Design of Mobile Application Using Location Based Adaptive Automation

by

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Mechanical & Industrial Engineering
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Abstract

Process industry workplaces are increasingly more automated and require workers to collaborate with an automated agent. Implementing mobile devices in such workplaces is expected to improve task performance and restore multi-sensory cues by providing information to workers at the point of work. Focus group was conducted with 23 field workers to identify challenges that they currently face and proposed opportunities to address them. This resulted in identifying 19 challenges and 7 opportunities to address them using mobile devices. I designed one opportunity that used Adaptive Automation to deliver location-specific equipment operational data to workers at the point of work. Usability results from four participants validated the application and earned an excellent mean System Usability Scale score of 85. The design is expected to provide workers with real-time and projected operational data using a mobile device, providing smart services and allowing them to deliver more accurate equipment diagnosis during maintenance work.
Acknowledgments

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# Table of Contents

Acknowledgments ........................................................................................................ iii  
Table of Contents ........................................................................................................ iv  
List of Tables ................................................................................................................ vii  
List of Figures ............................................................................................................... viii  
Abbreviations .............................................................................................................. x  

1 Introduction ............................................................................................................... 1  
1.1 Distributed Control System ................................................................................ 1  
1.1.1 DCS in Mobile Devices ................................................................................... 1  
1.2 Research Objective .............................................................................................. 2  

2 Literature Review ..................................................................................................... 3  
2.1 Method ................................................................................................................... 3  
2.2 Adaptive Automation ............................................................................................ 4  
2.3 Mobile Devices ...................................................................................................... 9  
2.4 Research Opportunities ....................................................................................... 11  
2.5 Scoping Review Limitations ............................................................................... 11  
2.6 Conclusion ............................................................................................................ 12  

3 Knowledge Elicitation .............................................................................................. 13  
3.1 Focus Group .......................................................................................................... 13  
3.1.1 Methodology ................................................................................................... 13  
3.1.1.1 Participants ................................................................................................. 13  
3.1.1.2 Procedure .................................................................................................. 14  
3.2 Results .................................................................................................................. 15  
3.2.1 Challenges ....................................................................................................... 15  
3.2.2 Opportunities ................................................................................................. 20
3.2.2.1 Limitations ................................................................. 22
3.3 Opportunity Ranking ......................................................... 22
3.4 Discussion ................................................................. 23
4 Custom Tailored Mobile Knowledge Bank ........................................... 25
4.1 Current Limitation and Purpose .................................................. 25
4.2 Research Framework .......................................................... 25
  4.2.1 Adaptive Automation ....................................................... 25
  4.2.2 Proposed Application Prototype ........................................... 26
4.3 Research Deliverables ......................................................... 27
4.4 Research Objective ........................................................ 27
5 Design of Mobile Prototype using Adaptive Automation .......................... 28
  5.1 Assumptions ........................................................................ 28
  5.2 Design Principles .................................................................. 29
    5.2.1 Adaptive Automation Framework ........................................ 29
    5.2.2 Neilsen’s Heuristics ......................................................... 30
    5.2.3 The Elements of User Experience ........................................ 31
  5.3 Design and Feedback ........................................................... 33
    5.3.1 Preliminary Design ......................................................... 33
      5.3.1.1 Feedback ................................................................. 35
    5.3.2 Iterated Design and Feedback ............................................ 36
    5.3.3 Medium Fidelity Prototype ................................................ 36
      5.3.3.1 Time Based Notification ............................................ 37
      5.3.3.2 Document Analysis .................................................... 37
      5.3.3.3 Motor Diagnosis Information ..................................... 43
      5.3.3.4 Pump diagnosis .......................................................... 46
6 Usability Evaluation ................................................................. 49
6.1 Methodology .......................................................................................................................... 49
   6.1.1 Participants ...................................................................................................................... 49
   6.1.2 Apparatus ....................................................................................................................... 49
   6.1.3 Procedure ....................................................................................................................... 50
   6.1.4 Tasks .................................................................................................................................. 51
6.2 Results ...................................................................................................................................... 52
   6.2.1 Participant Feedback ....................................................................................................... 52
      6.2.1.1 Product Feature ........................................................................................................ 52
      6.2.1.2 Prototype Testing ...................................................................................................... 53
      6.2.1.3 Complementary Feedback ....................................................................................... 53
   6.2.2 Usability Questionnaire .................................................................................................. 54
7 Discussion ...................................................................................................................................... 56
   7.1 Implications of Research Project ....................................................................................... 56
   7.2 Limitations of Research ..................................................................................................... 56
   7.3 Future Research ................................................................................................................... 57
      7.3.1 Cues from the Environment ......................................................................................... 58
      7.3.2 Ecological Interface Design ....................................................................................... 59
      7.3.3 Work Domain Analysis .............................................................................................. 60
8 Conclusion .................................................................................................................................... 61
References ......................................................................................................................................... 62
Appendices ....................................................................................................................................... 68
   Appendix A: Sketches ............................................................................................................... 68
   Appendix B: Usability Questionnaire ....................................................................................... 71
List of Tables

Table 3-1 List of Challenges........................................................................................................... 16
Table 3-2 List of Opportunities....................................................................................................... 20
Table 3-3 Opportunity Ranking....................................................................................................... 23
Table 5-1 Neilsen's Heuristics ....................................................................................................... 30
Table 5-2 Planes of Good User Experience .................................................................................... 32
Table 5-3 Information Requirements............................................................................................... 34
List of Figures

Figure 2-1 Types and Levels of Automation (Parasuraman, Sheridan & Wickens, 2000) .......... 5

Figure 2-2 Characterization of Adaptive Automation Systems (Feigh et al, 2012) .................... 8

Figure 5-1 Characterization of Adaptive Systems and Relation to Research Project .......... 30

Figure 5-2 Planes of Good User Experience (Garrett, 2010) ........................................ 33

Figure 5-3 Preliminary Sketches ...................................................................................... 35

Figure 5-4 Iterated Designs on Paper .............................................................................. 36

Figure 5-5 Time Based Notification ................................................................................ 37

Figure 5-6 Summary Page ............................................................................................... 37

Figure 5-7 Documents Tab .............................................................................................. 39

Figure 5-8 Documents Expanded .................................................................................... 39

Figure 5-9 Updated and Downloaded Motor Documents .............................................. 40

Figure 5-10 Pump Documents Updated ........................................................................... 40

Figure 5-11 Example of PDF Document (in the Prototype) ........................................ 41

Figure 5-12 Work Orders .............................................................................................. 42

Figure 5-13 Reports Tab ............................................................................................... 42

Figure 5-14 Reports Abstract ........................................................................................ 42

Figure 5-15 Full Report Sample ..................................................................................... 42

Figure 5-16 Motor Summary Page .................................................................................. 44

Figure 5-17 Expanded Display for Temperature ............................................................. 45
Figure 5-18 Detailed Motor Information ................................................................. 45
Figure 5-19 Motor Update Controlled Adaptation .................................................... 46
Figure 5-20 Pump Summary .................................................................................. 48
Figure 5-21 System Curve .................................................................................... 48
Figure 5-22 Pump Details .................................................................................... 48
Figure 5-23 Pump Details Controlled Adaptation ................................................... 48
Figure 6-1 Hotspots on InvisionApp Prototyping Tool .......................................... 50
Figure 6-2 SUS Questionnaire Results (with Standard Error)............................... 55
Figure 7-1 Canonical view of EID ................................................................... 59
Figure 7-2 Anticipated Evolution of EID ............................................................... 59
Figure A-1 Example of Early Sketch ................................................................... 68
Figure A-2 Example of Early Sketch (2) ............................................................... 69
Figure A-3 Example of Iterated Sketch ............................................................... 69
Figure A-4 Example of Iterated Sketch (2) ........................................................... 70
Abbreviations

AA    Adaptive Automation
ABB   ASEA Brown Boveri
CEL   Cognitive Engineering Lab
DCS   Distributed Control System
EID   Ecological Interface Design
HF    Human Factors
SUS   System Usability Scale
WDA   Work Domain Analysis
1 Introduction

The process industries, including power plants, mines, refineries, and the paper and chemical industries, have been subject to rapid automation since the last few decades (Hughes, 1987), and workers are increasingly conducting their regular work in collaboration with automated agents (Smith & Carayon, 1995). As a result, operations and maintenance workers in process industries spend less time working on manual activities (Bainbridge, 1983) and more time on new roles such as supervision of automated states (Jamieson & Guerlain, 2000).

1.1 Distributed Control System

A Distributed Control Systems (DCS) provides a centralized environment to support supervision and control tasks. The DCS helps run complex process facilities by distributing control elements throughout a plant. These control elements gather large quantities of data, as well as control and manage the process plant. DCSs are increasingly using automation technology to analyze and interpret the data to automate routine tasks and/or provide intelligence to the workers (Khan, Sadiq & Husain, 2002).

Workers at a plant typically interact with the control elements and automation via Large Screen Displays (LSD)s and desktop computers in a central control room setting, where workers can supervise the process but are disconnected from the physical environment. Even though data are available, information overload (Woods, Patterson & Roth, 2002) can be a challenge for operators when trying to extract information from a production context and make appropriate decisions.

1.1.1 DCS in Mobile Devices

Full or partial capabilities of a DCS in mobile devices can be implemented in instances where workers are disconnected from the environment, and allow them to return to the production environment. Mobile devices can provide up-to-date operational information to workers at the point of work. Allowing workers to return to the production environment can restore multi-sensory cues that help in expertise development (Wiggins, 2014). A literature review (Chapter 2) demonstrated that most current applications of mobile devices in process workplaces involved of either 1) replicating existing user interface from the control room or 2) perform computerized routine tasks (Emerson, 2014; Hajdukiewicz & Reising, 2004; Jamieson et al, 2015; Jokstad &
Rekvin, 2007, Ozdemir & Mevlut, 2006). The applications do not typically exploit the opportunity of integrating worker’s auditory, sensory and haptic cues and data collected by a DCS.

