer varied considerably between the different situations observed. Both in Benelux and Africa, the actions taken by the customer dependent heavily on how much the remote engineer trusted their abilities. The Benelux remote service engineer, for example, was observed to allow one customer to change a battery – a complicated and risky task – on their own, but in another case dispatched a field service engineer to perform a minor task, since they did not trust the customer well enough to do it themselves. In Africa, the engineers tended to trust customers less, since they were less likely to be trained biomedical technicians (see extract from Cultural Work Model in Figure 17).

A complimentary factor to this was the confidence and willingness that the customers had in fixing problems themselves. In hospitals without biomedical technicians (5 out of the 6 in Africa), customers described not being confident enough to perform certain actions themselves. Customers in Africa also felt themselves to have less responsibility for fixing the machine; a telling statement by one Egyptian customer was that “it’s the Company’s machine; not mine”.

However, all customers had a limited number of actions they considered “theirs”. This varied from customer to customer; some would perform their own calibrations (customers 1, 2 & 5), and all customers interviewed had the ability to change machine presets or adjust image grids on their own. Several customers interviewed had their own basic troubleshooting procedure they went through before calling an engineer – Egyptian radiographers (Hospital 3) described retrying scans using a mobile phone.
as a test object, and a South African customer (Hospital 1) responded to errors first by restarting the computer, then the whole system.

![Figure 17- Excerpt from Cultural Model for Benelux showing different levels of trust for different customers](image)

This varying level of confidence also affected remote servicing - while all customers were happy to be remotely guided through tasks they might also attempt themselves, they all hit a barrier of confidence at a certain point, after which they would insist a service engineer come in person. For African users in Hospitals 2, 3 & 4, the machine was the main source of the users’ livelihoods and there was no redundancy in their hospitals such that they could continue to take patients. Thus users were very anxious about accidentally breaking the machine.

This was exacerbated by the problems of transfer of context described previously. A South African radiographer described the exact point they became unwilling to perform remotely guided repair as when the remote engineer asked them to start removing cables from different circuit boards inside the machine. At this point the “technical language” used by the engineer to distinguish between the boards became too confusing.

Customers in busier clinics also expressed an unwillingness to attempt any activity that was too complicated— they were under a great deal of pressure from patients and thus found it difficult to switch their mind’s focus onto a complicated activity like machine repair. For this reason, though, remote service was still much preferable to having to go through a user manual themselves, which involved even greater mental effort. An Egyptian radiographer described “I already have enough patients to deal with, I don’t need [the machine to be] another one!”
For the African customers and engineers, the decision to send field service support was driven by a tradeoff between time, confidence and liability. In many cases engineers had to travel hours – even days – to fix a problem in person, so remote service had the potential to be faster, but also ran the risk of accidental damage, which the company would be liable for.

**Parts as Troubleshooting Aids**

Aside from the issues identified with remote connectivity, a commonly identified issue was that of part delivery. It had been noted early in the research (Section 2) that spare part delivery in Africa is challenging – even large manufacturers do not keep certain parts in stock, and customers and logistics barriers cause delays to shipping.

However, a crucial aspect discovered in this study was that in addition, sometimes changing a part is actually a step in diagnosing a machine error as well as fixing it. For example, fault isolation of a system (as described in Section 5.5.5) may come down to two components. The only way to distinguish which part is broken would be to replace one and see if the machine starts to work. Ordering both would mean at least one piece of extra stock would have to be held in-country, so engineers are encouraged to declare the case solved and order only one of the parts.

**Figure 18 - Part Delivery & Diagnosis problems**

This course of action is not an issue in Europe, where stocks are nearby and delivery methods fast. However for African customers, this means they may spend several days or weeks waiting for a part to arrive, only for this not to solve the problem. They then go through the waiting process again, losing patients and reputation in the process.
6.6 Design Vision & Conclusion: Philips User Research

6.6.1 Overview

In this section, a vision for a remote servicing product-service system is made based on the research results, and some comments are made on the scope of potential customers for this service system.

6.6.2 Design Vision

Based on this research a vision of an ideal system for remote servicing was developed, and is shown on the following page. Because remote servicing is a systemic activity, the requirements are shown related to the aspects involved in this system – the remote engineer, the customer, the communication channel between them and the machine.

Because the remote service engineers already have established tools, procedures and work environments, the design requirements for this part of the system can already address specific process improvements which were seen to be required in the user observation. On the customer side, however, since there are no existing tools the design requirements are more abstract, and relate to the desired “end state” that a customer should be brought to with a designed system.
Figure 19: Design Vision from Philips User Research

A communications channel which can transfer
OBSERVATIONS & ACTION
COMMANDS

A remote service engineering
tool which supports
DECISIONS

RESOURCES
Ability to tap into knowledge
networks & send the case
through them without losing information
Information on machine
history, common errors
and data

TOOLS
Tracking fault isolation,
and noting important
details of case
Easy task switching
between gathering
information, problem
solving and talking to

Wide range of media
Low bandwidth

Machine design which facilitates
customer
OBSERVATIONS & ACTIONS

INTERACTION
VISION

Helps customer confidently take
actions with remote support
Does not overly disrupt
customers workflow or cause
unnecessary stress
Uses clear and understandable
language/highly visual interface

Affordable service contract:
less than 5-10% of unit price

Easy to access and transmit
outputs
Remote Service ‘for Africa’?

It is important at this point to readdress the research questions, which asked about the difference between service in Africa and in Benelux. When the research was originally planned, it was assumed that service challenges for Philips in Africa would be different enough to warrant a separate research question. What the observational studies in Africa and Benelux found, however, is that there are not two distinct sets of problems for two different geographical areas - the types of problems faced are largely similar. The difference is that certain problems are amplified in an African context.

For example, the issue of trust in guided repair is made worse by the lack of biomedical technicians, and context transfer is made more difficult by poor connectivity and language barriers. The tools and environments used by remote engineers were almost the same in Benelux as in Africa, and resulted in the same types of obstructions to workflow, but the difference is in the impact of these obstructions. What is a minor inconvenience in a European context can have a much more serious outcome in an African context. In Europe, remote service is a money-saving measure which may result in slightly better uptime results for the customer, and always exists with the “safety net” option of sending an engineer to the field. Thus small inefficiencies in the process can be accommodated. By comparison, for a hospital in a remote area in Africa with no back-up equipment, remote service is essential (since in-person service may be impossible), and every minute of inefficiency in remote service represents a loss of revenue that the hospital may not be able to afford.

Thus, the design vision previously described could indeed by applied to remote servicing anywhere in the world – but in Africa it is most essential that these improvements be applied.

Africa User Differentiation

The problem statements described above were all present in different forms across several of the users observed. However, it was observed that there was a difference in the relative importance of these problems depending on the point in the repair timeline, and on the features of the equipment and user environment.

- Remote areas
- Emergency care (uptime critical)
- No hospital network access
- Modalities with large % software/application errors (US/DXR)
- Accessible (urban) African customers
- Modalities with large % part errors (CT/MRI)

Improvements in communication and resistance to geographic factors can be seen in the figure below.

Figure 20 - Pain points along machine timeline

Figure 20 shows a generalized timeline. Underneath the timeline are design challenges or improvement strategies, linked to the parts of the timeline where they would add the most value. Above the timeline
are the types of customers and machine types which have pain points at particular places along the timeline.

This is valuable because it shows that features of a product-service solution designed for the African market will have different added value for different customers. For instance, a customer in a remote area who owns an ultrasound machine may be helped a great deal by improved remote communication, since they could be helped to fix the software and simple hardware errors common in ultrasound machines themselves. However, this solution would not be of much benefit to the owner of a CT machine in a large urban area, whose main pain point is not diagnosis but waiting for spare parts. In his case, a proactive monitoring and maintenance system (as described in Section 4.1.2) would be of more value.
7. User Research: Customers Without Service Support

7.1 Overview

The user observation studies of Philips FSEs, RSEs and customers resulted in detailed insights into the remote servicing process and ways in which it could be improved in the Africa market.

The scope of this design project, however, goes beyond merely improving existing service support; the goal is to improve repair and maintenance for those machine users who currently have no access to a service contract at all. The observation studies suggested ways in which service costs could be lowered by better remote servicing, thus making a service contract potentially more affordable for less wealthy customers. But affordability alone may not prompt new customers to use a service system. Insights were still needed about the work practices and the particular needs and challenges of these customers.

To this end, detailed user interviews were performed with three such customers in Uganda, and one academic expert on biomedical repair and maintenance who had researched in both Uganda and Nigeria.

7.2 Research Scope & Participants

Uganda is an example of an “indirect” country for large equipment manufacturers. Unlike South Africa and Egypt, which are regional hubs for many companies, Philips, Toshiba & GE Medical all have no base in Uganda and sell through distributors (Kiboko Enterprises, 2016) (Toshiba, 2016) (GE Healthcare, 2016). This means that service support from these companies if offered would likely come from a different African country. A large proportion of Ugandan medical equipment is obtained through donations, and there is no restriction on the import of second-hand medical equipment. The country has a large public health system, supported by some private and faith-based hospitals. (Ugandan Ministry of Health, 2005)

The first biomedical engineering education program in Uganda, at Makerere University, began only in 2015, and other than the first cohort of this program most people who support medical equipment in the country are technicians with a mechanical or electrical background (Duke University, 2015).

Interviews were performed with four people:

| Table 5 - Participants in Research into Users without Service Contract |
|---|---|
| **Interview 1** | Biomedical engineer | Large regional (public) hospital |
| **Interview 2** | Biomedical technician | Faith-based rural hospital |
| **Interview 3** | Doctor (Ob/gyn) | Large regional (public) hospital |
| **Interview 4** | Researcher biomedical devices | Neurosurgery Clinic |
A semi-structured interviewing technique was used, in which a set of questions were pre-defined to guide the interview, but flexibility was given to follow up on topics raised by the user during the interview’s course. A full transcript of these interviews is available in Appendix XVIII.

