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Information Presentation on Mobile Device for Plant Operations

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INFORMATION PRESENTATION ON MOBILE DEVICE FOR PLANT OPERATIONS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering

By

Polakonda, Raghavendra Rao
(B.S.), JNT University, 2008

2014
Wright State University
I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Polakonda, Raghavendra ENTITLED Information Presentation on Mobile Device for Plant Operations BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Engineering

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ABSTRACT

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Process control and maintenance systems have been used in the petrochemical and refining industry for long time for improving operator performance and workforce efficiency. However, there is a need to integrate these systems with current technological innovations in a systematic and meaningful manner. Advances in mobile computing, sensor technologies, software algorithms, and computational methods provide the possibility for easy access to information anytime-anywhere. The issues associated with retrieving and reviewing this information directly affects the ability to make timely and quality decisions in high stakes environments like a petrochemical plant where time critical decisions are involved. This research investigates the use of mobile software systems in presenting information for process control and maintenance systems and focuses on identifying points of integration of mobile devices for information presentation of control elements and the related alarm information for field operators in the process industry. The research findings indicate that use of mobile systems for field operations in petrochemical plant enhanced the situational awareness and significantly reduced the mental workload on the field operator facilitating better interaction with the application. As mobile computing becomes ubiquitous and control operations become distributed over disparate geographical locations, the adoption of mobile systems for field operations will be more prevalent in the near future. This study sets the foundation for the
design of these mobile systems and makes a case for adoption of enterprise mobility management in process control industry.
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I. INTRODUCTION

Process control systems have been in use in enterprises for a long time for improving work force efficiency, operations management, and cost effectiveness and asset reliability. Through enterprise mobility management, organizations are realizing the tangible business benefits of a mobile, always connected workforce. It is predicted that by end of this decade, almost all employees will have access to a handheld device with capability to communicate directly with multiple components in the field (Motorola Corporation, 2009). Every component in field could be attached to a wireless transmitter similar to an NFC tag or other sensors. These sensors can communicate its parameters to remote devices to record the information directly thereby eliminating transcription errors. With access to live process data through a handheld on field, operators can resolve data anomalies before they can affect production of the crude output. Integrating information from multiple sources into composite variables and presenting them enhances human attention and cognition (Horvitz, E. et.al, 1995). With consolidation of control centers and addition of distributed field centers, the role of field operator is shifting from being monitoring and reporting component status to ensuring running a successful manufacturing operation through component maintenance and management. This does not eliminate the need for supervisory controller but increases the need for better communication and interaction of the field operator and supervisory controller. The notion of hybrid operator could also be applied to scenarios related to minimal field operators on task and having the supervisory controller take the role of field operator as needed. This is typically observed in a smaller plant manufacturing setting.

Advances in mobile computing, sensor technologies, software algorithms, and computational methods provide possibility for easy access to information anytime-anywhere. With the human-computer interaction model moving from traditional input
methods to more natural, ubiquitous input techniques such as gesture, touch-based interaction, voice input; there is a need for us to understand and increase the richness of the user experience with seamless integration and functionality of the mobile devices and the interaction affordances that they bring. Past research on information presentation on small form factor computing has highlighted the importance of presenting the right information in the right way to effectively engage the user. The screen space that is available on a small form factor is limited, and having detailed process information presented poses very interesting challenges.

The mobility feature of the handhelds creates new usage habits, therefore the interaction must be flexible and must provide efficient human computer interaction. The content should be organized using appropriate navigation patterns to limit objects that are continually on screen and to let users focus on relevant content. Although there are multitudes of process controls applications being used in petrochemical industry, there seems to be dearth of systems developed keeping mobile systems and their constraints in perspective.

The current implementations of these mobile systems are focused on directly porting the traditional desktop system on the mobile device. As seen by some of the examples shown in figure 1, many of the current system implementation use desktop interface that presents the process schematic interface on the handhelds. This does not take into account the benefits of mobile systems such as touch interaction, small form factor, and so on. Hence, there is a need to understand the affordances of the mobile system and to design the mobile systems to aid the operators efficiently.
There is an increased focus on developing interfaces to efficiently navigate through the data to retrieve desired information and the issues associated with retrieving and reviewing this information directly affects the ability to make timely and quality decisions. In high-stakes environments like in a petrochemical plant where time-critical decision-making contexts are involved, the ability of an operator to process information including short-term memory retention capabilities, cognitive load, and decision-making skills play an important role. In these systems, humans are often involved in re-planning, troubleshooting, and supervisory control tasks. In time-critical decision environments, operators have severe time constraints in reviewing critical information. The additional redundant information leads to confusion and sometimes errors or delays in executing their tasks (Miller, G., 1956).

A study conducted by Harvey (2011) has concluded that performance of the operator starts degrading if the system generates 20 alarms within a span of 10 minutes. Performance degradation was found to be greater with chronological display than categorical display. A more usable interface improves workforce efficiency by facilitating operators to perform more operations and the plant requires fewer workforce to carry out operations.