1.2 Research Objective

The Cognitive Engineering Lab (CEL) at the University of Toronto partnered with ASEA Brown Boveri (ABB) Inc. to conceive of, design and evaluate mobile displays for process workplaces. The research motivation is to envision mobile applications that complement ABB’s DCS solution by incorporating multisensory cues.

800xA is the flagship DCS of ABB Inc. As part of their research and development, ABB is interested in exploring how mobile devices can provide support to their customer support field workers in a process environment and complete their tasks more effectively. ABB is also seeking to gain insight into worker receptiveness to collaborating with automated agents (Christoffersen & Woods, 2002) through mobile device in a process environment. CEL’s research motivation aligns with ABB’s vision in implementing mobile applications.

My research project entailed:

1. Exploring and understanding problems that ABB workers currently face when assisting customers in process control environment.
2. Developing an understanding of current Human Factors (HF) and Adaptive Automation (AA) research, particularly related to impacts on operator task performance and workload.
3. Designing and evaluating original mobile display concepts using AA that aims to improve worker task performance.
2 Literature Review

2.1 Method

I conducted a scoping study review in order to understand the current state of HF research at the intersection of mobile devices and AA. The scoping study was formalized by Arksey and O’Malley (2005) as a framework to rapidly identify key relevant studies for a field of research. It is distinct from a systematic review in that whereas a systematic review attempts to focus the literature search on a well-defined research question, a scoping study tends to look at broader topic areas which allow for more varied search results.

A scoping study is conducted in five stages. To conduct a full scoping study, I identified research questions, identified relevant studies, selected studies, charted data and summarized results from the study.

Stage 1: Research questions: This scoping study aimed to address two key research questions.

1. What notable human factors research are currently studied in adaptive mobile systems?
2. What advantages and challenges will field workers encounter using mobile devices in process industries?

Stage 2: Identify relevant studies: The literature search was conducted on engineering databases including Compendex, Scopus, Web of Science and Google Scholar. I also selected noted HF and AA researchers’ publications, their research labs’ publications, and studies citing their publications. The search was limited to studies newer than 1989 and search terms were a combination of “mobile device”, “team collaboration”, “communication”, “adaptive automation”, “human factors”, “user interface”, “adaptive control system”, “human robot interaction” and “cognitive systems”.

Stage 3: Select studies: Search results were dominated by Human Computer Interaction (HCI) studies in the mobile domain. AA as a research field is highly relevant in mobile applications, but is not extensively studied in HF field. To limit studies to HF studies, studies were selected whose result metrics included “situation awareness”, “workload”, “task performance”, “system monitoring”, “collaboration” and “trust”.


**Stage 4: Charting data:** Studies were charted by their domain and the HF measures they tested. Studies in AA and mobile domain were ranked higher. Theoretical studies were ranked lower than industrial and/or consumer applications.

**Stage 5: Summarize results:** The scoping study aimed to present an overview of the state of research in AA and mobile systems. Results from the study are discussed in details in this chapter.

### 2.2 Adaptive Automation

Automation technology in process environment is mostly the use of control systems to complement or supplement human labour work in operating mechanical equipment. Automation is intended to alleviate humans of repetitive and/or less valuable work, and allow them to focus on more value-added work (Rifkin, 1998). Human workers in current process plant environment heavily rely and interact with automated systems.

Parasuraman, Sheridan and Wickens developed a framework to define types and levels of automation in human information processing, for use in defining automation requirements when designing automated and autonomous systems (Parasuraman, Sheridan & Wickens, 2000). The researchers modelled human information processing into four stages: sensory processing, perception/working memory, decision-making and response selection. Automation can be applied to any of these four stages. System designers implicitly decide on the level of automation that is to be applied at each step of human information processing when interacting with the system, partially or full automating it. Figure 2-1 below demonstrates how the level of automation was defined by the Parasuraman, Sheridan and Wickens.
The benefits of human interaction with full or partial automated systems for improved task performance and decision-making have been well-documented in healthcare (Manzey et al, 2011), aviation (Heere & Zelenka, 2000), industrial settings (Groover, 2007), education (Mubin et al, 2013) and driving (Ben-Yaacov, Maltz & Shiner, 2002).

For most automated systems, levels of automation (LOA) for users’ tasks rely on programmable logic that designers set during equipment configuration. In contrast, Adaptive Automation (AA) is an automated system that allows both the user and the automated system to adjust the level of automation depending on context (Scerbo, 2006). The benefit of such a system is that it allows both the machine and the users to mitigate the severity of automation needed from each other in order to achieve optimal task performance. The prevalence of AA technology increased with the development of artificial intelligence. Scerbo argued that early efforts towards using adaptive aids to assist human decision-making started in the 1970s and 1980s.
An early example of an AA system was developed in 1984 by Wilensky, Arenas and Chin (1984). They developed a Unix Consultant (UC), which was a smart computer that used natural language processing to teach users how to execute tasks in UNIX. Because each user used different languages to query tasks, UC had to understand and analyze queries, understand what the user was attempting to do and execute appropriate tasks. The automation system was not subjected to a controlled experiment, but was only described theoretically and its limitations stated. Such examples of early AA system are sparse. Researchers and engineers had to wait for more advanced technology to create effective systems that could be used in complex work environments.

Kaber and Riley (1999) developed an experimental prototype for a simulated radar monitoring task using AA to test for operator workload. For the primary task, participants were required to eliminate targets before they reached the centre of the screen or they collided with each other. Participants were required to do this manually and with the aid of an automation system. In the shared control condition, the automation controlled the scheduling and implementation of tasks, but the participants had the ability to override decisions. They were also subject to a secondary task of tracking a moving pointer and mitigating whenever the pointer deviated from “acceptable” position. AA was designed to assist in both task scenarios. They discovered that using AA significantly decreased workload in the primary task, but increased workload in secondary tasks.

These findings are consistent with a larger literature analysis (Kaber et al, 2001). The objective of the analysis was to highlight the current state of AA research at the time, and also to highlight areas of research needs to define optimal strategies in applying AA. The analysis demonstrated that although AA reduced information processing (Duley, Molloy & Parasuraman, 1997), and improved task performance, workload often increased due to the user’s need to monitor the AA system (Endsley, 1996; Kaber & Riley, 1999; Scerbo, 1996). The results indicated that early systems employing AA assisted in task performance, but may have introduced additional workload. Designers were advised to pursue more effective AA systems by addressing workload reduction.

It was observed in the literature analysis that experimental systems applying AA mostly followed these recommendations. Wilson and Russell (2007) used Adaptive Aiding in developing critical aviation tasks. Participants in the study were asked to monitor the movement of an Unmanned Air Vehicle (UAV) via 20-inch monitor screens. Participants were asked to identify potential targets.
from the UAV video feed in the monitor. The automation system calculated participants’ psychophysiological measures using electrocardiogram (ECG) electrodes, and the measures were used to control automated aiding. Results showed that the adaptation significantly improved task performance and decreased workload. Similar results in decreased workload and improved task performance were also observed in subsequent studies in adaptive systems (Baldwin & Penaranda, 2012; Parasuraman, Cosenzo & De Visser, 2009; Dehais, Causse & Tremblay, 2011).

In the medical field, Manzey et al (2011) demonstrated examples for AA implementation in surgical situations. The researchers used an advanced Image Guided Navigation (IGN) tool called Navigated Control (NC) to assist participants in performing a simulated surgery. NC was regarded as AA as it was able to track surgical tools inside the human body and adjust the camera angle to assist in surgery. Results from the experiments showed that although the system introduced additional workload, it decreased human error.

Research results have consistently demonstrated the effectiveness of AA in improving task performance. Results for workload reduction are inconsistent, however, and require more research to be validated. It is important to note that situational awareness (Kaber et al, 2006; Parasuraman, Cosenzo & De Visser, 2009), collaboration (Li et al, 2013) and trust (Moray, Inagaki & Itoh, 2000; Freedy et al, 2007) are other key metrics that are tested for in AA research but are not in the scope of this research project.

Feigh, Dorneich and Hayes (2012) developed a framework for designers to characterize AA systems. The framework is categorized into triggers of adaptation (what action dictates that the adaptation will happen) and types of adaptation (the level of automation is adapted for which context). The framework is first of its kind in addressing design method and provides a design space for systems utilizing AA.
Figure 2-2 demonstrates how an AA system will use one or more of five triggers (context) to assess the current state and adapt accordingly. The framework provides a useful language for defining adaptive behaviour in automation technology. Despite the presence of such a framework, alternate design methods and frameworks for implementing AA are underdeveloped.

Steinhauser, Pavlas and Hancock (2009) developed design guidelines on how to successfully implement AA. They proposed eight design principles that designers ought to follow to develop a successful AA system. However, this is a not a framework to characterize AA systems, and literature review showed this was the only other example of researchers establishing design guidelines other than the one presented in Figure 2-2. Furthermore, neither of the two guidelines have been cited by research demonstrating success or failure in its use. Research is therefore lacking in demonstrating the efficacy of the five categories of triggers in Feigh et al’s model under controlled conditions.
2.3 Mobile Devices

A new generation of workers is expected to rapidly replace older workers in industry (Dohm, 2000). This new generation increasingly defines both their personal and working lives with the use of mobile devices, and will carry their expectation to workplaces as well (Aruba, 2014). Challenges lie in identifying these expectations, highlighting the benefits of this technology, and designing robust mobile applications for workers. A key advantage of mobile devices is that they can respond to adapt to location, and respond to changes in context by adapting information content, changing their manner of interaction (Dorneich et al, 2012) or adjusting the time when tasks are delegated to humans.