For the biomedical engineer and technician, the following set questions were used to guide the interview:

- What tasks do you have to complete on a daily basis?
- What types of equipment do you work on?
- What’s the most challenging part of your job?
- What do you like most about your job?
- What would you change about your job if you could?
- What types of equipment do you service? Do you have any service contracts?
- How do you approach fixing equipment which does not have a service contract?

7.3 Results

7.3.1 Cultural Work Model

The biomedical engineer’s key responsibilities were creating and managing an inventory, planned maintenance, and addressing corrective maintenance issues. Responsibility for finding the right parts and finding out whether they were available in-country fell to the biomedical engineer, who would pass this information onto the purchasing department. However, the purchasing department (or the hospital manager, who has final responsibilities for orders) may decide that not enough budget is available for said part. The academic in Interview 4 described how a successful order was dependent on how well the biomeds – or the medics whose machines they fixed – could advocate to the hospital manager.
7.3.2   Spare Parts and the “courier service”

A challenge mentioned in all the interviews was finding spare parts for donated equipment which were not supplied in Uganda. Interestingly, three of the interviews (1, 2 & 4) mentioned a tactic for this: the so-called “courier system”. Occasionally, doctors or managers at the hospitals would either travel to Europe for training or a conference or be visited by European training staff. Before these trips, the biomedics and inventory department would give whoever was travelling a list of all the spare parts that needed to be bought, so they could buy them in Europe and bring them back. Interview 4 described some hospitals who used this ‘courier system’ as their main supply chain method.
7.3.3 Task Flow

The task flow of the biomedical engineer and technician (and, to a certain extent) the doctors, during repair was as shown in Figure 22 above. Key findings were that due to the hospital having a wide range of equipment and no history of biomedical support, biomedicals often had never before worked on or even seen the piece of equipment they were called to fix. Their process therefore involved a great deal of information to be gathered before troubleshooting could proceed. However, sometimes this was hampered because machines lacked a physical manual or even available online resources. Both biomedicals mentioned using the website “Frank’s Hospital Workshop” (previously mentioned in Chapter 5: Benchmarking Research), an unofficial online repository for medical equipment manuals, though not all equipment was present on it. Both the biomedicals and doctor mentioned online searching to be slow and frustrating, and the biomed in Interview 1 said the same thing of searching in a manual. The biomed in this interview emphasized the importance of getting to certain pieces of information quickly – how the machine is used, how it works, basic maintenance instructions and error codes. Looking for parts also involved a great deal of inefficient searching, both online and asking for advice from the local network of Ugandan biomedical staff.

7.3.4 Artifact: Equipment Inventory

Because the interviews were done remotely, the only artifact which could be observed was an inventory Excel spreadsheet created by User 2 for a small religious hospital in western Uganda.

Information was listed for each item for the equipment type (examples: Fetal Doppler, Endoscope), the manufacturer, model, serial number, location within the hospital (examples: maternity theatre, surgical ward – male), whether the machine was donated or bought and whether a user or service manual was available. Each machine was also given a rating from A-F where A was “Good, in use”, B “Good, not in use”, C “in use but needs repair”, D “in use but needs replacement”, E “out of order, repairable” and F “out of order, needs replaced”.

Figure 22 - Ugandan Biomedical Engineer Workflow Model
Figure 23 - Inventory worksheet created by biomedical engineer in Western Uganda

Extra comments added included notes of upcoming required repairs (“needs bulb replacement”), whether the machine was currently being fixed in a workshop, and the serial numbers of detachable components (e.g. ultrasound probes). Many pieces of equipment were labelled “not found”, meaning perhaps that they had been listed in some other hospital directory but not located by the biomedical technician during his survey to create the spreadsheet. Some of the “manufacturer” fields were also left as unknowns. This supports evidence given by User 1 (from a Ugandan regional hospital), who described how, biomedical staff being a relatively new phenomenon in Uganda, the first task of many newly hired technicians was to create an equipment inventory, based on faulty or non-existent previous records.

7.3.5 Existing Solution: The Biomed Network

When asked how they sourced information about machines for which they did not have a service contract, all interviewees gave the same answer: “the network”. Both of the Ugandan biomedical staff described a network of biomedical technicians, engineers and students who shared their knowledge using smartphone-based messaging service WhatsApp. User 4 described witnessing a similar phenomenon in Nigeria.

Using this network, biomedical technicians ask each other for help on identifying pieces of unknown machinery, on error resolution, and on where particular spare parts can be purchased within the country. Collective experience is thus built up as biomeds who have experience issues with a particular model of machine will be able to share what they have learned with others who have the same model.

This network is similar to the internal networks described by Philips engineers, in which engineers within the company know a certain number of people they can call for certain errors, and whom they warn about known errors and tips on repair. This lateral networking component seems to be an essential aspect of diagnosis of complex equipment. Since diagnosis is very experience-based, no one person can know everything there is to know about troubleshooting a certain piece of equipment, thus extending ones mental resources over a network is essential.

Interview 3 also mentioned this network sometimes being used by biomedicals working for equipment companies to direct hospital biomeds towards where they could order parts for that supplier’s equipment.
7.3.6 The practice of “Keeping Good”

One additional piece of information given by the doctor interviewed was the practice of keeping essential equipment “good”. If a piece of equipment is particularly important or costly, it will for the most part not be used. This is because if no reliable service support is available (note that due to the problems with part gathering and information access listed above, the presence of a biomedical engineer does not necessarily constitute ‘reliable service support’), constant use runs the risk of it breaking and thus being unavailable in an emergency. Thus the equipment is kept, sometimes still in dust jackets, for the most critical cases.

7.4 Conclusion & Vision

The key finding of this research was the improvised methods biomeds and their colleagues use to keep equipment working, even outside the official service “system”. In the absence of a service contract, biomeds find ways to acquire spare parts, and get troubleshooting support by sharing expertise through local channels. Any solution for a remote service contract would need to improve upon these existing methods in order for biomeds to find it worth paying for.

In addition, it was found that these users have a great deal more responsibilities internally than staff of hospitals with better repair infrastructure. Biomedical technicians and engineers are largely responsible for keeping an inventory – sometimes even creating it – and for finding parts suppliers. This means that a service system target at these users could provide significant added value by helping them with these other roles.

A “visioning” diagram is shown below showing the requirements of a service system which could help these users.
Figure 24 - Design Visioning for Service Solution for Biomed Users

**FAST INFORMATION GATHERING**

Biomed should be able to immediately get information on:

- User instructions
- Basic service instructions
- Error codes

**INVENTORY MANAGEMENT**

Track equipment type, model and source

Track functional status of equipment (including repair if in progress)

**USE EXISTING NETWORKS**

Local biomedical engineering networks are a valuable source of assistance and could be incorporated into a product.

**SIMPLIFICATION OF COMPLEXITY**

Biomeds/medics can deal with many different machine brands, sources and models with the same portal.

**BRIDGING THE PARTS GAP**

Rather than trying to source them individually, connect biomeds with manufacturers to buy used spare parts.
8. System Analysis

8.1 Summary

The previous two sections of the report focused on repair & maintenance and remote servicing at the user level. However, the design of a product-service system must also take place on a more systemic level. In the first scoping research (Section 1), a basic stakeholder analysis was made of all the sources and recipients of medical equipment in the developing world. A new analysis is now made using the narrower scope of service provision.

This analysis was made using information discovered during the two user research studies, as well as a series of interviews with service provision expert Sajith Kurian (head of Customer Service for ultrasound in Africa & the Middle East). The complete system analysis can be seen in Figure 25 opposite. The key needs identified are summarized below:

8.2 Manufacturer Quality Control

Manufacturers only have direct control over the quality of equipment service provision in the “direct” countries where they have an office. In countries with “authorized service providers”, the quality can be influenced somewhat by providing official company training and materials, but is still ultimately out of their control. In indirect countries, where a distributor sells and services the product, or for second-hand or donated equipment, the original manufacturer has no control whatsoever on the quality of service. This is problematic for manufacturers, since the machines still carry their brand, and thus poor service may impact their image.

8.3 Disconnected Networks

The diagram shows “indirect”, second-hand, or donation customers and the manufacturers are essentially disconnected – although customers ultimately use the manufacturer’s machines, there is no line of communication between the two. This has disadvantages for both parties – customers are not able to buy necessary spare parts, and the manufacturers are not able to sell to them. Manufacturers also have no visibility of the “grassroots” service networks where these customer’s problems are reported, even though they provide a valuable source of data on common machine errors and user needs.

8.4 Lack of Service Contract Flexibility

The user observation studies showed that different errors can be solved at different levels – the simplest problems can be solved by customers without technical expertise, and the most complex escalated to expert specialists. Though this tiered system exists within the company, there are fewer opportunities for escalation outside a service contract. Though distributors can receive official company advice on particularly difficult cases for a fee, there is no possibility for, for example, a customer with donated equipment to buy company remote servicing for a particular error on their most essential machine. This means that there are only two options for customers – an expensive service contract (approximately 10-20% the original ‘sticker price’ of the machine, or no service.
Third-party organizations like donation NGOs and second-hand resellers in some cases would like to provide service support, but are hampered by understaffing and in some cases having no access to proprietary information like service manuals. There is also no channel for them to purchase service support or information from manufacturers to help them provide basic service – sometimes the only access to crucial information is through ‘leaked’ documents on online forums which manufacturers try hard not to allow.

---

**Figure 25 - Map of Stakeholder Interactions in Medical Equipment Service in Africa**

- **AUTHORIZED SERVICE PROVIDER**
  - Machine is sold by a local distributor who is also trained by manufacturer and has access to proprietary information. Service is generally good quality but cannot be controlled by manufacturer.

- **SERVICE CONTRACT**
  - Manufacturer sells machine to customer with a contract to provide service.

- **DISTRIBUTOR**
  - Machine is sold by a local distributor who is not a partner in the same way as ASPs. Service quality may be poor and manufacturer has no control over it.