Due to the limitations of human information processing and cognitive abilities, human decision-making capabilities including quality of decisions being made decreases in cases where a large block of information needs to be reviewed while the time window for making
the decision is very small. According to Simon (1972), the information processing by humans is generally sequential. Studies have shown that human performance degrades as the information being presented increases and performance can be increased by showing only the relevant information by filtering out information not relevant to the task being performed. Research by Miller (1956) in human cognition has shown that when making decisions, humans generally can consider only five to nine chunks on information at the same time and this may reduce even further in crisis situations that need swift response.

Process Control Automated System have been used to improve process operations and to provide an easy, intuitive way to connect the people, the processes and the production.

Field operators operate in process area and usually perform process procedures and record different system observations. Field operators are usually in constant communication with control room to perform maintenance and collect the data needed to assess the current condition of the equipment and document it for the control room operators. In distributed mobile applications, where information has to be transmitted over limited bandwidth networks, information being transmitted should be prioritized or should be set to minimal so that the cost of transmission delay does not have a significant effect on actions being performed in time critical decision making contexts. In process control systems where information is transmitted and displayed in real time, the communicated content needs to be configured and controlled to enable timely, quality decisions despite time constraints. Some of these mobile process control systems have offline capabilities including built in intelligent decision support systems. The primary contention among these systems is identifying what level of automation should be used in time critical environments where automated decisions are not always perfectly reliable but at the same time understanding how it can be applied to help operators in carrying out scheduled and redundant tasks and to aid operators in responding to unforeseen events.

Different levels of automation can be used where the system can make recommendations but the operator is the final decision maker to carry out the tasks. Human cognitive limitations have to be taken into account when designing the automated systems so that increased automation may not cause skills degradation, reduce situational awareness or
induce automation bias in the long run. Automation bias can be found in critical event diagnosis where the operator disregards or does not look for any contradictory information when an automated solution is provided and the solution is accepted without any further analysis. Errors originating from automating bias are classified into commission errors and omission errors. In a typical commission error, an operator does improperly implement an auto generated system recommendation whereas in an omission error operator does not notice the new or existing problems because of the failure of the automated system to alert him. Intelligent decision support system in process control must actively consider human as an integrated component, failing which can cause the automated system to eventually fail.

Human cognitive limitations have to be taken into account when designing the automated systems so that increased automation may not cause skills degradation, reduce situational awareness or induce automation bias in the long run. Previous research on models for identifying the types and levels of automation that can be employed and that can help make choices objectively when designing automation framework (Parasuraman et al., 2000; Wickens C.D. et al., 1998). Automation can be varied from an entirely manual to entirely automatic system across four distinct functions –a) Information acquisition, b) information analysis, c) decision and action selection, and d) action implementation. Information acquisition (1st stage) at moderate automation comprises of classifying the incoming information e.g. presenting important information by highlighting them or by creating a list of important items for review.

Information analysis automation (2nd stage) at a lower level involves applying algorithms for predictive analysis based on incoming information like a trend display showing existing and predictive states of the process. At this stage, integrating information enhances attention and cognition of the human operators. Decision Automation (3rd stage) involves replacement of operator selection of decision choices with machine decision-making at varying levels. Action Automation (4th stage) includes performing the decision choice selected in decision automation stage and replaces human involvement. This stage involves “agents” that carry out specific context based tasks by tracking the interaction of
user with the system. Automation can also be adapted and varied during operation contingent on situational demands of the operator.

Four important human performance issues associated with automation include mental workload, situational awareness, and complacency and skills degradation. Mental workload on operators can be maintained at an appropriate level for operating an automated system by systematizing information like classifying data according to their priority, or by aggregating important information into data summaries so as to minimize time in searching for information and aid operators by presenting only the relevant information pertaining to the decision. Graphical representation of the information or transforming information to align with the operator’s mental model of the system can reduce the workload on the operator. Self-reporting methods such as NASA TLX, Subjective Workload Assessment Technique are widely used for measuring mental workload (Vidulich et.al, 1986; Wierwille et. al, 1993). Similarly several methods for measuring situation awareness has been proposed such as freeze probe recall techniques, real-time probe techniques, post trial subjective rating (Salmon et.al, 2009). SAGAT (Endsley, M. R., 1995) is the one of the most popular method in freeze probe technique and was developed to assess pilot Situational Awareness. For the purpose of this study freeze probe technique is not applicable as the nature of the task is related to easy recall of system state by viewing the process automation system. Hence, through the measurement of task related queries and time taken for the user to provide the information was used as a measure for situational awareness.