Mobile devices have been experimentally demonstrated to have several advantages that may help in a process industry workplace. Öquist and Goldstein (2003) implemented adaptive technology to a text presentation application on mobile device. Researchers used their knowledge of human information processing to hypothesize that users reading shorter and familiar words needed less exposure time to the word compared to long and unfamiliar words. They used this hypothesis to design an adaptive interface that adapts the exposure time of a segment of text depending on its length. Usability studies confirmed that the adaptation significantly decreased task load for longer texts and also resulted in a 33% increase in task performance rate.

Similar results by Gajos et al (2008), who developed an adaptive menu that predicted user behaviour as the user worked with their experimental software. They developed a menu algorithm that was able to learn the user’s text input behaviour and adapt menu items. They used a prediction algorithm from historical data to predict user behaviour (i.e., when users might choose to select appropriate menu items), and add the menu items to an adaptive menu. Participants demonstrated improved task performance rate and reported greater user satisfaction with the adaptive menu.

There are also notable examples of adaptive mobile interfaces improving usability (Wesson, Singh & Van Tonder, 2010), assisting in team collaboration (Jokela & Lucero, 2013) and error mitigation (Kane, Wobbrock & Smith, 2008). Using location based sensors and triggers, mobile devices could also steer workers away from high risk work areas, help locate team members and provide location specific alarms (Lee et al, 2009; Carbonari, Giretti & Naticchia, 2011). It is important to note that although research on safety and collaboration are prevalent in adaptive mobile user interface implementation, these outcomes are not within the scope of this research project. It is expected
that adoption of mobile devices will be of great assistance to workers in process industry setting, particularly in task performance and workload mitigation.

Despite mobile devices being proven to be beneficial to task performance and reducing workload, there are numerous challenges to implementing mobile in a process industry setting. Researchers at ABB developed a guide to designers and engineers on the challenges of implementing mobile (Vertiainen, Ralph & Björndal, 2013). Key points from the challenges are discussed below.

1. Current mobile applications in workplaces aim to replicate existing control room operational displays. The small screen space is not adequate to access targeted information at the point of work.

2. Mobile communication is unreliable and inconsistent at remote work sites. Gathering information via mobile network at remote work sites may be hampered by poor connection, and over-reliance on such device is discouraged on work site.

3. Data security is given utmost importance at complex work sites, and workplaces have been biased towards not accepting mobile devices.

4. Mobile devices may not be suitable for implementation at work sites that are deemed dirty, dusty and/or wet (e.g. offshore plants and mining facilities).

A limitation of the use of mobile in complex workplaces and situations is the lack of screen space available to the user. Mazaeva and Bisantz (2013) provided an example of a design approach that allows adaptation of information content to display the most relevant information on a small screen space. They designed the interface of a Digital Single Lens Reflex (DSLR) camera with dimensions of 102 mm x 76 mm. They used Ecological Interface Design (EID) methods to model the abstraction hierarchy and identify the information requirements (Burns & Hajdukiewicz, 2013). They developed both system and task integrated displays. The example is a demonstration of how to compensate for the limitation in screen sizes by delivering the most relevant information to the user at the point of work. They did not perform a controlled experiment, but mobile devices similarly can be catered to attend to needs of process industry workplaces.

Vertiainen et al provided explanation on the challenges of adopting mobile devices in a complex workplace. In developing mobile applications for process industry domain, I was able to identify primary concerns that existed in the field at the onset of our research project.
2.4 Research Opportunities

Since the Feigh et. al. framework is relatively new, research examples applying it have not been widely generated and/or published. Some notable applications of the framework include development of a flight deck application (Dorneich et al, 2012), experimental air navigation tools (Miller, Miller & Calhoun, 2014), an air defence application (Saqer & Parasuraman, 2014) and a case study on a tourist recommendation tool (Ettati & Sundaram, 2014). Moreover, there have been multiple theoretical research publications using this framework to enhance and upgrade existing design frameworks in measuring function allocation in automation (Pritchett, Kim & Feigh, 2013; Saqer & Parasuraman, 2014), function to task process model (Bindewald, 2014), use case design (Al-alshuhai & Siewe, 2015), user state assessment (Schwarz, Fuchs & Flemisch, 2014) and adaptation characteristics (Dorneich et al, 2013). There is a novel opportunity to demonstrate application of this framework in a process control setting, which will be the first of its kind. There is also an opportunity to apply this framework in a mobile setting without any previous similar implementation.

2.5 Scoping Review Limitations

The scoping review was useful at identifying most relevant papers to this research project. I was able to identify current literature in a wide range of domains that helped me understand the current state of research in AA and adaptive mobile interfaces. However, this process may have missed papers in publications, papers in other languages and research that may be relevant but not published in top journals and/or not cited well. Although I targeted key researchers in the field and studied their historical research publications, some publications may have been unavailable on electronic databases.

Additionally, I wanted to highlight HF research conducted using AA and mobile devices, as opposed to the research field of HCI. When studying evaluation metrics, search was limited to situation awareness, workload, task performance, system monitoring, collaboration and trust. Terms that relate to research publications in HCI community were not sought, and some papers might have been filtered out.
2.6 Conclusion

AA has been shown to improve task performance across various domains. Implementing mobile devices in process industry workplaces is challenging, and implementation strategies require careful planning and user feedback. The scoping study helped us identify research depicting the advantages of the use of mobile devices in workplaces, and how AA can be beneficial in routine and critical tasks. In order to stay competitive in the DCS market, vendors for process industries need to invest in mobile opportunities for their customers. The shift to mobile platforms will help ABB’s customers cater to their increasingly mobile friendly workforce. Research demonstrating the robustness of AA framework’s triggers is lacking, and we have identified opportunities to contribute to this developing framework in a mobile workplace setting in process industries.
3 Knowledge Elicitation

The CEL team approached ABB Canada to elicit knowledge from their customer support technicians and field service technicians. These workers have exposure to a myriad of industries in Canada including process control, mining, utilities, infrastructure, oil and gas and power generation. Our objective was to gain understanding of challenges that workers face on a day-to-day basis; how they use their tools; and how they work together as a team in a number of different industries. We also wanted to understand how they view the benefits of future use of mobile device and automation technology.

We organized focus group sessions with ABB Canada. The questions were designed by myself in consultation with the CEL staff. The focus group sessions were conducted by with the help of Dr. Greg Jamieson, Dr. Antony Hilliard, Jim Kambossos, Fiona Tran and Malini Pandya. All results, findings and opportunities from the focus group sessions described in this report were developed by myself, in consultation with Dr. Antony Hilliard.

3.1 Focus Group

We organized focus group sessions at ABB’s office in Burlington, ON. Compared to one on one interviews, focus group sessions allowed gathering knowledge of existing tasks and teamwork challenges. Participants could also provide answers from varying industry experiences to questions, providing valuable insight. We were concerned that focus groups participants might feel pressured to give similar answers to each other, and that they might not be open to sharing personal problems in front of peers. However, we did not notice this problem during our interaction with the participants; partly because of their expertise and also because they were trained to consult challenges they face in their annual safety training (see Chapter 3.1.1.1).

3.1.1 Methodology

3.1.1.1 Participants

We interviewed 23 participants. The participants were managers and ABB’s customer support team. The focus group was organized at an annual safety training meeting. The participants had an average industry experience of 21 years \( (SD = 9.4, \text{Min} = 3, \text{Max} = 39) \).
The customer support team was further separated into Service Technicians and Technical Support. Service Technicians provided in-field support to customers at their work sites. Technical Support team members specialized in remote technical support via telephone, remote desktop and Virtual Private Network (VPN) to customers. The 16 Service Technicians had an average experience of 20 years \((SD = 10, \text{Min} = 3, \text{Max} = 39)\). The seven (7) Technical Support staff had an average experience of 24 years \((SD = 7.2 \text{ years}, \text{Min} = 12, \text{Max} = 35)\).

### 3.1.1.2 Procedure

All feedback received from ABB by the CEL team were obtained in two separate focus group sessions. CEL team recorded conversation notes using notebooks and laptops. The conversations were transcribed and team-member notes were consolidated.

**First Session**

The first focus group session was 90 minutes long, and involved the CEL team and ABB’s sales manager and service manager. Key questions that were discussed are listed below.

1. What is a typical day of work for a Service Technician? What are their key roles within ABB?
2. How are work and projects planned? Who determines work schedule, estimate completion time, and how?
3. How do you manage the varied work environments of ABB’s customers? How do you decide which technician is appropriate for which customer?
4. How do support staff communicate with each other?
5. How do you handle emergency calls from customers and immediate schedule changes?
6. What is your vision for the service technician team in the near and long term future?

**Second Session**

The second focus group session was 50 minutes long, and involved the CEL team and 22 participants of the ABB customer support team. The CEL team divided into three groups of two focus group facilitators and conducted sessions with the three respective ABB groups.

- Seven (7) participants: Service Technicians – Drives;
- Eight (8) participants: Service Technicians – DCS / QCS;
- Seven (7) participants: Technical Support.

Key questions that were discussed are listed below.

1. Who do you communicate with at work and how is the communication managed?
2. How do you plan for a day’s (and week’s) activities? How do you plan for spare parts?
3. What is a typical good day and bad day at work?
4. What are routine challenges you face at your work?
5. How do you think mobile technology can help with your challenges?

3.2 Results

Notes, transcriptions and other source material used to gather information were consolidated and reported to ABB Canada in a follow up report. The report was written by myself in consultation with Dr. Antony Hilliard. We summarized the challenges that ABB support workers faced on a daily basis. These challenges were used to identify promising opportunities that ABB Canada and ABB Corporate Research might pursue to assist their customer support staff.

We also demonstrated understanding of current customer support roles at ABB. This information was critical to identify target users for new mobile opportunities, but are not included in this thesis.