- **TECHNICAL INFORMATION**
  - Company holds on to proprietary information and shares only with ASPs - but some ‘leaks out’ through informal channels.

- **DONATION NGO**
  - Other second hand machines are donated. Some of these NGOs attempt to provide service support, but is hampered by lack of resources.

- **SECOND HAND DEALER**
  - After some time in use, a machine is taken out of commission and resold to a hospital in Africa. Generally no service support is provided.

- **REPAIR SERVICES**
  - Local repair firms who perform repairs on a case-by-case basis. In some countries, regional workshops run by government.
9. Concept Design

9.1 Introduction

As with many design projects, this project followed an iterative path between design and research. The design process began after the first part of user testing (observation studies and interviews with Philips engineers and customers). From this, initial problem statements were developed and ideas brainstormed around them, and two potential concepts developed.

The evaluation of these concepts revealed – as well as many new design requirements - the need for deeper user insights into users outside the scope of service contracts, and thus research with Ugandan users was performed. These were used in the development and embodiment of the final design concept.

9.2 Brainstorming

9.2.1 Brainstorming Topics from User Research

Brainstorming was performed based on the design challenges generated from the research in the previous section. Ideas were generated around the four topics (below) individually.

<table>
<thead>
<tr>
<th>Problem Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giving context in remote service</td>
</tr>
<tr>
<td>Guiding remote repair</td>
</tr>
<tr>
<td>Troubleshooting structure</td>
</tr>
<tr>
<td>Replacement part delivery</td>
</tr>
</tbody>
</table>

9.2.2 Extreme Prompts

As recommended in design literature on idea generation (Tassoul 2009) an “extreme prompt” was also given for each problem statement, in order to generate more unusual ideas.

**Giving Context in Remote Service:** “Remote interaction where users share no common language”

**Guiding Remote Repair:** “Remote guided repair where one user cannot see”

**Troubleshooting structure:** “One single engineer diagnosing cases for thousands of users a day”

**Replacement part delivery:** “If there were no way to get anything in or out of the country.”

9.2.3 Generated Ideas

After ideas were generated they were “association clustered” (using no pre-defined categories) into different components of a solution, each addressing different parts of a product service system. A selection process based on the design requirements was used to discard around half of these. The remaining brainstormed ideas are shown in the following pages.
5. Communication across two languages by choosing stock questions/answers

5. Entirely symbolic communication: icons for typical parts and repair actions, translated into customer and engineer languages

5. customer fills out troubleshooting guide, results are sent to engineer to prepare for remote service

IMPROVING REMOTE COMMUNICATION

3. smartphone overlay uses stickers on machine to guide taking photos

8. Engineer sends instructional pictures for repair actions

4. use stickers to communicate about parts in remote service

2. place simple lettered/numbered stickers on machine components

1. annotated pictures

10. Low frame rate video turns into comic-strip picture series

9. Image library already on customer’s device/machine, engineer remotely fills up required picture

12. Image to sound converter, transferred over mobile phone

11. Transfer low-res annotations as separate images and overlay onto existing photos
**Network of internal sensors interface with mobile phone self-test app, giving an overview of machine condition**

**Legacy machines retro-fitted with a sensor device to measure power fluctuations and environmental data**

*For sites without a local network, data can be sent to the cloud for remote engineers to see by “piggybacking” on a mobile phone 3G connection.*

**Self-tests can be made more explicable by showing a map of voltages in the system rather than error codes.*

**Label parts by who can fix - local technician or expert**

**Parts coded according to ease of replacement and lifetime**

**Print opening instructions on case**

**Temporary access code (as in online banking) generated for ‘proprietary’ self-tests/log files**

**Access instructions using QR code displayed on screen**

**Searchable image library of instructions and reference diagrams**

**App to help NGOs create image library for legacy equipment**
Send spare parts on existing freight deliveries (e.g. for consumer products)

“Stock inventory AirB’n’B”: rent out spare space in local businesses to store inventory

“Part on a string” - engineer comes with toolkit of ‘test parts’ so he can change components for troubleshooting without ordering them. Designed not to seem like “real” part, to manage customer expectations.

Divide machine into ‘modular’ parts which can be easily removed by the customer. These can be opened and fixed at local service hubs.

‘Spare parts co-op’: Donation organizations who have the same type of equipment team up to bulk order spare parts that would be hard for them to buy alone.

Encourage NGOs to work in a service model by storing ‘uptime’ data from donations and using it to advertise success.

Build prevention into product: sounds alarm when dropped or used incorrectly

Encourage preventative maintenance with gamification - rewards for treating machine well

Company remotely track how product is used: don’t provide service if it is mistreated

Build prevention into product: sounds alarm when dropped or used incorrectly

Company sends alerts reminding customer to perform preventative maintenance (e.g. change filter) and instructions on how to do it.
55

**IMPROVING INITIAL INSTALLATION**

36 Online platform to map donor machines with customer requirements.

37 App that guides donation NGOs to assess use-worthiness of second-hand equipment.

38 App for scoping a site's infrastructure beforehand – guides taking pictures and measuring power stability.

**TRANSFERRING CONTEXT**

46 Train Company engineers to fix 'Africa' condition machines (humidity/temperature damage etc)

47 Nurse gives 'video tour' of hospital, watched by remote engineers.

48 Shirt front button camera so customer can fix while remote engineer watching.

**USING NETWORKED EXPERTISE**

40 Pages for a particular machine model pooling global data from repair cases.

41 Data packages built up into history pages for a particular unit, and those into data pages for a particular machine model (see idea 40)

42 Interactive map of machine system which allows engineers to mark off components that have been eliminated in troubleshooting.

43 Tag problems on a picture/diagram of the machine showing where errors are

44 NGOs use remote network of volunteer biomedical engineers

45 Combine remote servicing with Telemedicine to provide expertise both on medical issues and technological issues.

49 Give remote engineers components available in customer's local area and try to fix machine with them.
9.3 Evaluation Criteria

Though idea generation was targeted at the alleviation of specific problems, some additional criteria were needed to ensure that in addressing those problems, the designs still constituted a feasible solution.

Whatever product-service system designed was done so with the intention of first of all improving service provision as it is currently delivered, and widening the scope of service provision to new users. These are of course linked – a more cost-efficient repair service is able to be sold to a greater number of customers).

Two criteria were also put in to explicitly address the initial purpose of this assignment. The fundamental reasons that medical equipment breakdown in the developing world is a problem is because of the impact it has on human health and the environment – thus it must be ensured that solutions which address the more detailed problems do not ignore these higher-level objectives.

Evaluation Criteria

Product

- Improves accuracy of diagnosis and repair (effectiveness)
- Speeds up repair (time efficiency)
- Reduces costs of remote repair (cost efficiency)
- Reduces machine downtime and improves patient outcomes

Systemic

- Ability to reach wide number of users geographically
- Ability to reach new users who do not already have service contracts
- Less waste created from medical equipment

9.4 Development of Service Design Concepts

Because the design being developed was of a product-service system, service design techniques were employed in order to generate the first set of concepts.

A service system is broadly defined as a “chain of activities [controlled or provided by the company] which form a process and have value for the end user” (Saffer 2010). The key idea here is that a service design solution is a chain or process built up of separate solutions. It became clear that the individual
ideas generated were “building blocks” which needed to be joined together in order to create complete service solutions.

In order to do this, a particular tool was developed – the “Troubleshooting Timeline”. This uses ideas taken from existing service timelines (such as the Philips ‘customer journey’ or Bitner, Ostrom & Morgan’s “service blueprint”) (Bitner, Ostrom, & Morgan, 2007) (Saffer, 2010). Like these timelines, it uses a horizontal access split into chronological phases (in this case the phases of a remote repair), and a vertical access divided into key components of the activity (the product being fixed, the customer and the organization providing service). A detailed description of the Repair Timeline is given in the secondary manuscript of this graduation project, “Developing a Design Method for Troubleshooting” (Kane, 2016).

Concepts were developed by placing different ideas along this timeline and seeing which combinations generated feasible and complete product service solutions which fit the general requirements. Examples of this process for the final two concepts generating using this approach are shown in the next section.

9.5 Concept Selection

As these service design concepts were developed, individual ideas were evaluated against the criteria and abandoned if they did not meet them effectively.

The most notable outcome of this was that all concepts which involved technical modification of the machine design were scrapped. These concepts scored poorly on the system criteria – a solution which relied on a customer buying an entirely new product would fail to address the many existing systems already operation, so could not be expanded to customers who relied on donated or second hand equipment. These ideas also did not effectively address the criterion for lowered environmental impact, since they would require existing equipment to be scrapped and replaced.

Another set of solutions which were excluded were solutions involving the measurement or transferal of sensor or machine data (such as temperature, voltage or log files) remotely. Though these solutions do have the potential to improve service quality, remote data transfer for repair is a solution which is already at an advanced stage in developed nations, and thus only requires some technical innovation in connectivity to transfer it to a developing world context. However, as seen in the observational studies in Benelux, remote service interaction still has much room for improvement in all global contexts. Therefore ideas focused on interaction rather than data transfer were considered more valuable design directions.

9.6 Final Concept Solution Spaces

The final outcome was two complimentary concept ideas, shown here in their embryonic form on the Repair Timeline. The difference between these two concepts us the users and organizations that they targeted.

It was noticed during concept development that two distinct groups of concepts were emerging – one that was targeted at improving the service of existing manufacturers and lowering costs to make their
service support accessible to wider group of customers. These solutions assumed customers who had a reasonable remote connectivity, a small, known group of machine models (e.g. the product line of a particular company, like Philips) and an organization which had expert resources and existing mechanisms in place for logistics and information-gathering.

The other group of solutions, culminating in the second design concept ("Repair Aid"), addressed the most extreme end of the user spectrum – very remote hospitals who received only donated equipment and had very low levels of connectivity. This solution assumed only cellphone access, a highly fragmented range of equipment from many different manufacturers and eras, and service provided by an NGO which could not afford a large number of staff.