As supervisory controllers of dynamic situations, humans make decisions based on numerous factors including heuristics, biases, cognitive ability, time availability, and the amount of risk involved. Having information at-a-glance can help speed decision-making in supervisory control tasks. In the process industry, one of the most important supervisory tasks conducted by field operators includes managing and monitoring alarms and alerts. Alarms and alerts are used to give the user feedback about important activities that need attention. In designing alarms and alerts, it is important to understand the paths the user takes to address them (Bullemper P.T. et.al, 1994). Some of the key issues with interface design for the representation of information are (a) ad-hoc designs do not
support reusability and extensibility b) interface should provide useful cues and capture
the attention of the user appropriately without information overloading, and (c) interface
should identify and integrate relevant information and present it to the user in a
constructive way. Hence, there is a need to understand the information presentation of
process control elements and specifically alarms and alerts in a cognitively effective
manner that can help the field operators make informed decisions in an effective manner
that minimizes the downtime of the machine(s), multiple trips to the site, and also
prevents cascading alarms (Meshkati, N., 2006; Woods, D., 1995)

A. Research Questions and Hypothesis

The primary objective of this research is to understand the utility of mobile software
system in presenting intelligent information for process control and maintenance systems.
This research uses an mobile application to test whether more accurate and timely access
to information will result in better decision making and improve operator safety and
performance.

In a process control automation system, alarms enhance safety and performance of the
system and operators. Alerts notify operators if process is outside the optimized limits of
operation and prompts the operators to take appropriate action to achieve a stable state.
Under normal conditions of operation, automation system manages the plant according to
preset prescribed conditions. However under some exceptional circumstances, which are
triggered by an abnormal event, the automated systems may not able to adjust different
plant parameters automatically to return to the previous stable state. In these cases,
operator overrides the automated system and manually adjusts and compares the different
equipment to return system to prescribed conditions.

This research study investigates the use of mobile application to reduce the time taken by
operator to address each failure and whether the corrective action taken by the operator
correctly addresses those events with minimum number of steps and under minimal workload to the operator. NASA TLX Scores have been used to measure the operator workload and System usability Score (SUS) ratings measure the usability of the application. The following research questions have been developed for purpose of this study. The following table lists the research questions and associated hypothesis.

**Table 1: Hypothesis related to research questions**

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<td>Does Mobile Application helps operators to navigate among different components...</td>
<td>There is a significant difference in time taken to navigate among components and different scenarios in mobile application when compared to Process Schematic display.</td>
</tr>
<tr>
<td>Does Mobile Application helps operators to identify different components and their parameters accurately and within shorter time span compared to traditional application</td>
<td>There is a significant difference in time taken to locate components and their parameters accurately in mobile application when compared to Process Schematic Display</td>
</tr>
<tr>
<td>Does Mobile Application helps operators to address pump failures within shorter time span compared to traditional application?</td>
<td>There is a significant difference in time taken to address pump failures in mobile application when compared to Process Schematic display.</td>
</tr>
<tr>
<td>Does Mobile Application helps operators to acknowledge alarms within shorter time span compared to traditional application?</td>
<td>There is a significant difference in time taken to acknowledge alarms in mobile application when compared to Process Schematic display.</td>
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B. Research Approach

Phase I – Concept Abstraction The first step of this research was to understand the user and the user requirements. We tried to understand the traditional system limitations to get a baseline understanding of the current state of software and what users are doing today to accomplish the task. The reason for this is two fold:

1) It helps identify the users need(s) for a new system

2) It provides a reference point by which we can measure how much better a new system may be.

The user requirements gathered in this stage were translated to a cognitive model that was subsequently developed as a mobile application. specify what information the user will need, how it should be combined, and when it should be displayed.
Phase II – Application Development

The Traditional System (Emerson Delta V Automation System) was implemented in .NET, hence the mobile system was implemented in Windows RT for better compatibility.

Phase III - User Testing: An empirical study was conducted to study the effect of intelligent information presentation on mobile device. The testing was conducted in two steps. The first step was testing the application with 10 participants who were domain experts and employees of Emerson Process Management. The second step involved testing the application with 10 novice users who were students of Wright State University.
II. LITERATURE REVIEW

Most of the accidents that have taken place in petrochemical industry in last few decades can be attributed to failure of the system architects to recognize design flaws within the systems leading to lack of situational awareness caused by fatigue, confusion and substandard collaborations among operators. Making designers cognizant of these flaws is first step towards developing systems that minimize operator workload and maximize situational awareness.

Most of the incidents are not due to any inherent fault in the system but due to fact that they are used by operators in a way they was not originally intended to be used by the system designers. During normal operations, the system is put in automatic mode, the operator waits for it to fail and then reacts to the situation. This approach causes issues when multiple alarms become active at same time and the operator is lost in details instead of understanding the overall perspective. As the situation worsens and alarms start cascading, the alarms system becomes inoperable. In these situations, there is a very high prospect of operator overlooking critical information and making errors. In these scenarios, the Alarms management system itself becomes part of the problem as the loss of situational awareness slows down the communication between operator and the controller while the active alarms levies additional stress on the operator.

On July 24th 1994 (Meshkati N., 2006), an explosion occurred in the Pembroke Cracking Plant in Texas when highly inflammable hydrocarbon fluid was being moved into a vessel which had its outlet
closed. The excess fluid was redirected to flare lines through a pressure relief system. The Flare system was not designed to endure this abnormal conditions and failed at an outlet pipe releasing 20T of hydrocarbon fluid, causing an explosion. The incident was caused by chain of actions including carrying out actions without considering the consequences and use of control graphics omitting important process information in their displays. Multiple human factors issues contributed to the incident caused in the Fluidized Catalytic cracker unit (FCCU) Control System. The FCCU Control System display did not use any color to highlight the intensity of the process values and contained limited process data for each individual screen. Few of the displays contained details of the internal plant structure without measurements including temperature, flow pressure or plant status information. Most of the information displayed was textual and using color changes could have better indicated this information.