3.2.1 Challenges

All work-related challenges based on focus group feedback are summarized in Table 3-1. Because ABB Corporate Research were interested in mobile-related opportunities, we filtered raw data to focus on challenges that may be mitigated with mobile devices. We did not focus on challenges that are related to management, sales, engineering and system design.
### Table 3-1 List of Challenges

<table>
<thead>
<tr>
<th>Communication</th>
<th></th>
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<tbody>
<tr>
<td><strong>1. Network connection</strong></td>
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</tr>
<tr>
<td><strong>C1. Mobile network connection</strong></td>
<td></td>
</tr>
<tr>
<td>• Industrial facilities and remote work locations such as underground mines had unreliable mobile and internet network at work sites.</td>
<td></td>
</tr>
<tr>
<td>• Access to ABB server via internet enabled information and troubleshooting tools, which were often unavailable at such work locations.</td>
<td></td>
</tr>
<tr>
<td><strong>C2. Use of mobile phones for communication</strong></td>
<td></td>
</tr>
<tr>
<td>• Similar to C1, network was often hampered and unreliable in remote work locations.</td>
<td></td>
</tr>
<tr>
<td>• Mobile phones were used by customer support staff to talk to off site technicians, engineers and managers to quickly troubleshoot new problems. This was often unavailable at remote work sites.</td>
<td></td>
</tr>
<tr>
<td><strong>C3. Problem escalation</strong></td>
<td></td>
</tr>
<tr>
<td>• Customer support staff often had to escalate problems to higher levels of support, which operated on a “pull” system.</td>
<td></td>
</tr>
<tr>
<td>• Because resolving tickets at higher levels were dependant on support staff picking up tickets rather than assignment of tickets, both ABB customers and support staff at lower levels were blind on how far issues are resolved at a point in time.</td>
<td></td>
</tr>
<tr>
<td><strong>C4. Managing customer ticket information</strong></td>
<td></td>
</tr>
<tr>
<td>• When customers requested support via official channels (1-800 number), the call server automatically created a support ticket to track the problem.</td>
<td></td>
</tr>
<tr>
<td>• Customers might often choose to bypass official channel by directly contacting customer support staff, and/or managers, which did not create a service ticket and required manual data management work at a later time.</td>
<td></td>
</tr>
<tr>
<td><strong>C5. Availability of staff at customer site</strong></td>
<td></td>
</tr>
<tr>
<td>• Service ticket information often summarized problem information and/or had brief description without providing context of errors that customers faced at the moment in time.</td>
<td></td>
</tr>
<tr>
<td>• Having access to customer’s staff who were present at the time of error was valuable, however, was often not possible as</td>
<td></td>
</tr>
</tbody>
</table>
workers worked on shifts and/or not present at work sites when ABB staff were present.

<table>
<thead>
<tr>
<th>C6. Customer DCS access</th>
<th>• Customer adoption of DCS access via VPN was limited, and ABB support staff often were not able to directly access customer’s DCS to diagnose problems. This increased both labour cost and time spent to diagnose simple and often trivial problems.</th>
</tr>
</thead>
</table>
| C7. Security of data transmission | • Customers were concerned about security of data transmission, resulting in restrictive security policies.  
• It was difficult for ABB support staff to transfer configuration files and/or documentation for product upgrades and repairs. |
| C8. End of day procedure | • Getting signatures for timesheets and sign off sheets after completing support work was difficult, frustrating and time consuming. ABB support team expressed an interest in minimizing time spent in paperwork and maximizing their involvement in customer support tasks. |

**Work Planning**

<table>
<thead>
<tr>
<th>C9. Tickets and knowledge bank</th>
<th>• ABB Canada recently implemented a new ticketing system, which did not have access to historical tickets stored in the old ticketing system. Customer support staff were starved of information on old tickets which might have been relevant and useful.</th>
</tr>
</thead>
</table>
| C10. Billing customers | • If customers bypassed official support channel (1-800 number), support staff often did not have adequate time and/or resources to check whether the customer had a service agreement with ABB Canada.  
• Staff did not want to keep paying customers waiting and with denied service, but there had been cases of non-paying customers getting free service due to difficulty in getting appropriate contract information in time. |
<table>
<thead>
<tr>
<th>Safety</th>
</tr>
</thead>
</table>
| C11. Safety assessment at work sites | • Safety assessments were mandated for all maintenance activities at customer sites, which were slow to conduct before and after work was completed. They were usually conducted on paper and required customer signatures.  
• Similar to C8, this required a lot of work that are did not add value to ABB and customers, and faster alternatives were desired. |
| C12. Fatigue and isolation | • Customer support staff were mostly dispatched to work alone, which increased risk of overlooking safety hazards or trivial issues. They might also be subjected to fatigue and boredom, increasing risk of errors and reduced concentration. |

<table>
<thead>
<tr>
<th>Diagnosing client issues</th>
</tr>
</thead>
</table>
| C13. Documentation | • ABB documentation were written in generic terms and were not customer specific.  
• Service staff needed to access to documentation at the point of work, and getting the right documents took time.  
• Documentation for legacy products were rare and/or hard to follow. |
| C14. Software tools for problem diagnosis | • ABB proprietary software tool was essential to customer support work in the field, but connecting to customer’s equipment had a success rate of 10-15%.  
• Unreliable network connection played vital role in this limitation (see C1). |
| C15. Black box ABB products | • ABB equipment were engineered as black box solutions to make it easy to replace than attempting to fix them.  
• Customers had expressed displeasure with replacement costs when they were faced with un-diagnosable fault in such solutions. |
<p>| C16. Familiarity with site | • ABB support staff were often assigned to repeat customers in order to build relationship and improve site familiarity. |</p>
<table>
<thead>
<tr>
<th>Topic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C17. Knowledge of customer’s work</td>
<td>• ABB did not have any documentation for customer specific work setup, and when new staff were assigned to customers, they lacked resources to familiarize themselves with customer’s setup.</td>
</tr>
</tbody>
</table>
| C18. ABB product capabilities               | • ABB’s DCS products had a lot of features which were mostly disregarded by customers. Support staff noted that customers only used a fraction of all capabilities.  
  • Support staff reported features that customers did not use, but bugs in them had cascaded to other mission critical features within the DCS. |
| C19. Worker turnover                        | • As noted in chapter 3.1.1.1, ABB support team faces an aging workforce and there is an urgent need for worker turnover.                     
  • ABB Canada has plans to hire new people for replacing current employees, but has concerns about succession plan. |
3.2.2 Opportunities

We suggested key opportunities to ABB in order to address challenges highlighted in Table 3-1. As noted in research objectives (Chapter 1.2), ABB was looking for mobile solutions that could complement and address current limitation in workplaces. We focused on developing opportunities which might be addressed with implementation of new tools or features in mobile devices. We de-emphasized policy, organizational, management and sales solutions unless they are directly related to mobile application.

Table 3-2 List of Opportunities

<table>
<thead>
<tr>
<th>O1. Mobile Service Ticket Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>We proposed mobile applications that help customers take accurate and easy error logging via photos and videos. The application would have access to past error logs.</td>
</tr>
<tr>
<td>Challenges addressed:</td>
</tr>
<tr>
<td>• Customers might have difficulty in reporting problems (C4);</td>
</tr>
<tr>
<td>• ABB support staff needed access to historical data and staff to diagnose problems correctly (C5 and C17);</td>
</tr>
<tr>
<td>• ABB support staff often needed to complete tedious paperwork (C8).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>O2. Tailored Mobile Knowledge Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile application could be designed to customize access to documents for customer site-specific equipment and software. We could allow support staff to pre-load relevant documents and access them at work site via mobile device.</td>
</tr>
<tr>
<td>Challenges addressed:</td>
</tr>
<tr>
<td>• Limited network connectivity (C1);</td>
</tr>
<tr>
<td>• Documentation for ABB equipment were generic (C13);</td>
</tr>
<tr>
<td>• Support staff did not readily have access to historical diagnosis data (C9).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>O3. Issue-Centred Mobile Communications</th>
</tr>
</thead>
<tbody>
<tr>
<td>We saw an opportunity for a mobile application that consolidated all forms of communication (text, message, email, etc.) and related them to customer’s service request. An example of such application is Slack¹.</td>
</tr>
</tbody>
</table>

¹ https://slack.com/
Challenges addressed:
- Using mobile for communication was dependent on reliable network (C2);
- Customer’s service request could often be untracked (C4);
- Such application could also provide consistent information chain to familiarize new support staff (C16).

O4. Mobile Customer Contact

We proposed a mobile application solution that would provide customers with up to date information on service tickets. Mobile application could be developed to expedite customer work and timesheet approval.

Challenges addressed:
- Customers often had no idea on their problem solution if they were escalated to higher levels of support (C3);
- Work authorization, timesheet approval and other paperwork were complicated due to unavailability of customer’s staff and their managers (C8).

O5. On-call Support Aid

Mobile application could be designed for 24 hour on-call staff, where in case of multiple concurrent calls, automation could manage and prioritize customer calls. Mobile application could sort through calls for customers who did not have service contracts. It could also manage call volume when staff were busy (such as away from home).

Challenges addressed:
- On-call staff might be unfamiliar with customer (C16);
- Support staff often needed time to identify customers who paid for service contract (C10);
- Problem escalation (C3) and record keeping (C4) could also be easier with such solutions.

O6. Mobile DCS Diagnostics

New mobile applications could be designed with improved capability that diagnosed problems and provided intelligence locally at the point of work, without the need for network connectivity. New data transfer technology such as USB-C could also be used via connection to mobile tools, in order to expedite data transfer and use of troubleshooting tools.

Challenges addressed:
- Unreliable network connectivity (C1) and diagnosis tools (C14).
O7. Safety Aid

We proposed mobile application that could be used to conduct routine safety assessments and record keeping. Mobile application could also be used for location and task specific safety alerts. Challenges addressed:

- Safety assessment and record keeping were tedious (C11);
- Safety hazards were unknown (C16) and/or working alone introduced fatigue (C12).

3.2.2.1 Limitations

There were several limitations that were considered in our research, but their solutions were not within the scope of this research project.