Because of their difference in focus, these two solutions could not be consolidated further at this stage. Validation of their design and service components was also required. They were thus developed into demonstrable concepts (detailed in the next section) and sent to target users to gather feedback.

**Figure 27 - Repair Aid Target Customers and Service Mappin**
**ServiceBox: Target Customers**

Large company with fixed product catalogue, limited range of equipment models

**Concept Scope:**
Aims to improve communication between remote engineers and customers. Can be used for both new and ‘legacy’ company equipment. Must be affordable for customers as a service contract.

Customers have smartphones and internet access, but expensive and unreliable.
Trained medics/radiographers but not trained in machine repair

**Figure 28 - Service Box Target Customers and Service Mapping**
10. Preliminary Concepts

10.1 Development of Concept Designs for User Feedback

The two concepts shown in the last section in their ‘Troubleshooting Timeline’ form – ‘Repair Aid’ and ‘Service Box’ - were subsequently developed to a point where they could be understood and evaluated by target users.

In order to present the concepts coherently and receive feedback specific to product features, the service interaction aspects were decoupled from the systemic aspects. Demonstrations of the step-by-step service interactions involved in the two concepts were put into storyboard form, referred to as the ‘Repair Aid’ and ‘Service Box’ service storyboards. In addition, the broader organizational system behind the “Repair Aid” concept – a platform comprising a network of remote volunteer engineers and using product information crowdsourced from NGOs and users - was visualized as a system diagram, referred to as the Open Repair Platform. All these materials as shown to the users are displayed in full in the following pages.

Two broad groups of users were given the designs for evaluation – within Philips and outside Philips. Users within Philips were sent the service interaction storyboards for both the higher-tech “Service Box” and the lower tech “Repair Aid” solutions. Since these users already work within the context of Philips’ organizational systems (and were intended to evaluate the designs as such), they were not given the Open Repair Platform material.

This Open Repair Platform was, however, given to users outside Philips, since feedback was required on how their existing work could adapt to such a platform. These users were given both the Repair Aid and Service Box storyboards, with the Service Box storyboard slightly altered. The altered version removed the automated user-troubleshooting guide and replaced it with a section where an app guides the NGO though performing a viability assessment on donated equipment and helps it create the instructional images subsequent communications.
“Service Box” Service Storyboard

This is the second of two designs for how engineers can communicate with machine users using the RepairAid website. This design assumes that users have access to a smartphone and limited 3G connection. It also assists donation organizations in uploading information and creating photo guides for how to repair their machines.

1. Before donation, the RepairAid app guides NGOs through performing basic functionality and safety checks and recording the device’s specifications.

<table>
<thead>
<tr>
<th>Model</th>
<th>Voltage</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>DuraDiagnosis D1035</td>
<td>400V, 50-60Hz</td>
<td></td>
</tr>
</tbody>
</table>

2. The app also helps NGOs to create their own image galleries and step-by-step photo guides for common repair processes. The app automatically uploads these into repair “libraries” on that machine’s Model Page.

Figure 29 - Service Box Storyboard extract: first two steps sent to non-Philips users
‘Service Box’ Service Storyboard

This is the first of two designs for an application to help service engineers better communicate with customers. This design assumes that users have access to a smartphone and some limited 3G connection.

1. The ServiceBox app is installed on the customer’s device when they purchase the machine. When the machine has an error, the customer first consults the Service Box app.

2. The app takes the customer through a series of troubleshooting steps. If after this the machine is still not fixed, the customer is given a link to call or email Customer Service Support.

3. After being assigned to the customer, the Service Engineer is sent to a webpage associated with that customer’s machine. (the “Machine Page”). The troubleshooting steps already taken by the customer in Step 2 are shown in the chat window, so the Engineer can see what has already been done.

4. The Service Engineer can type directly into the chat window to talk to the customer about the machine problem.
Both the engineer and the customer can make annotations to the image with text and simple drawings, in order to draw attention to a particular part of the image.

To keep track of their process as they troubleshoot the problem with the user, the engineers use a “troubleshooting tracker”. This is a system diagram of the machine on which engineers can make notes. Engineers can also mark as “suspected” the sub-systems which they think may be the root cause of the error, and as “eliminated” sub-systems they have ruled out.

If an engineer needs extra help on a repair case he can request assistance from another service engineer. The new engineer is sent an email notification which has in it the updated “troubleshooting tracker” for a quick reference to what has already been done on the case.
Repair Aid Service Storyboard

This is one of two designs for how engineers can communicate with users of equipment in remote areas. This design assumes that users do not have smartphone or internet access, and uses a system of coded stickers to help communication over text or phone.

1. Before shipment, each important component of the machine is labelled with a sticker, according to a specific pattern.

2. The location of these labels is captured in a photo gallery in the Service Database, which remote service engineers can refer to.

3. When the equipment breaks down, the user texts the service number and a notification is sent to an available engineer. The engineer can then directly text the user through the web page.

4. The Engineer receives an alert and goes directly to the “Machine Page” for that customer. This page contains information on the machine, past error cases, and the photo gallery showing label locations referred to in Step 2.
5 The engineer can look at the photo gallery for reference and use the labels to help direct the user remotely to troubleshoot or fix the machine.

6 The Machine Model Page is related to the particular model of the machine (e.g. DuraDiagnost). Here, engineers can access reference manuals for the model, and look at tips other engineers have left on the forum.

7 As well as talking to the user through the chat interface, the engineer can use it to leave notes that he or other engineers can refer to later.

8 If the engineer needs extra support, he can pass the case on to a Tier 3 or other Tier 2. The new engineer will immediately have access to the chat history and notes left by the previous service engineer.

Figure 31 - Repair Aid Service Storyboard
Open Repair Platform

ORP is an online platform for NGOs which donate medical equipment or vendors of refurbished equipment. The platform provides machine repair assistance to hospital biomedical technicals with the help of an online network of engineers. This page shows how the platform works. Each machine donated or sold has its own "Machine Page", through which the hospital staff and remote engineers can communicate. This in turn is connected to a "Model Page" which contains useful information specific to that brand and model of machine more generally.

Each specific machine has its own website page, containing specifications and photo galleries of the machine uploaded by the NGO or vendor and basic information about the recipient hospital.

Each Machine Page is linked to a "Model Page": a hub for useful information (e.g. manuals, how-to-guides) about a particular brand or make of machine. Engineers can use this to help with remote diagnosis and repair.

NGOs who have donated the same equipment models in nearby locations can join together in "parts clubs" to bulk-buy parts & consumables for their equipment.

Volunteer engineers and hospital staff can share their tips on machine repair in the Forum on the Model Page.

Engineer Network

An online community of biomedical engineers and technicians, either internal NGO/Company staff or external volunteers, remotely helps hospitals to repair broken equipment, and contribute their knowledge to the forums on the Model Pages.
10.2 User Evaluation

A list of the users approached for feedback is shown below:

Table 6 - Product Concept Feedback Users - Philips

<table>
<thead>
<tr>
<th>User</th>
<th>Role</th>
<th>Context</th>
<th>Modalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philips User 1</td>
<td>Remote service engineer</td>
<td>Benelux</td>
<td>MRI/Diagnostic X-ray</td>
</tr>
<tr>
<td>Philips User 2</td>
<td>Training coordinator, former field service engineer</td>
<td>Benelux, Africa</td>
<td>Ultrasound</td>
</tr>
<tr>
<td>Philips User 3</td>
<td>Service support manager</td>
<td>Africa</td>
<td>Ultrasound</td>
</tr>
</tbody>
</table>

Table 7 - Product Concept Feedback Users - Non-Philips

<table>
<thead>
<tr>
<th>User</th>
<th>Role</th>
<th>Context</th>
<th>Modalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>External User 1</td>
<td>Donation/service support</td>
<td>Donation NGO (US, supporting Africa)</td>
<td>All (including imaging equipment)</td>
</tr>
<tr>
<td>External User 2</td>
<td>Biomedical engineer</td>
<td>Medical Refurbishment NGO (French, supporting Africa)</td>
<td>All (including imagine equipment)</td>
</tr>
<tr>
<td>External User 3</td>
<td>Doctor (OB/GYN)</td>
<td>Ugandan regional hospital</td>
<td>Ultrasound, spyrometer, other maternity</td>
</tr>
<tr>
<td>External User 4*</td>
<td>Biomedical engineer</td>
<td>Small manufacturer, mostly supplying Africa</td>
<td>Anaesthesia/surgical support</td>
</tr>
</tbody>
</table>

*Note: due to issues surrounding intellectual property of the material, External User 4, an employee of a potential competitor to Philips, was not sent the designs but was given an aural description of the system for comment.
10.3 Concept Feedback

The feedback given could be generalized into two categories – comments on specific product features and comments on the system enabling the design concept. Comments on the product features are listed in the table opposite.

10.3.1 Feedback on Product Features

Overall, the smartphone interface for communication was preferred to the communication system involving SMS-texting and references to physical labels. Though some users acknowledged the need to cater to users with no access to smartphones, the sticker system was not considered to add enough value to the remote repair conversation to be worth the effort of labelling (which NGO users with experience in the field indicated would be considerable). Both Philips and External User 3 (Doctor End-User) noted that the type of customer who does not have smartphone access would also probably not be confident using this system to attempt a remote repair without any feedback for the remote engineer to confirm they were proceeding correctly. External Users 4 (equipment company) and 1 (NGO) did note that labelling parts clearly would bring added value to remote repair, but that it would not constitute a complete solution.