Investigation into the incident reports of accidents indicate that most of the operator errors were induced when the operators missed, ignored or suppressed the alarms and occasionally the operators were overwhelmed with multiple alarms. Disparities between training manuals and actual procedures and lack of training contributed to human errors. Poor User interface design including inefficient navigation within the application, improper highlighting of different components, lack of proper overview displays and sole reliance on alarms and not using trend displays led to operator fatigue, memory traps and lack of situational awareness ultimately leading to these incidents.
Alarm management issues can be solved by developing a superior life cycle design by better understanding of key performance indicators of alarm metrics including designing alarms using appropriate UX guidelines and using data analytics and process trends to reduce reliance on alarms for situational awareness. Operator’s workload has a direct correlation with alarms as most alarms necessitate operator intervention and the operators trust and response to these alarm systems is shaped by their experience with the alarm system. Imprudent alarm filtering conditions, alarm limits and questionable stability of the mechanical equipment are detrimental to alarm reliability. Industry standards developed for Alarm management include the EEMUA 191 for alarm rationalization.

User interface design has not been given the necessary consideration in developing process control applications (Nimmo, I., 2006). Current graphical applications are not optimized for operators and have found to frequently fail under abnormal situations. Most of the issues stem from poor overview displays, complicated navigation, improper highlighting of components and missing crucial information. The user interface is affected by lighting and colors being used like a black background used in some applications caused glares on screen making it difficult for operators to discern the on screen information. Some vendor used bright colors imitating actual components to promote their software suites but the screen was overwhelmed the low priority information with some data pushed to background.

Efficient User interfaces should be designed with emphasis on critical information and displayed information should be selected carefully for optimum use of existing real estate
in case of handhelds. Proper coloring standards should be used where color brightness and other visual parameters will dictate importance of the components.

Different UI layouts should be used on basis of operator experience and should be task oriented. Different color contrasts can be used to distinguish static information like plant equipment from dynamic information like component set points and alarm information.

Figure 3: A large overview display example (Nimmo, I. 2006)
Large Screen displays (LSD) are currently being promoted to improve overview displays and for better control of the processes and for management of key operational variables. The LSDs complement operators’ individual desktop display by headlining critical information like important active alarms and production parameters and other process KPIs. Most of the LSDs have textual displays instead of graphics and do not show low level information like low priority alarms. A new outlook should be considered for all process control displays to reconcile different presentation formats across multiple platforms keeping UI consistency and color schemes in perspective.

![A control room of Shell Corp (Nimmo, I. 2006).](image)

Figure 4: A control room of Shell Corp (Nimmo, I. 2006).
A. Evolution of HCI in Process Control

Figure 5: Panels containing Component Status (lights at left), alarms (two deck components arrangement at right), component Process variables (at center windows) and an operator. (Nimmo, I. 2006)

Pneumatic panels were the first generation Human Computer interfaces in automation solutions for process industry. Panels were task oriented and controls were grouped logically allowing operators to operate specific equipment like an boiler and furnace from one location with better awareness and division among controls. The measurements in these panels were run vertically up and down to control the values. These panels were
limited in their display capabilities and recorded the current alarms, component parameters and the equipment status but these panels relied heavily on operator awareness.

These Panels were replaced by DCS which were enabled with low resolution graphics and were designed based on control engineer’s understanding of the process but were not in sync with operator’s mental model of the plant. The Operator had to customize the interface to prevent loss of task organization. Uniform color standards were not followed which resulted in alarms and other components being represented with same colors, improper details of objects and their layouts with respect to their importance, use of difficult to read fonts and parameter values and use of conflicting graphics to represent engineering equipment as a screen space saving initiative were some of the drawbacks of these systems.

The third generation DCS system evolved to display high resolution 3D graphics, but the graphics occupied large part of screen and in some cases up to 60% of screen size. The important component parameter values were pushed to background to occupy remaining part of screen. Most of these issues can be traced back to lack of human factors engineering education among human machine interface designers.