1. Mobile applications developed often lacked coherence and information sharing between each other. As a result, the same information entered needed to be re-entered into another app, providing negative user effort. Both customers and support staff expressed their reluctance in using such applications.
2. Customers in the process industry are still identifying methods to integrate mobile devices in their workplace and may be reluctant to adopt new mobile applications.
3. North American process industries are not early adopters of technology and will not be receptive to new mobile solutions unless they are market-proven and provide notable process improvements.

3.3 Opportunity Ranking

We compared potential mobile implementation of each opportunity listed in Table 3-2 by rating them based on the following business criteria:

1. Frequency: How frequently it could be used and applied in customer support work.
2. Cost/Benefit: Cost of implementation and relative benefit.
3. Marketability: Whether solution could be marketed as beneficial and not intrusive to work.

We also defined whether we anticipated solving these opportunities as requiring short term or long term solutions. Short term solutions referred to opportunities that could be solved using available technology and current engineering practices. Long-term solutions referred to opportunities that
could be implemented using future or near future technology, and/or will need future research studies to validate performance enhancement.

### Table 3-3 Opportunity Ranking

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Frequency</th>
<th>Cost / Benefit</th>
<th>Marketability</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Mobile Service Ticket Aid</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>Short term</td>
</tr>
<tr>
<td>2: Tailored Mobile Knowledge Bank</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>Short term</td>
</tr>
<tr>
<td>3: Issue-centred Mobile Communication</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>Short term</td>
</tr>
<tr>
<td>4: Mobile Customer Contact</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>Short term</td>
</tr>
<tr>
<td>5: On-call Support Aid</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>Long term</td>
</tr>
<tr>
<td>6: Mobile DCS Diagnostics</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>Long term</td>
</tr>
<tr>
<td>7: Safety Assessment Aid</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>Long term</td>
</tr>
</tbody>
</table>

*Legend:*  
- ⚫: Most benefit from this implementation  
- ⚫: Noticeable benefit from this implementation  
- ⚫: Marginal benefit from this implementation  
- ⚫: Low benefit from this implementation  
- ⚫: No benefit from this implementation

### 3.4 Discussion

The knowledge elicitation process provided valuable input on problems and issues customer support workers faced on a daily basis. Despite the prevalence of technology use in their workplace, participants helped the research team identify valuable opportunities that could provide ABB with marginal and noticeable benefits. These opportunities could be used to develop design concepts to be tested for human performance improvements.

We consulted with ABB Canada and ABB Corporate Research to gather their input on which opportunity (Table 3-3) they preferred for further exploration. ABB’s goal was to identify opportunities that were beneficial to their business and they perceived as the best short term
promising opportunity. ABB identified their two most promising opportunities as Opportunity 1 (Mobile Service Ticket Aid) and Opportunity 2 (Custom Tailored Mobile Knowledge Bank).
4 Custom Tailored Mobile Knowledge Bank

I decided to further pursue Opportunity 2 and design a working medium fidelity prototype. The following sections outline idea generation for solving this opportunity and the research frameworks used to design the proposed mobile application.

4.1 Current Limitation and Purpose

My research topic attempted to address several challenges identified in the knowledge elicitation (Chapter 3) process:

- Lack of network connections at customer sites hampered access to documents and tools hosted by the central ABB servers.
- Accessing historical information that might be relevant to a customer’s problem in the current knowledge bank was time consuming.
- Generic or customer-specified documentation was often hard to transport and/or access at customer sites.
- New staff had to get familiarized to a customer site as well as to ABB products that were installed at the customer’s site.

The key objective of the prototype implementation was to allow ABB workers to download and access customer specific documents and files in their mobile device, before they reached a customer’s location and/or while they were actively working at customer sites. Anticipated benefits were noticeable performance enhancement in gathering information and diagnosing problems.

4.2 Research Framework

4.2.1 Adaptive Automation

I used Feigh et al’s adaptive system characterization framework to develop ideas for how the workers will interact this application (Feigh, Dorneich & Hayes, 2012). The framework classifies adaptive behaviour in automation systems by what will be adapted (type of adaptation) and how and when the adaptation will occur (triggers of adaptation). For this project, I used Content adaptation and both space and time aspects of Spatio-Temporal triggers.
4.2.2 Proposed Application Prototype

The application was designed to be a two-tiered adaptive mobile system. I anticipated to provide the following adaptations to the primary user.

1. When ABB service staff were scheduled to visit a particular customer site, the mobile application would use a time-based trigger to alert the user to download the customer’s information. The application would download all relevant information if the user chose to do so. Information would include the following contents: (a) customer’s hardware and software reference sheets (b) configuration files and updates (c) knowledge bank entries (d) service history (e) safety related documents, and (f) maps.

2. If the mobile device had access to location services, the application would use location-based triggers to identify the ABB products that were nearest to the user. The application would adapt the content to highlight information for the nearest product. Other information from tier 1 would still be accessible, but the application would adaptively highlight content based on location triggers.

Some possible actions that the ABB workers might take with this application were:

- Access information for ABB products at customer site from the ones noted in Tier 1.
- Add photos, short videos and notes for service logs.
- Edit service log details.
- Update and maintain configuration files for ABB products at customer site.

Identifying which information was relevant for the user to know for both tiers 1 and 2 was a design objective of this project. Information available to the user to download was expected to vary by customer’s location, their industry and/or the ABB products installed at customer’s location. Subject Matter Experts (SME)s consulted during design of this prototype were Dr. Maria Ralph and Jonas Brönmark, working at ABB Corporate Research in Västerås, Sweden. I consulted with them to identify the information requirements. The list of actions available to the user were also finalized after consultation with them.

To design a coherent and user-friendly mobile interface, I used Nielsen’s Heuristics (Neilsen, 1994) and user experience best practices (Garrett, 2010), both of which are industry-accepted
standards for mobile interface design. Further explanations of the application of these two sets of design guidelines are provided in Chapter 5.2.

4.3 Research Deliverables

The research project delivered a medium fidelity prototype to ABB (see Chapter 5). I provided a proof of concept prototype with usability results to ABB. The designed prototype assumed access to ABB server databases, and full implementation of this application would need to involve synchronization with these databases. Further consultation with ABB would be necessary to identify which databases would be used in the full implementation:

- ABB Sales database
- Solutions bank
- Customer work site map (if applicable)
- ABB knowledge bank
- Ticket system database
- Configuration files database
- Database of all relevant documentation (either generic or customer specific)
- Any other relevant database (to be determined during design)

4.4 Research Objective

The objective for this research project is “validate usability of a mobile application prototype that adapts Content using Spatio-temporal triggers for maintenance work at process plants.” Prototype and usability testing were designed to address this research objective.
5 Design of Mobile Prototype using Adaptive Automation

I designed a medium fidelity prototype to address the design and research objectives stated in Chapter 4. Preliminary designs were sketched on paper. Information and parameters required for the prototype were discussed with operators and SMEs (see Chapter 4.2.2) at ABB Corporate Research.

Feedback received from the SMEs was incorporated to iterate on the designs in a MS PowerPoint slide deck. Both the sketches and slides in MS Powerpoint were designed to simulate a mobile application screen on smartphone (i.e. iPhone 6). A prototyping tool InvisionApp was used to simulate user interaction with the application prototype. This chapter details the evolution of design and final prototype developed for evaluation with users.

5.1 Assumptions

There were three key assumptions that were agreed upon with ABB research during design of this prototype.

1. I intended to use location triggers for adaptation that require advanced sensors and sensitivity to nearby machines. GPS was a common example of location sensitive technology which could be used to physically locate a mobile device. But this was infeasible for equipment in a process plant, where multiple ABB equipment might be close to each other. The proximity of equipment was confirmed by both ABB service technicians and SMEs. Such close proximity might introduce interference when a mobile device attempted to isolate and identify individual equipment.

One alternative solution around this problem was to scan barcodes and/or RFID chips on equipment, but they required physically tapping mobile devices to intended equipment (Günther, Kletti & Kubach, 2008; Nilsson et al, 2000). SMEs confirmed that such maneuvers were often undesirable due to physical safety hazards. The ABB research team is currently working on proprietary solutions to solve this problem of identifying nearby equipment using a location sensitive mobile device. I assumed that near future technology such as ABB’s project could support identifying equipment with location sensors.
2. I worked with SMEs from ABB’s office in Västerås, Sweden. It was noted during consultation that it was common for European customers of ABB to run process plants using equipment also manufactured by ABB, such as motors, pumps, valves, etc. This stands in contrast with North American customers of ABB, where the focus of ABB’s sales was in DCS and Drives. I assumed during design that field workers would go in the plant to support and maintain ABB equipment, similar to how it was being conducted in Europe.

3. Document version control was noted as difficult to manage since each local ABB office (by country or state) managed their own database and servers. The models and types of product available to customers were different across locations. Although documents were periodically updated, small markets such as Canada often lacked a centralized database for all new versions. It was assumed that any mobile application would be able to access the newest version of any documents necessary from a centralized database. ABB Canada mentioned that they are already working towards this method of document management.

5.2 Design Principles

5.2.1 Adaptive Automation Framework

I used Feigh et al’s AA framework as a design framework for this prototype. I used Location (Spatio-Temporal) triggers to adapt Content in the prototype. Instead of subjectively designing user interaction and what adaptations will occur, the framework provided theoretical design guidelines that I could use to develop the prototype. It is important to note that the AA framework was explicitly used in the initial stages of design to develop ideas on when and where adaptation will occur, and when developing technical and user requirements.
5.2.2 Neilsen’s Heuristics

I used Neilsen’s Heuristics to evaluate each intermediate stage in design (Neilsen, 1994). He developed a usability evaluation framework that helps in assessing usability problems when designing user interfaces. The heuristics are briefly discussed in Table 5-1 to explain how the intermediate designs were evaluated.