The use of images, annotations and videos was well-received among all users. External Users 4 (equipment company) and 1 (NGO) said that they already used some of the same techniques, but would appreciate the proposed design concept as a more structured system with which to deliver it.
<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Feature</th>
<th>Philips</th>
<th>NGO</th>
<th>End User</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
<td>Labelling equipment</td>
<td>cannot reach current install base</td>
<td>would help give context in remote calls</td>
<td>- most NGOs not willing to take time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- good practice, we do this</td>
</tr>
<tr>
<td></td>
<td>Creating image libraries/</td>
<td></td>
<td>good to have a pre-formatted way of helping us create this for our own</td>
<td>few NGOs capable of knowing what content to capture, even with guided</td>
</tr>
<tr>
<td></td>
<td>manuals</td>
<td></td>
<td>machines</td>
<td>format</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>build up content as remote repairs are performed</td>
</tr>
<tr>
<td></td>
<td>Guided safety/readiness</td>
<td></td>
<td>good way of enforcing standardized procedures</td>
<td>require complicated and extensive data-may not be possible to automate</td>
</tr>
<tr>
<td></td>
<td>checks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Customer pre-troubleshooting</td>
<td>put in clinical terms for user understanding / medic to biomed</td>
<td>Good idea- we waste a lot of time not having this</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Image/video transfer</td>
<td>makes communication much easier</td>
<td>already use whatsapp, good to have ready-made library</td>
<td>what we already do over email, more structured method would improve it</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Picture annotation</td>
<td>good, simple interface- very easy to annotate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMS interface with labels</td>
<td>not clear what is added value compared to phone call</td>
<td>some of our customers do not have smartphones, but could access SMS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Note-taking in chat window</td>
<td>really helps with workflow, especially if being passed on to other</td>
<td></td>
<td>- would still need some sort of technical understanding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>engineers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Escalation (pass on to other</td>
<td>send customer notification of status</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>engineers)</td>
<td>good that escalation in-built</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>marking fault isolation on system map unnecessary &amp; complicated</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Double window with content</td>
<td>easy to see resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>good to have single machine on one page, but maybe problems tracking</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Machine information pages</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Network of volunteer engineers</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The design feature of troubleshooting questions posed to the user before entering the remote service interaction were recognized as useful by Philips and External User 4 – all stated it would save considerable time in the remote repair process. Philips Users 2 & 3 gave some interesting insights into how these troubleshooting questions should be tailored to particular users. Philips User 3 warned that if medics were using the guides, then errors should be described not in the “type” categories used in the Service Box design concept, but by how the users experience and understand them as they impact their clinical work. Philips User 3 suggesting a “switchover point” between doctors and biomedical engineers.

The engineer’s workspace was also well received – Philips users in particular commented that various aspects of it would greatly improve remote service workflow. In particular, the ability to write personal notes directly into the chat window (seen in the RepairAid concept) was valued, as was the ease of passing the case to other engineers.

10.3.2 Feedback on Product System

Perhaps more interesting than the feedback on specific product features was the feedback given – particularly by the NGO users – about the system in which the product was proposed to be used. This was especially relevant to non-Philips users, who had been sent the system diagram which detailed the way that the ‘Open Repair Platform’ could help service support be provided by crowdsourced expertise, and would guide NGO’s process to make donations more effective.

Both NGO users liked the theoretical idea behind using the app to give a structured approach to safety and readiness checking before donation. However, they both doubted the feasibility of this – one (External User 1) suggested that, even with the additional ease of use provided by the app, it would be difficult to persuade NGOs who were not already “donating properly” to take the time to do so. The other (External User 2) warned that the scope and detail of safety checks required may be difficult to put into a single app.

Both were also skeptical about the idea of NGOs creating their own reference materials. External User 2 explained that many NGOs were staffed by medics rather than biomedical engineers or technicians, and so even given easy formatting tools for creating user guides, they would not know where to begin to decide which faults or procedures to show guides for. He suggested that an alternative path could be to organically create picture libraries from the successive remote service interactions performed in communication channel in Service Box.

Interestingly, this process was actually far preferred by the user from a small equipment manufacturer (External User 4), who said that though his team certainly had the information and expertise required, a guided approach to content creation was save them a great deal of time and cost.

External User 2 also suggested some rather more serious problems with the Repair Aid system. He warned that it could potentially be used by second-hand equipment dealers to claim they were performing “ethical” donations, while still not performing adequate training and handover. He also warned that if used incorrectly, the system could prevent the development of local skills by bypassing local biomedical equipment companies. He suggested two ways of avoiding this: firstly by making sure licensing of the system was carefully performed, and secondly to keep donation NGOs involved in service calls (even if crowdsourced) so they could make sure their donations were having positive outcomes.
Philips Users 2 & 3 both gave the same opinion on the potential use of the product within the existing Philips system – that it could be used as a way of giving additional training to Authorized Service Providers or Philips Distributors, or allowing them to receive help with service support from Philips.

10.4 Conclusion & Development of Final Concept

The user feedback on the design concepts could be grouped into two distinct areas; one which is rather straightforward to act on from a design perspective, and the other which is somewhat more complicated.

The straightforward component is the product itself. All users responded positively to the two main components of the remote service application – the communication interface between the customer and remote engineer (henceforth referred to as ‘Communication Channel’), and the workspace used by the remote service engineer to talk to the customer, gather information and collaborate with other engineers during a service call (henceforth referred to as ‘Remote Engineer Workspace’). Users were also generally agreed upon the different product features they preferred within these two interfaces.

More complicated, however, is incorporating the feedback about how this remote service application could actually be delivered on a systemic level. In contrast with the user interface storyboards, The Open Repair Platform received largely negative responses from the users it was shown to, as did some storyboard panels which related to this system design (e.g. the app feature allowing NGOs to create their own service materials). Most of this feedback was motivated by a skepticism about the ability of NGOs to staff and create content for such a platform.

At this point in the project, the idea of an Open Repair Platform could have been scrapped. A direction could have been taken, for example, in which the Communication Channel and Remote Engineer Workspace were developed as an internal product for Philips. These product features received very good user feedback, and if applied within Philips could improve service to customers and, as Philips User 3 suggested, help bridge the service quality gap between Philips and its authorized service providers.

However, a direction was taken instead which continued the idea of an open repair platform, but one which included both NGOs and equipment manufacturers, to the mutual benefit of both, rather than assuming these two stakeholders would remain isolated from each other as they are now.

The Case for a Collaborative Platform

The motivations for this decision were as follows. Firstly, the negative feedback given on the Open Repair Platform was largely motivated by doubts about the ability of NGOs to staff and provide material for the platform. This suggests that it is not the platform itself which is a problem, but the idea that this platform’s main stakeholders and contributors should be NGOs. Manufacturers like Philips, by contrast, would be more than able to provide this material and staff – but would there be any motivation for them to assist with such a platform?

It can be argued from the previous research in this report that manufactures could indeed gain from doing so. As described in the system analysis in Chapter 8, repair and maintenance of medical equipment
in Africa currently takes place in two largely disconnected spheres of activity. On the one hand there is an official network of manufacturers (and subsidiaries) and their customers. Manufacturers have difficulty expanding their customer base beyond this sphere, particularly for servicing. On the other hand, there is a much larger sphere containing customers who rely on donated, second-hand or simply unserviced equipment. These customers have developed grassroots networks to deal with the lack of service support – for instance the whatsapp-based “biomed networks” in Uganda and Nigeria or donation NGOs like Repair Aid (Chapter 3: Scoping Research) who try to provide basic remote service. These solutions are far from sufficient for ensuring equipment uptime, but service contracts are inaccessible and unaffordable.

Having a platform to connect these two spheres could benefit each of them in several ways. Firstly, customers who cannot afford service contracts may still require smaller, one-off purchases such as spare parts, or remote service support for a particularly crucial problem. Today, since they do not purchase equipment from manufacturers directly, these customers are not even ‘visible’ enough for manufacturers to offer them these purchases. A Repair Platform could serve to connect customers to manufacturers for these small purchases, bypassing the usual lengthy sales route to acquiring customers.

Secondly, the existing grassroots networks used in this “disconnected” sphere could serve as an important resource for product feedback and improvement for manufacturers. The types of errors talked about on these forums, if manufacturers could access them, would be valuable data for product and service improvement.

The final argument for connecting these two spheres in a shared platform is the fact that these grassroots networks, though nowhere near as effective as a service contract, are still useful enough to hospital staff that they serve as competition to manufacturers in resource-poor settings. As seen in the biomed user research (Chapter 7), the stock of medical equipment in a typical African hospital is very fragmented – it is typical for machines to come from a wide range of manufacturers. In this context, a remote servicing app provided by Philips might only be useful for one or two pieces of equipment; the biomedical technician would resort to grassroots networks for the rest, thus making the Philips app seem less convenient, and potential less worth paying extra for.

Thus a final concept design was developed (detailed in the following chapter) for a repair platform which is experienced as a single access point for a hospital clinician or biomed, but which connects and incorporates service support from a wide range of existing stakeholders – manufacturers, NGOs, distributors and so on.

The two most successful interaction/software design features of the concept ideas – the Communication Channel and the Remote Engineer Workspace – are used as building blocks in the creation of this platform.
11. Final Concept Design

11.1 Vision: Combining the grassroots and ‘birds-eye’ views

In a market where resources and logistics are still challenging, remote service is essential for providing the expertise required to keep medical equipment running. The research in this thesis revealed remote service in Africa could be improved by tackling the problem at two vastly different scales. On the level of the user, both hospital end-users and remote support engineers lack software & communication products that are specifically designed for the needs of providing remote service support. At a systems level, service provision must be diversified, opening up new types of service contract to users who are currently unable to enter into “traditional” contracts. To tackle this, Cadence was developed.

Cadence is a service platform design which aims to provide:

- A platform to connect the fragmented medical equipment industry
- A work environment to support efficient and effective medical equipment repair and maintenance for local machine users and remote repair service providers.

11.2 Product Description

Cadence is a platform tool designed to connect different stakeholders involved in medical equipment repair support in Africa, and to enable a diverse range of contracts, transactions and information sharing between them.

The building blocks it uses to do this are two basic software tools. It provides two user environments – one for remote support engineers and one for hospital end-users –which are specifically designed to support the workflow of medical equipment service and repair. Highly visual communication channels between these environments enable remote service support.