To address these concerns, EEMUA (The Engineering Equipment & Materials Users’ Association)(Nimmo, I) has published "Process Plant Control Desks Utilizing Human-Computer Interfaces: a Guide to Design, Operational and Human Interface Issues". The document sets the standard for designing human machine interfaces in process plant industry.
Figure 6: A 2nd generation DCS system with low resolutions and improper use of colors for highlighting different process conditions (Nimmo, I. 2006)

Figure 7: An 3rd generation DCS which uses 3d objects to depict components. These graphics occupy large part of screen and push vital component parameter information to background. (Nimmo, I. 2006)
B. Abnormal Situation Management in Process Control

As process control systems evolve to be more automated and complex, the necessity to train operators to handle abnormal situations is imperative. In most of these automated systems, user interface has not been developed by keeping Abnormal Situation management in mind and has been concentrated more on Alarm Management and presentation and providing better contextual access to data. With increased sophistication of these state of the art systems, operators have to assess multitude of complex conditions to deal with different situations. Albeit Imprudent handling of abnormal situations do not result in major disruptions like explosions or fires, regardless they eventuate delays in planned schedules and affect product quality. According to Bullemer et.al (1994), the inefficacy of operators and control systems to manage abnormal situations costs $20B annually to petrochemical industry. In a classic control room in oil refineries and petrochemical plants, the operator monitors the plant and oversees different plant component parameters and in case of abnormal situations, strives to bring the plant back to optimal condition. The operator senses the current plant condition, investigates for any anomaly and makes adjustments to redress the abnormal conditions.

Abnormal situations is defined as any condition in which plant’s normal state of operation is disrupted and diverges from normal due to unanticipated circumstances and
abnormal situation management refers to “proactive or reactive” mediation by operators to rectify the situation.

According to Buellemer, three type of factors are responsible for problems causing these abnormal situations.

a) People and Work Context
b) Equipment
c) Process

Figure 8: Leading factors of problems in abnormal situation management
In the causes involving People and Work Context, the following factors were identified

a) Improper or no procedures (27%)
b) Incorrect or inadequate action (22%)
c) Failure to follow instructions (22%)
d) Inadequate work practices (17%)
e) Defective installation (6%)
f) Failure to recognize program (6%)

In an abnormal situation, supervisors, control room operators and field operators need to be in constant communication to coordinate and debug the erroneous conditions and to bring the process state back to normal within appropriate timelines. In these abnormal situations, mediation by human subjects involves orienting, evaluating and acting activities. Inadequate training, lack of knowledge Failure in orienting activities are induced when human subjects are presented with too much information with disproportionate level of details or if they are subjected to excess workload. Conflicting information or imprecise information leads to failures in evaluation. Failing to adhere to standard procedures or sketchy instructions or complicated procedures lead to failures in acting. On further investigation, the documentation indicated that most errors ensued during “acting “activities.
Regarding Current Training practices, attention is on “hands on” training. In a classical training scenario, an expert operator used to guide a novice around the plant to make the novice cognizant of different actions that need to be performed. The novice used to observe the Expert’s actions and would apply them later himself. Some concerns with these practices included quality of training and time needed to be trained to be competent enough to perform the operations. The Quality of training depends heavily on the proficiency of the expert. It may not be possible to train the personnel on all sporadic conditions that may occur during different phases of operation. When a new technology is introduced, the competency of the current “experts” to train novices can be disputed.

On job learning faced different hindrances in most of the organizations. Personnel of the operating staff were more knowledgeable about the DCS and its functions. As such, most of the decision making authority was vested with control room operators. Consequently in abnormal conditions due to their low proficiency regarding processes and low situational awareness, the field operators felt constrained in their ability to contribute to patch the condition and succor the control room operator. To counteract these effects few plants experimented with rotating workforce to enhance their skills but this led to inadequate experience among the operators due to constant rotation.

Responding to the above abnormal conditions need a revamp of existing training procedures to factor in the human demands and their limitations. Attempts must be made to improve interactions among personnel, processes and equipment that take place every day as work environment is principal learning environment and work environments should be constructed accordingly. The learning can be classified into knowledge
development which encompasses acquiring facts about plant operations including how the plant functions, the processes involved and their behavior under different conditions. Skill Development refers to the competency of the operator in responding to different conditions swiftly by being perceptive and without deliberation.

To facilitate knowledge development, work environment should stimulate teamwork and collaboration and decision making should be apportioned among multiple levels of personnel. Access to precise information is vital in abnormal situations to mitigate their adverse effects. Operators need to make swift decisions without conscious deliberations and work environment should simulate these abnormal conditions and should provide individual performance appraisals on decisive learning parameters for skills development.

In Future Control room Operations will be consolidated in few Business Operation Centers (BOCs) located far away from plant facilities in a secure location within a corporation and these centers will be networked into the production facilities. Instead of using images in overhead displays, a video wall will be used to present context sensitive detail plant view information and controller can navigate between multiple levels of details and diagnostic display information. Controller can visualize different predicted simulations based on present conditions and do a what-if analysis based on past process data before making a decision.

The Process plants will be equipped with smart valves and will have transmitters and controllers embedded within them with the intelligence to perform heuristic diagnosis of problems and transmitting the process information to remote distributed control system.
A remote diagnostic software will control the DCS and will monitor status of different controllers based on the transmitted diagnostic information.
III. RESEARCH COMPONENTS

A. Process Schematic Display Description

Crude units are used to refine crude oil and separate crude oil into different components such as gasoline, kerosene, naphtha and butane. A plant operator uses the Delta V Operate control software to keep a simulated Crude Oil Refining Plant running within the specified flow constraints.