<table>
<thead>
<tr>
<th>Heuristic step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Visibility of system status</td>
<td>The user must know where they are in the system (mobile application) at all time. Navigation should be intuitive, and the user should be presented with visual cues indicating their current state.</td>
</tr>
<tr>
<td>2. Match between system and real world</td>
<td>The design should ensure that there is no mismatch between information and state of the system (mobile application) and the user’s physical environment.</td>
</tr>
<tr>
<td>Heuristic step</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3. User control and freedom</td>
<td>Design should support undo and redo function. The user should be able to retract unintended actions.</td>
</tr>
<tr>
<td>4. Error prevention</td>
<td>Present users with confirmation before critical actions. This eliminates the problem in number 3 (User control and freedom).</td>
</tr>
<tr>
<td>5. Help users recognize and recover from error</td>
<td>Any error messages should be presented in plain language (no error codes).</td>
</tr>
<tr>
<td>6. Consistency</td>
<td>Actions and screen design elements should be consistent and follow defined convention. I used design guidelines published by ABB to achieve consistency.</td>
</tr>
<tr>
<td>7. Recognition rather than Recall</td>
<td>Users should be able to recognize actions in screen, instead of remembering complex options.</td>
</tr>
<tr>
<td>8. Flexibility and efficiency of design</td>
<td>Prototypes should be designed to cater to both experienced and novice users. Frequent actions should be highlighted if applicable.</td>
</tr>
<tr>
<td>9. Aesthetic and minimalist design</td>
<td>Screens should eliminate or de-emphasize information and/or components which are not frequently used by the user. Most important information should be highlighted first.</td>
</tr>
<tr>
<td>10. Help and documentation</td>
<td>Users should be presented with help options if required.</td>
</tr>
</tbody>
</table>

Each intermediate prototype design was evaluated using this heuristic method to improve functionality in each iteration.

5.2.3 The Elements of User Experience

Garrett (2010) developed a framework that provides guidance on how to organize information and architecture for a software application to improve user experience. His framework was designed for a web application, and provided design guidelines for development of a software application from idea generation stage to implementation. Although my prototype was a mobile application and did not proceed to the development stage, his framework provided engineering guidelines during the design process.
Garrett proposed decomposing an interface design project into five “planes”. Planes at the high levels deliver concrete details of the application, which in turn are supported by lower levels that provide abstract representation. His framework is briefly described below. Explanation is catered to software projects for context to this project. Figure 5-2 provides a visual representation of this framework.

Table 5-2 Planes of Good User Experience

<table>
<thead>
<tr>
<th>Plane</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Complete visual design that the user interacts with. This plane should ensure that all the planes underneath have been addressed.</td>
</tr>
<tr>
<td>Skeleton</td>
<td>Finalize design components, navigation options and information presentation on the screen.</td>
</tr>
<tr>
<td>Structure</td>
<td>Define interaction steps and options for the user. The objective is to complete actions defined in the Scope and be consistent.</td>
</tr>
<tr>
<td>Scope</td>
<td>Identify functional specifications of application and contents required to assist users in making decisions.</td>
</tr>
<tr>
<td>Strategy</td>
<td>Define user needs and application objectives</td>
</tr>
</tbody>
</table>
5.3 Design and Feedback

I designed all interface components and defined application interaction. Dr. Maria Ralph and Jonas Brönmark from ABB Corporate Research in Västerås, Sweden provided feedback as SMEs for field worker needs for my designs. The purpose of this application was to allow users (in this case ABB field workers) access to up to date operational and related documentation depending on their physical location within a process plant. Both Neilsen’s Heuristics and Planes of Good User Experience were used to iteratively design the interface.

5.3.1 Preliminary Design

I sketched preliminary designs on paper. During discussion with SMEs, I inquired about information required by field staff to complete scheduled pump and motor maintenance. Pumps and motors were chosen as pilot units because they are prevalent in process plants. The following design subsections were identified as key design requirements.
### Table 5-3 Information Requirements

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client management</td>
<td>• Application shall provide client specific documentation.</td>
</tr>
<tr>
<td></td>
<td>• Documents shall include maps, equipment inventory list, and calendar of scheduled tasks.</td>
</tr>
<tr>
<td></td>
<td>• The interface shall provide options to users to confirm when service is starting and when it is completed.</td>
</tr>
<tr>
<td>Equipment diagnosis</td>
<td>• The application shall provide information for motor and pump diagnosis from the DCS at the plant.</td>
</tr>
<tr>
<td></td>
<td>• Application shall highlight real time and historical runtime information, documents, equipment lifetime information and past error logs.</td>
</tr>
<tr>
<td>Error logs</td>
<td>• Application shall provide access to historical error logs related to a particular piece of equipment.</td>
</tr>
<tr>
<td></td>
<td>• It shall also provide access to database of service tickets and historical logs (Table 3-1, C9).</td>
</tr>
<tr>
<td></td>
<td>• The worker shall have option to add photos, videos and quick notes on any diagnosis completed.</td>
</tr>
</tbody>
</table>

Figure 5-3 below demonstrates an example of initial sketches completed. Detailed preliminary designs are attached in Appendix A.
5.3.1.1 Feedback

The prototype was demonstrated and discussed with SMEs. Their feedback is summarized below.

- Eliminate the error logging action. A similar application was being developed by ABB Corporate Research and testing it on this prototype was unnecessary.
- The scope was too broad. I was advised to focus on demonstrating the adaptive technology, and less on what kind of documents were available to the user. The research objective was to test the effectiveness of location triggers, so I should eliminate functions that do not relate to this objective.
- Incorporate ABB interface design guidelines.
5.3.2 Iterated Design and Feedback

The design was iterated to address SME concerns. Feedback for the iterated prototype was positive, and mostly dealt with how to incorporate advanced interface features.

- Use common icons to indicate download, add, delete and progressive disclosure.
- Allow users to filter information as required.
- Gray out background when inactive.

Figure 5-4 Iterated Designs on Paper

5.3.3 Medium Fidelity Prototype

Through discussion with SMEs and incorporating design guidelines, I designed a medium fidelity prototype. The prototype addressed time-based notification, document analysis, motor diagnosis and pump diagnosis.
5.3.3.1 Time Based Notification

Time based notification was incorporated to alert workers of impending site visit. It was intended to provide workers enough time to download or update documents they might require for their upcoming work engagement. The notification would be triggered three hours before a scheduled site visit, wherever the field worker might be. If the worker was actively engaged with the mobile application at a different work site, then notification would be delayed until the worker was done interacting with the application.

![Figure 5-5 Time Based Notification](image)
![Figure 5-6 Summary Page](image)

Selecting “Details” in the popup options (Figure 5-5) forwarded the worker to the home page of the work site in the application. In the example, the interface forwarded to summary page for University of Toronto (Figure 5-6). The summary page provided general information about the site location, date/time of service and general notes.

5.3.3.2 Document Analysis

Providing field workers with documents at the point of work was a key requirement of this application. It was decided that the following information was necessary for a minimum viable product.
1. **Client specific information**: maps, policy, safety and list of contacts for each client.

2. **Motor and pump information**: motors and pumps were decided as pilot equipment for this application due to their prevalence in process plants, and workers’ familiarity with them.

3. **Work orders**: work scheduled for the day, extracted from server calendar.

4. **Reports**: past maintenance reports, error logs, customer interaction notes and completed safety assessments.

Selecting the “Document” tab presented documentation information to the worker (Figure 5-7). Documents were aggregated by Client, Motors and Pumps. Expanding Motors (Figure 5-8) demonstrates that motor documents were aggregated by model number, and the number of units for the particular model were highlighted. The design assumed that model number of a pump would be the same for all units.

The application would gather information on document version control from a centralized database (see Chapter 5.1 Assumptions). Once the application synchronized with database version, a green dot (●) indicated that the most updated document version was downloaded on the mobile device. An orange dot (●) indicated that the document was downloaded but an update was available, and (□) represented that the document was not downloaded and was available. A green dot (●) on a section name represented that all documents under it were updated.
Tapping the orange dot (⊙) would update the desired document and tapping ( ▼ ) would download the document as necessary (Figure 5-9).
Selecting the document icons (≡) forwarded the worker to the document pdf stored in the mobile device. A mock document is demonstrated in Figure 5-11.
The “Work Orders” tab provided information on tasks scheduled at the work site (Figure 5-12). The “Reports” tab provided information on historical maintenance logs (Figure 5-13). The worker had the ability to review an abstract (Figure 5-14) and a complete report (Figure 5-15) if required.
Figure 5-12 Work Orders

Figure 5-13 Reports Tab

Figure 5-14 Reports Abstract

Figure 5-15 Full Report Sample
5.3.3.3 Motor Diagnosis Information

When workers reached a client site, the application would use location-based adaptation to activate itself without user interaction. If the worker did not use their mobile device, it would run in the background to save battery. But workers would be presented with information regarding the nearest ABB equipment upon activating the application. The design anticipated that the mobile application to communicate with the existing DCS at the customer site. All real-time information would be synchronized with existing DCS servers. Parameter limits, data restrictions and alarms would be the same as it was configured for the customer’s DCS.

This section demonstrates information that may be presented for a motor. Critical parameters for smart diagnosis of motors were decided in consultation with SMEs and field workers.

1. Motor temperature;
2. Motor voltage;
3. Vibration rating;
4. Humidity;
5. List of small equipment associated with the motor;
6. Remaining life of motor, based on Original Equipment Manufacturer (OEM) recommendation;
7. Time till next maintenance (if applicable).
Workers would have access to the motor “Summary” (Figure 5-16) where they had access to visualized parameters for motor operations. Selecting a parameter provided the worker with expanded display (Figure 5-17).