For Hospital End-Users, the Cadence app is free – with it they can manage their inventory, and gain access to an “open” area containing basic repair and troubleshooting information for products, and a messaging network where they can ask other Hospital End-Users for advice on repair issues.

NGO Users can sign up for a low-cost “Service Provider” subscription to use the Remote Engineer Workspace. With this they can provide service support to donation beneficiaries who have the Cadence Hospital app. Through the workspace, NGOs can access the open product information on Cadence and use it to support their calls, or create their own remote support materials.

Manufacturers can also subscribe use the Remote Engineer Workspace, and can customize it with their own product information. They too can use it to directly support users with service contracts, but can also use it in more diverse ways. For example, they can license customized Remote Engineer Workspaces with different levels of product information for a fee to 3rd party distributors or service providers, and/or they can provide these 3rd parties with contract or one-off expert remote support.
Manufacturers can also use the platform to connect with hospital end users who have no service contract or direct sales channel with them. For example, they can make information about spare part sourcing available to these, or offer customers with donated or second-hand equipment remote service contracts. Since they also have access to the Cadence Hospital open chat network they can use it to gather data on machine errors that they would otherwise never have seen. A map of the Cadence System and its product features is shown on the following pages.
**Cadence: System Map**

**Authorized Service Provider**
Manufacturer licenses their custom communication channel, workspace and information to an Authorized Service Provider, who uses them to support the end-user. Manufacturer also gives ASP remote support.

**Direct Service**
Manufacturer gives remote service directly to hospital end-user through Cadence, using their own custom communication channel and remote engineer workspace.

**Partial Licensing with Support**
Manufacturer licenses a more limited version of their tools and information to a distributor, who uses them to support the end-user. Manufacturer also provides them with remote support.

**Partial Licensing, No Support**
Manufacturer licenses limited tools and information to a distributor or NGO to let the NGO support hospital end-users, but does not provide them with support.

**NGO Open Support**
NGOs subscribe to Cadence to use the remote engineer workspace to provide service support to their recipients, using materials openly available on Cadence.

**No Service Support**
Hospital end-user has no service support - they use the Fixer’s Network and open information available on Cadence to perform repairs. They can, however, get in touch with manufacturers to get quotes for spare parts.

**Information**

<table>
<thead>
<tr>
<th>Source:</th>
<th>Accessibility:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>proprietary</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>partial, licensed</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>open</td>
</tr>
<tr>
<td>End-user</td>
<td>open</td>
</tr>
<tr>
<td>End-user</td>
<td>private</td>
</tr>
</tbody>
</table>
**Cadence: Product Features**

**Remote Engineer Workspace**

A web portal designed specifically for providing remote service support. It helps engineers access the right data for troubleshooting, and collaborate with other engineers on a case. The basic workspace framework is the same for all Cadence service-provider users, but each user populates it with their organization’s own custom content.

**Communication Channel**

Web-messaging based connection for remote servicing. Can be used by a service provider to support a hospital end-user, or give expert input to another service provider. Service providers fill these channels with a library of instructional images, for quick transfer during service calls. Extra features such as a troubleshooting checklist to automatically send to customers before a call can also be added.

**Hospital End-User Workspace**

Mobile portal into Cadence for hospital end-users (biomedics and medics) that is a single point of access for all their repair requirements. Users can manage their inventory, and in the case of a breakdown can access free information on the platform or ask the peer-to-peer network for help. If they have service support for any machines they can access it through this.

**Fixer’s Network**

Hospital end-users can ask each other for advice and share tips on machine repair in chat-based message forums, based around equipment model and geographical location.

**Open Information**

Open information, manuals, and repair guides associated with a particular model of product. Either released by manufacturers or built up by users. These can be accessed by all Cadence users.
Cadence: Cashflows & User Types

Super Service Provider
- Customizable Remote Engineer Workspace
- Ability to license out customized Workspaces
- Ability to provide remote service to both Service Provider and Hospital users
- (for manufacturers) ability to create marked “official” information on the Open Platform

Service Provider
- Customizable Remote Engineer Workspace
- Ability to license out customized Workspaces
- Ability to provide remote service to Hospital Users
- Ability to buy licenses and support from Super Services

Hospital User
- Hospital inventory management
- Access to remote service channels to multiple (Super) Service Providers

All users can access:
- Open Platform product information
- Fixer’s Network

Cadence: Single Service Point for Diverse Inventories

Hospitals have many different types of equipment, from different suppliers, countries, of different ages and with vastly different service options. Cadence allows a biomed to access all this equipment from the same app, simplifying and streamlining the repair process. In the diagram to the left, a user has one remotely serviced machine, one with a spare parts reply, and one which can only be serviced using information from the open network.
Cadence: Example User Stories

The Hospital End-User
Jonah, a newly-trained engineer in Uganda, is the first biomedical the rural hospital he works at has ever hired. He downloads the free version of Cadence so he can use it to build an inventory for his hospital, and also starts to use available open-source information to fix small equipment errors. His hospital is given an aid grant with which it purchases a second-hand CT scanner, whose original manufacturer also uses Cadence. Because of the importance of the CT scanner, Jona is able to secure a low-cost remote service-only contract with this manufacturer which allows him to deal with the sporadic imaging problems that it has.

The Small Manufacturer
Coltram Industries are a Kenyan start-up company who make robust, simply-designed oxygen concentrators. Since they are a new company without much experience of service support, they sign up to the Cadence Remote Engineer Workspace as a platform to provide customer service. After some months, they notice through the data logging function of the Workspace that overheating has been a frequent error. Based in this, their engineers find a flaw in the design, and fix it for their future machines.

The 3rd-Party Repair Service
Genevieve is a biomedical engineer trained in Kenya, who now wants to back to her native Gabon to set up a repair and maintenance business there. Because few companies have direct offices there, she offers to become a licensed repair business for them through Cadence. Some manufacturers license her their proprietary information and service tools. If she encounters a problem she cannot solve, she can escalate it to a remote engineer at the manufacturer for a fee.

The NGO
Humanitarian Efforts are a US equipment donation NGO. They sign up for Cadence as a way of improving the service that they already try to offer recipients over the phone. Thanks to a WHO grant, they receive a very large donation of new portable ultrasound machines to respond to the aftermath of an earthquake crisis. They decide to sign up for a temporary support contract with the ultrasound manufacturer, who also licenses them some extra support information.

The Multinational
Bentham Medical is a large multinational equipment manufacturer. They have a base in South Africa from which they intend to expand, but are struggling to enter the market in Botswana. Through Cadence, which they use for their customer support in South Africa, they learn that a large number of Botswanan users are posting service requests on the Fixer’s Network for second-hand or donated Bentham machines. Bentham reaches out to these users and creates a small supply
Figure 33 – Cadence: System Map

Figure 34 – Cadence: Product Features

Figure 35 – Cadence: Cashflow & User Types

Figure 37 – Cadence: Example User Stories

Figure 36 - Cadence: Single Service Point for Diverse Inventories
12. Final Concept Embodiment

12.1 Final Concept Embodiment: Hospital App

As stated in the product design overview (Chapter 11) a very important component of Cadence is the ability for local biomedical engineers, technicians, or medics who manage their own equipment to be enabled to manage their own inventory, tap into a network of peers and exchange effective remote communication. The user requirements and vision for a product targeted at this user was detailed at the end of Chapter 7.

These requirements were translated into an app interface design using the method of “Focus Area” interface designing of Beyer & Holtzblatt (Beyer & Holtzblatt, 1998). This advocates, rather than jumping straight to user interface design, designers should first map out all the ‘focus areas’ their target customer has in their work. The connections in this diagram are used a base for designing the UI. The Focus Area diagram for the Cadence Hospital App is below, and a finished UI design shown on the next page.

![Focus Area Diagram](image-url)

*Figure 38 - Focus Area Map, Cadence*
The hospital end user can respond to an error using the Cadence Hospital App using three possible routes. In Route 1, the user knows they already have the machine in their inventory, so they simply look it up. From that machine’s page they can either access information about the equipment model to attempt a fix themselves or, if the machine has a Service Provider, initiate a service request.

In Route 2, the machine is not already in the inventory. The user searches for the right equipment model, after which information about it can be accessed. From here the user can also add a machine of that model type to their inventory.
In Case 3, the customer goes straight to the Fixer’s Network chat associated with the relevant equipment model and searches it for keywords which match the error they are looking for. This allows them to see previous chats about the topic.

### 12.2 Final Concept Embodiment: Remote Engineer Workspace

The same process of “Focus Area” design was used to design the Remote Engineer Workspace as in the previous section. Map of the Focus Areas of the Workspace is shown below, and a full page in the subsequent pages.

![Figure 40 - Remote Engineer Workspace Focus Map](image-url)
Cadence: Remote Engineer Workspace

The two main parts of the Remote Engineer Workspace interface design are a chat window, with which the engineer can give remote support, and an Information window with which they can access useful information for troubleshooting. Depending on who is using the workspace, this information could be licensed to or created by the user organization, or sourced from the Open Platform Information on Cadence.

Only if user has a service contract with a manufacturer. Links to window to create an abridged report which can be sent to a manufacturer service engineer for analysis.

Pass call to another engineer

ClearVue Ultrasound D452A6
Fairview Hospital
Kampala, Uganda
Installed 2003/11/20

Instruction Manual | Case History | Data & Chats | Image Libraries

Labelled Components

Scan images  Keyboard buttons  Transducers  User Interface  Internal Components

How-to Guides and Videos

Dismantling  Transducer tests  Measurements  Part Removal  Change Presents
Look for important messages

Search chat

Mark certain messages or notes as important

Sends message to customer

Leaves a note directly in the chat, only seen by other engineers, not sent to customer
**Cadence: Remote Engineer Information**

The left hand side of the Remove Engineer Workspace has a series of tabbed browser windows containing information that can be used as a resource while troubleshooting. The exact information in the tabs is customizable by the Service Provider using the workspace, but the examples given here show the types of content which are possible.