1. Plant Operation

In order to maintain control of process plant operations, the operator needs to monitor the different processes and have high situational awareness of the operating conditions of the processes. The software system that provides the process operating condition information is an automated system that connects to the process sensors in the plant and provides information on current conditions of the plant equipment by monitoring the measured flows, pressures, temperatures, and levels of material inside the vessels and pipes. The operator has the ability to control the process variables and bring them to the optimum operating conditions. In a traditional desktop system, the operator is presented with a process schematic interface that provides information of the process measurements for pressures, flows, temperatures and levels on a graphical representation of equipment, piping, pumps, and valves within the plant. Under normal operating conditions, the
automation system manages the plant according to prescribed preset conditions.

However under some exceptional circumstances, which can be triggered by an abnormal event, the automated systems may not able to adjust different plant parameters automatically to return to the previous stable state. In these cases, operator overrides the automated system and manually adjusts and compares the different equipment to return system to prescribed conditions.

Field operators operate in process area and usually perform process procedures and record different system observations. Field operators are usually in constant communication with control room to perform maintenance, collect the data needed to assess the current condition of the equipment and document it for the control room operators. As shown in figure 9, the field operator and control operator work as a team to keep the process running. Even though they work as a team, the type of information seen by both of them is different. The field operator does not have all the necessary information at hand to have a holistic understanding of the state of the process control plant. Hence it is important to keep the individual and the team aware of the system operation.
In the petrochemical, the role of the field operator is more of a passive operations and the control room operator handles most of the active system changes. For example, if a pump fails then that information gets conveyed to the control room operator and the control room operator needs to convey that information to the field operator and then once the pump is turned back on (either the backup pump, or the original pump) the field operator informs the control room operator and this is confirmed by the control room operator. This results in back and forth communication and time delay. This can be avoided if the field operator can directly get that information and can act upon that. Although, this results in role shift from the traditional operations method, this is useful especially in
systems where there are limited resources. By providing field operators with smartphones and tablets, control rooms can be consolidated and being made in charge of overseeing assets and processes at high level. During normal operations control room staff presence can be minimal with plant operators doing large part of the plant operations like observing plant parameters and performing maintenance tasks.

Control room operations can be manned during emergencies and special production events depending on needs basis. The goal is not to eliminate control room operations completely but to get the operators into the plant and use mobile solutions to enable staff to make better decisions by keeping them informed of all the events in real time. Control rooms will still play a critical room with use of large displays to monitor critical processes and alarms.

An operator monitors the system’s performance as well as responds to alarms when activated. The system will start in steady-state. Events will occur through unforeseen device failures that will cause pumps to fail, flows the increase/ decrease. It is your responsibility as an operator to detect those changes and correctly address each failure. The steps for addressing failures and alarms are outlined later in this document.

Monitoring temperatures, levels, pressures, volumes, etc. of various components is done by various types of electronic devices located throughout the plant. A monitored/sensed value is known as a Process Variable (PV) and is measured by an instrument in the plant.
PV can indicate:

- The amount of material in a tank or other kind of vessel (i.e., level)
- The temperature of material and/or pressure in a pipe or vessel
- The volume of fluid going through a pipe or vessel in a given time (i.e., flow rate)

To Control the Plant, the Automated Control System needs to:

1. **Sense** what is going on within the plant equipment by monitoring the flow, pressure, temperature, or level values of material inside the vessels and pipes. These values are called Process Variables (PV).
2. **Compare** the PV values to specified values called Set Points (SP)
3. **Adjust** equipment controls to bring the PV values as close to the SP values as practical

The components of this system are pumps, control valves, flow meters, and vessels. Below, an illustration and description of each is provided.

**Pump:**

A pump is used to move liquid or gas through a pipe. Pumps in this simulation are powered by electric motors, so to start a pump the operator can turn on the motor, and to stop a pump, turn off the motor.

**Control Valve:**
A control valve works like a faucet to restrict the flow of material. Instead of a handle, there is a pneumatic plunger that adjusts the opening in the valve. The controller adjusts the opening so that the process variable (PV) matches the set point (SP).

**Flow Meter:**

The flow meter is made up of a flow sensor (silver body) and a flow transmitter (blue top). The flow rate of material going through a pipe is sensed, and then translated into a process variable (PV) value. That PV value is transmitted to a controller where it is used in flow control calculations.
Figure 10: Crude unit overview interface in Process Schematic Display
B. Plant Operation Basics

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Figure 11: Components within Process Schematic Display
Vessels

Illustrated below are the components of the Crude Unit. A description of each is provided.

**Desalter:** Process unit that removes salt from the crude oil.

**Heater:** Process unit used for heating the crude. Temperature can be as high as 750F

**Distillation Column:** Process unit where components are separated according to boiling point. The heavy components drop to the bottom of the column while the gases are removed from the top.

**Overhead Receiver:** Process unit where the gases are kept.

**Pump around Reflux:** A heat exchanger, which takes vapor from the upper parts of the fractionator, cools it to liquefy it, and reintroduces it to lower part of the column.
Figure 12: Different sections within Process Schematic Display
Below is an example of a **Pump faceplate** and its most important components. This faceplate will appear when operator clicks on a Pump icon.