Figure 5-16 Motor Summary Page
Workers had the ability to zoom into detailed information from visualized data. Detailed interaction steps are not highlighted in the prototype. “Details” tab listed all information in text format (Figure 5-18). Red texts were used to highlight parameters outside the customer’s operating range as defined in the customer’s DCS configuration. The list of documents available under PDF was the same as those that the worker configured in Chapter 5.3.3.2.
When the worker physically moved to a different motor in the plant without interacting with the current motor, the information content would adapt with new motor’s information in place of Figure 5-16. However, when the worker attended to information needs for the current motor and simultaneously moved to a different motor, they would be presented with a prompt for updating the interface (Figure 5-19). This prompt was designed to control automated adaptation of content when the worker might be busy. When the worker chose to update the interface to the new motor, they were presented with information on the new motor.

### 5.3.3.4 Pump diagnosis

Information and adaptive interaction for pump diagnosis was similar to that provided for motors. (Chapter 5.3.3.3). Critical parameters for pump diagnosis are listed below.

1. Pump temperature;
2. Voltage rating;
3. Vibration rating;
4. Humidity;
5. Pump curve;
6. System curve;
7. List of small equipment associated with the pump;
8. Remaining life of pump, based on OEM recommendation;
9. Time till next maintenance (if applicable).

Interaction with pump information was the same as interaction with motor information. When workers approached a pump, the interface adapted to present pump summary information (Figure 5-20). The worker was able to interact with the information (Figure 5-21) and view detailed information (Figure 5-22). When the worker physically moved to a new location without interacting with the pump, the interface content would adapt to new equipment in proximity. Conversely, when the worker moved to a new location while interacting with the pump, the interface would prompt the worker for controlled adaptation (Figure 5-23).
Figure 5-20 Pump Summary

- Temperature: 20.3°C
- Flow Rate: 10.2 GPM
- Vibration: 0.1 Hz
- Pressure: 81.9 PSI

Figure 5-21 System Curve

- Temperature: 20.3°C
- Flow Rate: 10.2 GPM
- Vibration: 0.1 Hz
- Pressure: 81.9 PSI

Figure 5-22 Pump Details

Figure 5-23 Pump Details Controlled Adaptation
6 Usability Evaluation

The prototype was validated via usability evaluation. I used System Usability Scale (SUS) to assess the results of the user studies (Brooke, 1996). The scale evaluates the overall usability of a system, and has been widely used in experimental and industrial research. Evaluation was conducted after participants had a chance to complete mock tasks with the application and provide feedback.

It is important to note that the literature review stage of this research project focused on understanding how AA and mobile devices assisted in improving task performance and workload mitigation. Due to time and resource limitation – explained in the sections below – this research project did not perform controlled experiments, but rather completed a usability study to validate a mobile application design that used AA. This lack of direct experiment to test for task performance and workload is acknowledged, but the literature review is still important to consider as they were used to understand how to design adaptive mobile application. There was also evidence of AA improving usability of applications.

6.1 Methodology

6.1.1 Participants

I interviewed four (4) participants at ABB Canada. I intended to interview eight to 10 participants for the usability study, but efforts to get more participants were unsuccessful due to the demand on prospective participants’ work hours. All participants were customer support staff at ABB Canada, with an average experience of 19 years ($SD = 5.6$, $Min = 13$, $Max = 28$). All studies were conducted in ABB’s home office at Burlington, Ontario in a meeting room setting. Participants were not paid directly, but were on regular work hours.

6.1.2 Apparatus

An iPhone 6 (4.7” screen, 16GB memory) was used as the test device. Designs from the medium fidelity prototype in Powerpoint were exported as jpeg images. The images were uploaded to a prototyping tool called InvisionApp$^2$. InvisionApp allowed for manipulation of images on a touch screen by creating hotspots for clicking. Participants could use images of the screen to simulate

$^2$ https://www.invisionapp.com/
intended user actions using hotspots. It provided a real feel of using the application for the participants, allowing them to comment on both the concept and intended interaction. Figure 6-1 below demonstrates an example of hotspots created on a mock screen design.

Figure 6-1 Hotspots on InvisionApp Prototyping Tool

6.1.3 Procedure

I introduced the project to the participants, emphasizing the rough nature of the prototype and the need for user critique. Participants signed an informal consent form and provided permission to publish their results.

10 minutes of familiarization time with the prototype was provided to each participant. This allowed them to get introduced to the prototype, interact with it, and ask any questions. They had 30 minutes afterwards to complete three mock tasks (Chapter 6.1.4) using the application prototype. Interaction with the experimenter at the task execution stage was minimal, and only limited to inquiries about confirmation of user actions. All participant comments and observations were recorded in a notebook.

After completing the three tasks, participants completed a usability questionnaire designed using SUS (Appendix B). I used all the standard questions from SUS, and only replaced the word
“product” with “app”. The participants completed the questions, and provided additional feedback on their overall impression.

6.1.4 Tasks

Participants were asked to complete three tasks. Given the fidelity of the prototype, participants were asked to simulate actions they would take in the application and/or provide additional information details wherever they were missing.

Task 1

Manage documents needed for the day

You have two maintenance tasks scheduled for the day. The client locations are University of Toronto and Xerox Corporation. University of Toronto is located in Toronto and Xerox Corporation is located in Mississauga. From the work plan, you can see that at University of Toronto, you need to perform a routine maintenance for Pump # Roh462-77, and Motor # Eom22-96. You know the model for Pump is Roh462 and the model for Motor is Eom22. At Xerox Corporation, you are scheduled to perform an emergency maintenance on Pump # Ort7X2-12. The pump’s model name is Ort7X2. From past experience, your manager knows that the particular pump model may act faulty due to faults in its corresponding motor. The model of motor attached to this pump is Argen. Navigate through “Mobile Helper” to check if you have all the documents you anticipate to using during the day.

Task 2

Conduct site inspection

You are at University of Toronto for a non-scheduled maintenance. ABB Pump # Min123-02 is faulty and the customer is not sure of its root cause. You want to inspect the pump in question. The pump’s model is Min123. To get a complete picture of the workplace, you also decide to inspect the other ABB machines that are related to the pump, along with their maintenance history. You know from the diagrams that you need to inspect Pump # Min123-05, Motor # Tir25-71 and Motor # Arg471-06. The models of the pumps and motors are Min123, Tir25 and Arg471 respectively. Navigate through “Mobile Helper” to conduct inspection on all the units.
Task 3

Complete a maintenance task

You are at Xerox Corporation for scheduled maintenance on Pump # Eye666-22. The model for Pump is Eye666. The maintenance is to be performed during plant operation. Use “Mobile Helper” to use information to correctly diagnose the root cause. During diagnosis, you realize that the problem is not with Pump # Eye666-22, but instead is a fallout from failure in Pump # Naz616-52 (model Naz616). Navigate through “Mobile Helper” to help you with maintenance on all the units.

6.2 Results

6.2.1 Participant Feedback

User feedback on the developed prototype was very positive. Feedback is discussed with regards to the product feature, prototype testing, and complementary feedback.

6.2.1.1 Product Feature

This section describes feedback that was received from participants regarding the use of AA in the prototype. All four participants were generally able to complete the three tasks. Because actions in the interface were repetitive (e.g. data management and data retrieval), participants were able to get acquainted during the familiarization session and complete the tasks well. I was able to spend more time discussing viability of the AA concept.

Three of the participants noted that the adaptation of content was expected to be very helpful. The tool would be helpful for novices to learn about new customers. It would help to learn about new and legacy ABB products in the field, which novice workers might not have encountered before. One participant noted that it would also help expert workers in gathering location specific operational data, which would reduce distractions. The interface was deemed to be clear of clutter and easy to navigate and use.

All four participants mentioned that it will be helpful to have prediction tools for future performance based on actions taken. This will allow field workers to understand positive and negative consequences of actions that they may choose to take. It is also beneficial to display
recommended operational parameters for equipment and allow field workers to compare it with actual operational data.

6.2.1.2 Prototype Testing

I wanted to highlight key takeaways from prototype testing for use in future experiments. Even though I highlighted that the experimental objective was to test the adaptive technology, and designed the interface to highlight adaptive interaction, participants sometimes found it difficult to relate to how they would use the application. Two of the participants were trying to imagine how they would use the product. For instance, this prototype was specific to field workers, but technical support staff who provide remote support to customers would want information on a less granular level. Although our objective was to test for user receptivity to adaptive technology, I often had to improvise hypothetical scenarios for the participants so they could picture use of information in the application. In the future, it is recommended that experimenters highlight the objective of the usability study first and foremost.

The prototype that was presented to participants was well developed, and researcher used ABB design guidelines to design the user interface. Although functionality in the prototype was limited, the visual features gave the prototype an impression of a finished product. In the future, it is recommended that participants be presented with lower fidelity visual features to provide a concept impression.

6.2.1.3 Complementary Feedback

There were several comments I received that are not related to implementation of adaptive technology but were important to note for our research partner. Three of the participants were concerned about the viability of a centralized data management system, which was assumed in this project (see Chapter 5.1). They mentioned that data resources were often decentralized and immense manpower would be needed to coordinate a centralized database. The current data architecture would also need to be addressed to allow extraction of operational data. Product managers and developers of 800xA would need to define how data would be organized and extracted for each local zone, if they are to allow mobile devices to extract operational information.

There is a need to incorporate smart services from equipment of other vendors. Customers are free to choose equipment from multiple vendors for a subsection of their plant, and designers need to
incorporate external data to provide smart services. Automating mandated safety assessment using mobile device is also mentioned as a possibility. Both these feedbacks reaffirm our findings from focus group report (see Chapter 3).

Two participants expressed their interest in adding and accessing maintenance logs, which is currently in development at ABB Corporate Research. They mentioned that some worker roles, such as maintenance managers and/or customers, would want to access information with less granularity. Finally, data security is of utmost concern to customers, and customers might be reserved about allowing either their own or ABB workers to access operational data using a mobile device.