**Instruction Manuals**

![Instruction Manual Image]

**Case History for the Customer**
Documents containing chat history and error resolution for previous service calls made by the current customers.

<table>
<thead>
<tr>
<th>Date</th>
<th>Resolution/Root Cause</th>
<th>Customer Issue</th>
<th>Engineer</th>
</tr>
</thead>
<tbody>
<tr>
<td>24/08/2015</td>
<td>Software crash due to power instability</td>
<td>Screen will not turn on</td>
<td>Steve Lenner</td>
</tr>
<tr>
<td>22/08/2015</td>
<td>Dust buildup in fan</td>
<td>Error transducer overheating</td>
<td>Steve Lenner</td>
</tr>
<tr>
<td>01/04/2014</td>
<td>Software crash due to power instability</td>
<td>Machine startup error</td>
<td>Jane Faulks</td>
</tr>
<tr>
<td>17/03/2014</td>
<td>Transducer not cleaned, buildup of gel</td>
<td>Fuzzy image</td>
<td>Steve Lenner</td>
</tr>
</tbody>
</table>

Click to access case history document
Machine Model Data
Data on common errors for the particular model of machine being serviced. The top half of the screen shows data automatically drawn from company call records and the lower half shows common hashtags or phrases in the Fixer’s Network for that particular model. Both are searchable.

Service Image Database
This is a library of service images which are useful to send to the customer during a remote service interaction. They include labelled parts, instructional photos for troubleshooting or repair actions and certain views of the machine. How these are used will be detailed more fully in the next page.
**Cadence:**
Example of a Remote Service Interaction

1. After seeing some image problems on a serviced machine, the customer goes to the machine page in his inventory and begins a service request. This begins with a troubleshooting checklist.

2. The results of the checklist are sent automatically to an available engineer from the service provider.

3. The customer and engineer can now chat directly about the problem.

Hi, this is Steve. Can you remove that?

Hi, how do I do that?

Let me show you:

Customer Troubleshoot: Artifacts in image

Customer Note: “started yesterday”
4. When the customer requests some instructions on how to perform a repair step, the engineer can go into the image library and send the customer an instructional image.

5. The engineer suspects a known error has occurred - he makes a note to himself and marks it as important.

6. Later in the chat, the engineer thinks he may have been wrong about the battery and would like a closer look at the image. He uses the image annotator to show the customer where on his original image he would like him to focus.
13. Platform Design & Evaluation

13.1 Using the Platform Design Tool for Evaluation

For such a complex system involving a balance of different stakeholders, a detailed examination of the structure of the platform itself was required.

The detailing of the platform design was performed using the Platform Design Toolkit of Simone Cicero as a guide (Cicero, 2016). This toolkit maps the different stakeholders in the platform and their underlying motivations, the transactions they make and the value they extract from the platform.

It is vital when working with a platform design involving many stakeholders to make sure those stakeholders needs are being met, that the platform continues to bring them value and they continue to have motivation to use it. Shown below is an excerpt from Cicero’s 2016 Platform design canvas (the full filled canvas is in Appendix XXI).

Each box shows what value the stakeholder in the column can give to the stakeholder in the row. The diagonal line represents the key value propositions for each stakeholder. The blue items in the value propositions are those values that are inherent in the Cadence app (e.g. its service support tools), whereas the black depend on the exchange or participation of other stakeholders.

This shows that in order for the platform to function, it is essential that all stakeholders must actively participate. This runs the risk of making the platform a delicate “house of cards” unless adequate thought is given to how value can be guaranteed for each stakeholder.
13.2 Guaranteeing Value

13.2.1 Multi-Vendor Approach

Examining the value propositions leads to perhaps the most noticeable feature of the Cadence design in the context of this graduation project – the fact that it is a third-party system, rather than owned by a particular manufacturer. This is perhaps slightly unusual given the fact that the project was commissioned by Philips. However, one of the main ways in which Cadence can bring value to the Hospital End-User is by being a multi-platform system.

The primary reason for this is the fragmented nature of medical device ownership in Africa. As shown in the biomedical user research, most hospitals contain equipment from a wide range of vendors and ages, and are likely to do so until vast geopolitical changes end reliance on donated or second-hand equipment. Even if they move beyond donated equipment, low-income hospitals may still have the desire to pick and choose devices from different vendors to exactly meet their needs. Thus any solution which is useful to the customer only for a single brand of equipment will bring little value to them and so may not be used. It is for this very reason that multi-vendor service contracts are increasingly popular in the US and Europe. These service contracts currently consist of large manufacturers (like Philips & GE) attempting to outcompete for the service of each other’s systems (Philip Healthcare USA, 2016) (GE Healthcare, 2014). Cadence proposes a different approach, in which the “multi-vendor contract” experience is delivered to the customer through a single common interface, but each manufacturer is still able to control quality of, and collect revenue from, service of its own equipment. As seen in the canvas, this is one of the main value propositions for both the Hospital end-user and the manufacturers themselves.

13.2.3 Manufacturers: Exchanging Information for Value

As seen in the canvas, the success of Cadence depends on a crucial exchange of value – manufacturers open up a small amount of their information in the form of user manuals and quick service guides, in return for the potential value the platform could bring them. Without this open aspect of the platform, the communication tools and remote service workspace aspects of Cadence could simply be a proprietary software sold to manufacturers to help them manage existing service contracts and control service quality in their distributors. The Hospital End User work environment – with its inventory management capabilities and peer-to-peer networked – could also exist as a separate platform which would in itself bring value to users. This would have a clear value proposition to both parties and involve none of the risk of releasing any information. However, manufacturers do stand to gain additional value if these two systems are combined into an open, collaborative platform. And since manufacturers are the main revenue stream which would allow Cadence to be funded, proving the value to them is extremely important.
13.2.4 Reaching Out – New Revenue Streams

The primary value for manufacturers is the ability to identify and reach out to new customers they would otherwise be unable to reach. A basic level of open information needs to be released in order to draw hospital end-users to the platform (as it were, to fulfil their value proposition), but once those users join, they are now “on the map” for manufacturers. Philips (or another manufacturer) could, for example, offer a remote service contract to a customer with a donated CT scanner – the customer could then take the risk of continually using the machine rather than “keeping it good” for emergencies (as often happens with critical equipment), generating the revenue required to pay the service contract. In another example, Philips could sell used spare parts generated by its refurbishment department to owners of donated or second-hand equipment. Thus it enables the manufacturer to quickly and efficiently gain many small revenue streams from the Africa market, including existing install base and donations, rather than expending its sales resources to chase a few large contracts for new equipment. Given that an estimated 80% of equipment in the developing world is donated, this represents a large untapped market (THET, 2003).

The ability to license their service information and communication channels or provide one-off/contracted service support to 3rd parties and NGOs also opens up a wide range of previously untapped users to manufacturers. As shown in the scoping research, many NGOs would like to provide service support for their users but struggle with the resources to do so. These users would be drawn to Cadence by the improved service offered by the open tools (the Remote Engineer Workspace and open-access communication channels), and would mostly likely become billable one-off customers for manufacturers to sell service advice on difficult errors they could not tackle themselves.

Licensing and outsourcing to 3rd parties may even be essential for the growth of service provision. If the introduction of Cadence resulted in service contracts expanding rapidly across the newly-opened market of donated equipment users, it would likely be unfeasible for a company like Philips to match this growth with the human resources required to directly service all of these customers. Thus it may be in fact most effective for a manufacturer to strike a balance between direct customers and the licensing of their material to NGOs and distributors. Cadence would thus ideally allow manufacturers to flexibly edit the content of the information and communication channels they license, enabling them to offer different price levels of license to different third-parties.

13.2.5 Useful Data

The second value proposition for the manufacturers is the visibility they gain of the conversations on the peer-to-peer network. This represents a potentially vast database of customer queries which can be extremely valuable for manufacturers in identifying common bugs or error trends, but which was previously hidden away in informal channels. As noted in the user research within Philips, failure analysis for a given piece of equipment is a constantly growing field of knowledge, and the more data that can support it the better. Note that in the interface design for the Remote Engineer Workspace, the engineer can search not only previous chats with Philips customers but also search the open peer-to-peer chat about that equipment model.

The inclusion of this open peer-to-peer channel also increases the value of Cadence for the hospital end-users. The Fixer’s Network enables the hospital end-user to also have a “human interaction” resource
for its equipment which is unsupported by a service channel. This is important because, as discussed earlier, a key value proposition of Cadence for the hospital end user is that it allows them to perform all their servicing from a single point. Without this capability, end users would resort to existing informal networks to service their unsupported equipment, reducing the value and impact of Cadence. The more Cadence is used and valued by hospital end-users, the more it can be used as a platform for manufacturers to reach out to new customers.

Indeed, if Cadence does become the main method used by hospital end-users to perform equipment servicing and inventory management, as envisioned, they might begin to make purchasing decisions based on which manufacturers have opted to participate in the system, and which have released the best-quality open user guides and information. However, this value only comes into play after a certain “critical mass” of manufacturers have joined the system.

13.2.6 Crowdsourcing for NGOs

An unexpected benefit which came out of the Platform Design Canvas which was not purposefully thought of in the design was that the peer-sharing aspects of the Engineer’s Workspace, which allow a customer case to be passed easily between and collaborated on by multiple engineers, is a good reason for NGOs to reduce costs by crowdsourcing their remote service, as was originally imaged in the previous “Open Repair Platform” concept.