Figure 13: Pump faceplate in Process Schematic Display
C. Pump failures and Alarms

When a pump fails, the flow through the downstream valve will drastically drop. There are HIGH and LOW flow alarms on these valves. There are no alarms on pumps. When a pump fails, a low flow alarms will be triggered on the downstream valve shortly after the pump failure.

**How to address pump failures and acknowledge alarms on a workstation:**

1. Open the pump faceplate.
2. Restart the pump.
3. Open the downstream faceplate. (There will be active alarms)
4. Acknowledge the alarms.

Alarms can be acknowledged from the faceplate. Each component (valve, pump, flow controller, etc) has a faceplate where active alarms will appear. To acknowledge individual alarms, click on the blank section under “Ack” as displayed in the figure below.
Figure 14: Faceplate with active alarms
How to restart a pump on a Process Schematic Display:

1. When the alarm banner starts blinking, and the name of the alarm displayed starts with the letter P, the alarm is a Pump Failure. Ex. “P-130A” will appear in the alarm banner.

2. Click on the alarm in the alarm banner and it will redirect you to the correct screen where the pump is located and the faceplate will appear.

3. Click on the Start button to start the alternative pump.

4. Acknowledge any alarms.
Figure 15: Starting a pump in Process Schematic Display

Click on the Start Button

Acknowledge any alarms (if applicable)
IV. EVALUATION/METHODOLOGY

A. Windows 8 UX Guidelines

Microsoft Windows 8 introduced a new “Metro Style” design feature which defines the User Experience for touch enabled Applications on Windows 8. A defining characteristic of this UX design is elimination of checkboxes, radio buttons or tiny controls that need a mouse to interact with. In Windows 8, we have big square tiles as primary items within an application. Most of the controls like textboxes are bigger than in a traditional windows application so that they are easy to interact with a finger. One of the defining features of a Windows 8 apps is that they are full screen by default. So there are no overlapping windows, there is no chrome on screen and organization of content is through whitespace. Different portions of the screen are not delineated by 3D Bewelled borders like in a traditional windows applications but we just use whitespace and grouping of items through it to indicate structure to the app.

The UX Features of Windows 8 Include

a) Non Over Lapping Windows

b) Full Screen Applications by Default
c) Apps support both snapped and filled views

d) Apps optionally support Landscape and Portrait Orientations for Mobile Devices

e) “No Chrome” within apps.

f) Use of Whitespace to distinguish UI elements and to organize them

g) Use of Page Based Navigation.

h) Use of App Bars for Commands and Navigation

i) Use of Contract for common functionality (Search, Settings, Sharing...)

A Metro Application takes over entire screen of the device and doesn’t allow multiple apps to overlap over one another now does it allow persistent popup windows. All popup windows are modal, that is user clicks somewhere else on background, and the popup window goes away. The underlying purpose of this feature is that users can concentrate on only one task at any given time, and the modal popup windows enable users to keep focus on a single window at a time and eliminates background distractions including menus, toolbars, and chrome and so on.

All Windows 8 Applications on startup, take over entire main screen of the device to allow users to maximize their experience when interacting with the application. All Apps are required to support filled views and snapped views. Snapped View fills up small portion of screen on left or right and filled view occupies the remaining screen estate. So we can snap app1 to left and we can launch app2 in filled view so that we can have 2 apps showing on screen at same time.
Many Windows 8 apps are designed for tablets and tablets can be rotated by users. A well
designed app will try to take advantage of portrait or landscape orientation of device by
relaying the content, as its being held by the user. The Apps support the concept of “No
chrome”. Chrome refers to menus, toolbars and other 3D bevelled edges on controls
which were pretty with traditional windows applications. The UI tries to embrace
whitespace by increasing open space and reducing lack of clutter so that users can focus
on content instead of surrounding adornments. Apps use different spacing sizes and
different layouts for elements as a way to organize groupings and to distinguish different
chunks of UI from one another.

To interact with the app, users need point of interaction including commands and
navigation they can select at appropriate times when they want to interact with the app,
but don’t clutter the screen at same time. So Windows 8 uses Appbars that can come up
at top and bottom of screen and commands and navigation buttons then show up in the
Appbar. Users can right click or use a swiping gesture on a touch based device and top
and bottom app bars appear on screen. These are Metro apps replacement for toolbars and
menus.

The Bottom appbar will have commands like refresh in bottom right and top appbar is
used for navigational links. Apps uses page based navigation to navigate among different
contents in the hierarchy of the app. An App displays a finite amount of content at one
time to users and allows them to navigate from one piece of content to another piece of
content in a page based manner. All Apps support horizontal scrolling as left and right
sweeping gestures are very natural and easy.
Many apps need to support common functionality such as the ability to search for content within app or the ability to allow users to configure settings of the app. This common functionality should be exposed to user in a consistent way across all apps. To enable this, Windows 8 provides contracts into which the application can opt into and the user interface that user interacts with is provided by the operating system itself. So instead of embedding a search box feature in the app that users may have to find, users can swipe from bottom left corner of the screen and app provides an in-app search experience driven by Operating system.