6.2.2 Usability Questionnaire

After completing tasks and consulting with the researcher, participants completed a SUS questionnaire. SUS is a well-established method to assess overall subjective usability of a product (Bangor, Kortum & Miller, 2008). Score was out of 100 for the 10 questions, and a standardized scoring algorithm was used to calculate a final score (Brooke, 1996). The average score for four participants was 85, which was well above the average score of 68 (Sauro, 2011). Scores over 68 are considered above average, and an indication of high perceived ease-of-use. Figure 6-2 summarizes a breakdown of scores for each SUS question. All error bars presented are standard error. Responses were positive, and participants liked the concept of adapting equipment related information at the point of work.

It is important to note one key limitation in the research results. I was only able to conduct usability studies with four participants. A meta-study by Brooke demonstrated that results of SUS are highly reliable from eight to 12 participants (Brooke, 2013). This thesis is published at a time when only four studies are completed. Validated publication for this project will need to conduct at least four more usability studies. SUS questions and all other research methods will be consistent.
Figure 6-2 SUS Questionnaire Results (with Standard Error)
7 Discussion

7.1 Implications of Research Project

This work demonstrated a first of a kind mobile industrial application of AA framework developed by Feigh et al (2012). I demonstrated the use of a notable framework to develop a mobile application prototype for a process control environment. Feedback on the prototype demonstrated a high usability score.

I identified key gaps in the literature during the Scoping Study phase. There was a lack of experimental studies demonstrating the efficacy of adaptation triggers. I found consistent results indicating that AA increases usability, and supports task performance; and inconsistent indication that AA may increase workload. In developing new adaptive systems, designers should follow established AA guidelines.

During the knowledge elicitation phase, we explored and highlighted potential problems that workers currently face. Service staff at ABB Canada highlighted key areas of concern where mobile solutions might be applied to address problems. Some notable instances are the lack of available documentation; unreliable network connections; unorganized and unrelated data sources; and hazards posed by working alone in a complex work facility.

I successfully designed an original mobile display concept using AA framework. The framework was used to design what adaptations will take place and when. Usability evaluation from the research participants demonstrated an above average SUS score, providing argument of their receptivity in using mobile compared to current solutions. We anticipate that mobile devices will become more prevalent in process work environment, and that using AA framework may assist in designing value-added mobile applications.

7.2 Limitations of Research

This study faced time and resource limitation, which may hamper applicability of this design. Key limitations are discussed below.

1. Knowledge elicitation was conducted on ABB Canada service and support staff. ABB Canada is a small component of ABB Inc’s core business, the majority of which are in
USA and Europe. Our feedback was limited to workers in a small segment of ABB’s breadth of expertise, which may have limited our knowledge extraction.

To mitigate this, I asked participants about their interaction with current technology, regardless of what devices and equipment they currently use. This allowed for richer feedback on their problems with interacting with devices rather than technology limitations.

2. Due to time and resource limitations in performing the evaluation phase, I was unable to conduct a controlled experiment to calculate the effects on HF metrics. I was unable to test the effect of using AA in a mobile application on user task performance or workload. I instead used SUS as an industry accepted method to test usability of the prototype. I am satisfied with positive results from the usability studies, and anticipate that the mobile prototype will help to improve task performance compared to the current work setting.

3. Our designs are limited to design feedback from engineers, designers and researchers in ABB Corporate Research in Sweden. ABB conducts business very differently in Europe as compared to Canada, and it is imperative that for future prototype designs, we should consult design engineers in Canada as well as in other locations. To mitigate problems in limited design feedback, I highlighted the potential of AA technology to research participants, and prioritized their feedback on the technology rather than the interface content. I emphasized that interface content in mobile application will vary by location, and that I was looking to test and demonstrate the effectiveness of adaptive technology in process workplaces.

7.3 Future Research

There is an immediate opportunity to use my research prototype to test HF measures to further test viability of implementing AA in process workplaces. Some metrics that can be tested for are:

- Task Performance Rate
- Speed of equipment diagnosis
- Cognitive Workload reduction

The mobile prototype developed in this research project addressed one of the seven opportunities that we highlighted to ABB Canada and ABB Corporate Research. We discussed all opportunities
with them, and they expressed their interest in further exploration of other opportunities. The list below ranks them in order of preference expressed by ABB.

1. Mobile Service Ticket Aid (Opportunity 1)
2. Mobile DCS Diagnostics (Opportunity 6)
3. On-call Support Aid (Opportunity 5)

All these opportunities are viewed as promising to provide valuable customer solutions and marketability by ABB.

Furthermore, we have visited other customer sites as part of the broader research contract with ABB. As we gain exposure to problems in multiple industries, we can highlight key challenges that ABB customers face across varied industries with different work requirements. We can both provide intelligence on challenges that workers face and highlight opportunities that we believe will provide performance enhancement to a variety of ABB customers.

### 7.3.1 Cues from the Environment

Cue usage is a promising area of research that this project can be extended upon. Introducing mobile devices in process environment will provide workers access to environmental cues that are inaccessible to them in a control room setting.

In a traditional control room setting, workers in the control room or remote workstations do not have access to cues at the point of work. Conversely, they do not always have access to operational data for an equipment at the point of work. We see promising research opportunity to explore how we can gather cues from the environment and integrate them to a DCS. Integrating cues may allow the DCS to provide smarter services and/or more accurate forecast data. My literature review did not reveal any relevant research in this field, and we believe is a great opportunity.

Wiggins proposed identifying cues by expert workers, and including them in design to minimize cognitive workload and facilitate skill acquisition to novice workers (Wiggins, 2014). It was noted that ABB and process industry customers are facing rapid workforce change in the near future. It will be beneficial to explore and research how to incorporate cues identified in process workplaces, and integrating them in a mobile application to facilitate skill acquisition. We see an opportunity to contribute to cue utilization literature proposed by Wiggins.
7.3.2 Ecological Interface Design

Ecological Interface Design (EID) is an interface design framework that suggests cue identification of field workers, and guides their integration in computer-mediated work (Vicente & Rasmussen, 1992). Cue analysis methods include Work Domain Analysis (WDA) and worker competencies analysis in terms of Skills, Rules and Knowledge (Naikar, 2013; Kilgore & St-Cyr, 2006). When workers are in a control room setting (Lau et al, 2008), they may not have access to work-related cues in the field. EID was developed to mitigate this problem to ensure that interface cues correspond to real world cues and the interface is interpretable by humans (Burns & Hajdukiewicz, 2013; Bennett & Flach, 2011). Figure 7-1 demonstrates how EID was intended to connect workers to the world (work environment).

![Figure 7-1 Canonical view of EID](image)

EID yields extensive information requirement for an interface and have been used in multi-screen displays. Mobile interfaces rely on small display (Mazaeva & Bisantz, 2014; McIlroy & Stanton, 2015), and there is a need for information prioritization during visualization. However, workers have direct access to cues and environment in the environment that is not addressed in canonical EID framework. Figure 7-2 depicts how we anticipate an evolution in EID to address new opportunities with the advent of increased mobile adaptation in workplaces.

![Figure 7-2 Anticipated Evolution of EID](image)
We foresee promising research opportunities in evolution in EID as portrayed in Figure 7-2. Further research is needed to validate evolution in EID framework and demonstration of their viability in designing mobile interfaces for complex workplaces.

7.3.3 Work Domain Analysis

WDA is used to highlight work related cues and information that are critical to designing an interface for a workplace (Naikar, 2013). WDA provides valuable information and context for interface designers who may not be familiarized with a work setting. Over the course of research project with ABB, we anticipate to visit pilot sites in multiple industries (e.g., specialty chemical, process and mining). We foresee an opportunity to conduct WDA for each site. It will allow ABB to better understand their customers and their interface requirements in varied industries. It will also provide an opportunity to contribute to and enrich the WDA knowledge base.
8 Conclusion

As process industry workplaces are increasingly automated and mobile devices become increasingly prevalent, it is possible for field workers to have access to historical and/or real time information needed to diagnose equipment problems. It is anticipated that design and development of an adaptive mobile application that highlights equipment-related data based on location will help in faster and more accurate equipment diagnosis.

We developed the first mobile application in the process domain to use Feigh et al’s (2012) AA characterization framework published in literature. The framework was used to design a medium fidelity prototype that adapts content using spatio-temporal triggers. The System Usability Scale was used to evaluate the prototype and resulted in a high usability score. Adaptive mobile technology is promising to implement in a process control environment, and this framework presents design guidelines for engineers. Further research can be done to validate the use of mobile adaptive system in improving task performance rate and reducing cognitive workload in a process control work setting.
References


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Appendices

Appendix A: Sketches

The following diagrams depict some examples of early sketches and iterated designs for the mobile prototype. The medium fidelity prototype was designed after completion of these sketches and gathering feedback from them.

Figure A-1 Example of Early Sketch
Figure A-2 Example of Early Sketch (2)

Figure A-3 Example of Iterated Sketch
Figure A-4 Example of Iterated Sketch (2)
Appendix B: Usability Questionnaire

The following page details the usability questionnaire that the users completed after evaluation. This is a standardized SUS questionnaire where the work “product” is replace with “app”.

**Evaluation Questionnaire**

Now that you have interacted with the mobile application prototype, please answer the following questions. This will allow us to justify further needs to refine the application.

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<th>Strongly Disagree</th>
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<th>Strongly Agree</th>
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<tbody>
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<td>1. I think I would like to use this app frequently.</td>
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<td>2. I found the app unnecessarily complex.</td>
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<td>3. I thought the app was easy to use.</td>
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<td>4. I think that I would need the support of a technical person to be able to use this app.</td>
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<td>5. I found that the various functions in this app were well integrated.</td>
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<td>6. I thought that there was too much inconsistency in this app.</td>
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<td>7. I would imagine that most people would learn to use this app very quickly.</td>
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<td>8. I found the app very awkward to use.</td>
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<td>9. I felt very confident using the app.</td>
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<td>10. I needed to learn a lot of things before I could get going with the app.</td>
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Other Comments

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