13.3 Challenges to Providing Value

13.3.1 Customer Progression

In order for the value of customer accessibility to be delivered to manufacturers, two things are required. One is a robust procedure for users to move “up the ladder” from the free version of the Cadence app to entering into service contracts, one-off service requests and component purchases. A method is required by which hospital users can easily request and be quoted for a service contract or part through the app, ideally automated in such a way that it entails little extra work for the manufacturer, and allows the manufacturer to internally manage resources such that it is equipped to take on new service contracts. The design of such a system is outside the scope of this project, and would require additional research into the internal operations of manufacturers. A secure and reliable system of payment and financing would also need to be developed, which would enable customers to pay for service contracts or one-off payments in a way that suited them and enabled manufacturers to hold them to account. Existing initiatives such as Pharmaline’s Medical Credit Fund – which allows pharmacies and hospitals to pay for stock and equipment through microcredit loans and mobile money - and MDaaS - who enter into joint ventures with hospitals to share machine profits in exchange for service - can be investigated as potential models for this (PharmAccess, 2016) (MDaaS, 2016).
13.3.2 Official, unofficial and licensed services: making a distinction

The second challenge to providing this value to manufacturers is to ensure that, given the free services available, customers recognize the value of paying for an “official” service contract. The platform could make a strong impact on health provision by giving NGOs the tools to provide quality remote service to very low-resource hospitals who are unable to pay for servicing. But if such a hospital did gain enough resources to afford servicing, what would make it move beyond this free resource?

It is likely that manufacturers, given their vast human and knowledge resources, would be able to provide a notably more reliable and effective service than an NGO, and thus be a more attractive option. However, several measures can be put in place to ensure that “official” manufacturer service contracts are distinct from services provided by third parties. This could be embodied in interface design, for instance – an official service communication channel in the Hospital App could have a very different look to an unofficial one. The information levels would also be distinguished – an official communication channel would include a more extensive range of instructional images and videos. And it is likely that manufacturers, when deciding which information to release, will keep some proprietary such that certain errors require escalation to (and thus revenue to) the companies from NGOs or distributors.

Another situation in which the problem of distinguishing official and ‘unofficial’ material may be encountered is in the product information provided on the Open Information Platform. Hopefully manufacturers would be willing to compile and release information on equipment they currently sell, in the hope that they would get some customer visibility and data in exchange. However, much medical equipment in the developing world is old and even out of production, so it is unlikely manufacturers would be willing to put in the time to create content for them. If, however, an NGO servicing a lot of 20-year old X-rays of the same model decided to make a page for them – how would this need to be distinguished from the manufacturers’ “official” pages for its younger machinery? This is a question which needs to be addressed.

13.3.3 Safety & Liability

Closely related to this is the issue of safety and liability. The question of who is at fault if a customer causes damage through a repair is a difficult one even with remote service currently, and would be made more difficult if the manufacturers were also to release any amount of information openly as envisioned in Cadence. Strict policy on liability would have to be laid down and enforced so that it was clear who, in a remote service system involving many parties (e.g. a 3rd-party remotely guiding a customer using licensed manufacturer information) was liable for what.

13.4 Getting there: Roadmap to Cadence

Given the number of stakeholders who need to be in place for Cadence to function optimally as a platform, a reasonable question to ask is whether the platform could be started and grown ‘organically’ or would a critical mass of these stakeholders need to be lined up beforehand in order to make the platform function at all? To answer this question we can look again at the platform design canvas. What it shows is that, because of the tools inherent in its design (the Engineer Workspace and Hospital App),
Cadence does provide some value to users even without the collaborative aspect. The most effective way to begin Cadence may be by starting with the Hospital App. Uptake on this is likely to be fastest, firstly because no equivalent product currently exists in its place, and because its users are mostly single biomedical or medical staff within a single hospital. These users are likely to be more agile in adopting new systems compared to large manufacturers who have firmly ingrained process for servicing already.

13.5 Conclusion

The platform design canvas reveals the importance of the value-trading taking place within Cadence. All stakeholders stand to gain a great deal of value from the platform, but this is dependent on certain issues, notably ones of legality and financial channels, being addressed and embodied in more detail. This is outside the scope of this project, but would be essential were it to be carried further.

14. Recommendations

14.1 Testing the User Interface Design

The easiest next step to take in embodying this design is to focus on the most easily realizable aspect – the Communication Channel and Remote Engineer Workspace user interfaces. Before building a back-end prototype, a mock service portal can be created and tested with representative users. The object would be to verify, in the case of the Workspace, its improved usability with respect to existing software packages. For the Hospital App, since no similar product is currently used, the focus of the testing should be to see if it is easily understandable and navigable, particularly in varying cultures within Africa. Development of the Hospital App should be priority since, as described in the previous section, this is the most likely place for Cadence to initially gain traction.

14.2 Financing and Information Systems

Another aspect of Cadence requiring investigation is the database structure that underlies the transactions, financial and informational, which underlie the platform. Existing technologies (such as Mobile Banking) can be assessed and used to implemented systems that ensure users can safely share information and bill each other securely through the platform.

14.3 Part Sourcing and Logistics

A feature of Cadence which was not investigated and embodied thoroughly due to time constraints was the mechanism for sourcing spare parts. Though it was suggested that users of the Cadence app would be better able to source parts directly through manufacturers, this research did not investigate the cost-effectiveness of this in terms of transport and logistics. An earlier idea in the design phase of this project
was the idea of a “parts club” – hospital end-users or NGOs in similar areas who order parts or consumables together to reduce costs. This idea could be revisited and the issue investigated further.

14.4 Competition to Collaboration

The last design recommendation is more a philosophical than a technical or design point. The linchpin of the Cadence platform is the idea that if medical equipment manufacturers are willing open up a modicum of helpful repair information they stand to reap the benefits in the form of wider access to customers, data and diversified revenue streams. However, this does not fit the general trend within the medical equipment industry. Whereas consumer product brands such as Microsoft and Hewlett-Packard are slowly beginning to recognize that having quality, open repair material will make them more attractive to customers, the medical industry is becoming increasingly proprietary and closed in its design.

Safety is of course paramount for medical equipment, and any move towards “repairability” which in any way compromises patient or operator safety should be avoided at all costs. However, it was noticeable in this research that not all barriers to repair involved a safety risk. In fact, some of the most innocuous operations from a safety perspective – machine self-tests, calibrations and even taking screenshots – were the ones which were blocked from non-proprietary users.

The objective of this is presumably to ensure that service contracts will stay with the original manufacturer. Whereas this may be a good move to ward off competition in developed markets where service is relatively cheap and easy, in the developing world it renders functional products frustratingly obsolete and in fact actively hinders the expansion of these markets.

What Cadence is attempting to show is a vision for how manufacturers could move towards collaboration rather than competition. Or rather, they can compete in a different way. By jointly supporting a shared platform that hospital end-users experience as single, free portal, manufacturers can compete within this platform using the quality of their customer service and of the information they release. This is a type of competition which directly benefits the end-user in the Africa market – whereas the current tactics are increasingly shutting him out.
15. Reflections

15.1 Reflections on Process

The project was from the beginning a difficult – though ultimately enjoyable and rewarding - one to plan and execute as a designer. The decision to design a service system – rather than a product – inevitably meant investigating the many stakeholders this service would involve or touch on. This led to a much extended research section of the project, and there were points where it seemed that the design goal had been lost. A lesson to be learned from this project is that, especially when potential users of the product are distributed globally, a great deal of time must go into finding and arranging research. In particular, feedback from the non-service contract end users was not obtained until well into the design phase. However, this may have not been entirely damaging to the project. The fact that a basic concept had been developed before talking to certain groups of users meant that it could be used as a basis for discussion, and valuable new insights learned. In the end, the truly “systemic” design of Cadence could not have occurred without this broad base of diverse user research.

15.2 Frugal Design vs. Frugal Servicing

An important realization which began and evolved during the course of this project was the idea of Frugal Servicing as opposed to Frugal Design. In the very nascent stages of the project, when scoping research was being performed, the assumption of the researcher was that the project would result in a redesign of a physical medical product to be more suitable for lifecycle management ‘in Africa’. The realization that this assumption may not be a good one came early in the scoping research. An stakeholder interviewee was asked if she had ever seen any products which had been designed to function robustly in Africa. She answered tactfully “Well, I’ve seen a lot of student graduation projects…”

At several points along the process a similar pattern of incidents occurred – designers and engineers told about the project would inevitably assume a new product was being developed, while several more stakeholders who were approached for research input answered by pleading that the project should lead to a maintenance service, rather than the design of a new product.

It seems that, especially in terms of products “designed for the developing world” there is a large disconnect in attitudes between designers and technologists, and those actually working in the field. In recent years, there has been a lot of interest in designing medical devices for the developing world. A common approach is to strip out complexity and cost from a device to make it more cheap, reliable and simple to use – so-called “frugal innovation”. But these ‘frugal’ devices still face the same essential problem as second-hand donated equipment - if they break there is nobody to fix them.

What there has been comparatively less of is ‘frugal innovation’ of repair and maintenance services. As the research in this project partially highlighted, repair services do not always need to involve the expensive transport of people and parts – they could be stripped down and simplified to be cheaper and more appropriate. It is hoped that his report is one of many steps towards a shift in attitude to innovation for emerging markets.
References


http://kibokoenterprises.com/our-companies/philips/

https://davidkvcs.files.wordpress.com

http://www.looksee.do/services.html

Malking, R., & Keane, A. (2010). Evidence-based approach to the maintenance of laboratory. Medical &
Biological Engineering & Computing, 721-726.


Perry, L., & Malkin, R. (2011). Effectiveness of medical equipment donations to improve health systems:
how much medical equipment is broken in the developing world? Medical & Biological

https://www.pharmaccess.org/activity/health-investments/

Healthcare USA: http://www.usa.philips.com/healthcare/product/HCNOCTN159/philips-healthcare-multi-vendor-services

https://www.youtube.com/watch?v=AMQA6HyDO_o

Press.

Riders.

https://theelectricsquirrel.wordpress.com/


The Imperial College London/ Lancet Commission. (2012). Technologies for Global Health. The Lancet,
380:(9840) 507–535.

London: THET.

Toshiba. (2016). Global Network Africa/Middle East. Retrieved from Toshiba Medical Systems:
http://www.toshibamedicalsystems.com/corporate/global/af_me.html