On the Start Screen, other distinguishing UX features include live tiles that can dynamically update in real time to give a more immersive user experience and to give a summary level information of what the app is about.
B.  **MVVM (Model View View-Model)**

Model View View-Model has its roots in two design patterns

a) Model View Controller (MVC)

b) Model View Presenter (MVP)

Model View Controller is an older and more current framework used ASP.NET MVC4 framework. It is structured around request-response type of interaction with user like in rendering of webpages in a web application. Model View Presenter is a variant of MVC with different responsibilities for presenter. It is used for stateful ongoing rich client type applications where interaction with user is more ongoing and constant.

In all these three design patterns, model and view mean the same layer but there are subtle variations on responsibilities and communications of the third layer (Controller, presenter and View Model) and nature of communication between these three layers.

MVVM is technically not a design pattern in itself. It is closely coupled with specific implementation mechanism of XAML technologies, with data bindings, commands and property change notifications among other features. MVVM is based on the Presentation Model design pattern documented by Martin Fowler.
**Design Goals of MVVM**

Two fundamental architectural goals of MVVM are

a) Loose coupling

b) Separation of Concerns

MVVM implementation leads to better

a) Testability

b) Maintainability

c) Extensibility

All Windows 8 Apps are packages as a signed appx bundle and run within security sandbox. It is not possible to use/download a dll directly into a folder and extends its functionality like in a traditional Win32 app.
C. Windows RT Platform

![Windows RT Architecture Diagram]

Figure 16: Windows RT architecture
D. Mobile System Description

The mobile system was designed based on Microsoft’s model-view-view-model (MVVM) design paradigm (MVVM Pattern, 2012). The MVVM pattern clearly defines responsibilities of each of the three layers. The model layer defines the business logic of the app including the business objects, data validation and data access rules. The model includes the data access layer to support retrieving and updating data using internal application storage or through a Web Service. The view defines the user interface of the application and the user actuates with this layer. View layer defines the appearance and layout of the “Tiles” that user can see on the screen and is defined primarily in XAML (eXtensible Application Markup Language). View-Model acts as liaison between Model and the View and defines the presentation logic including the data to be displayed and methods to interact with both Model and View Layers. The View Model retrieves data from model and makes it available to view and reformats data in some way to make it simpler for the View to handle. The View-Model is “view-agnostic”, it serves the function of providing data and methods to interact with the view but it doesn’t control how the view will display the data.

In the mobile system, when user clicks on a “Tile” on the “Home” screen, it triggers a command in the “View Model”. The “View Model” triggers the “Model” which retrieves the data through a JSON Web Service. The model typically queries the web service every one second and send notifications to the “View Model”. The View Model reformats the data and sends it to the “View”. The “View” uses its limited “code behind logic” to
update the User Interface and for Data Binding the data to its UI components. In distributed applications that require communications with remote machines, a data interchange format and exchange protocol are required. JavaScript Object Notation is an open, text-based Data Interchange format and is used for transmission of structured data over the networks. In COP Mobile, JSON is used as protocol for information interchange between the traditional Delta V System and the COP Mobile through HTTP Transfer protocol.

According to Bullemer et. al (2008) regarding navigation within displays, primary displays should be directly accessible and all secondary and associated displays should be accessible with least possible clicks. In real-time process monitoring (like in petrochemical plants), the time to call displays should be less than three seconds and averaging around one second while navigating to an operating interface. To ensure a simple and flat navigation model, the information display hierarchy to navigate to detailed information within each display level should not exceed three levels for operating displays. With a simple and flat navigation model, it is less probable for users to get confused among different hierarchies. Operators should be able to navigate to primary displays within a single click and all non-primary displays within two clicks from any task context as operators may need to access primary displays quickly to resolve any high alarms or in emergency situations. Displays that are important for process operations should be accessible through direct navigation such as using navigation controls on screen or through dedicated soft keys on keyboard because using display menu directory to navigate to an interface may necessitate more time for completing the navigation task. Use of tabbed navigation customized to be context –
specific can reduce reliance on soft key navigation and provides for quick navigation to secondary displays as menu can be updated depending on the display. Yoking is a navigation technique used in hierarchies that involve displays of multiple levels at once so that users can have an overview of different levels in a single interface. In Yoking, navigating to a component display in a particular hierarchy level automatically refreshes the corresponding displays below that level to the appropriate displays for the new component.

The system design for the mobile interface is based on a flat navigation hierarchy with three levels of display as shown in Figure 17.

Navigation of the mobile system uses a hierarchical system. This pattern is used to display distinct sections of content at different levels of detail.

The Navigation Design includes three different levels of information presentation.

a) Hub Pages: The Hub page or the “Home Screen” is the first screen user will see on launching of the app. The Content displayed in Tiles shows Different Sections in a Petrochemical plant and provides a summary of Alarms in each “Section” at that instant.

b) Section Pages: Section Page is the second level of the app and represents the various components in that “Section”. These Components include Pumps, Hand Valves and storage tanks specific to that section. If any Component has active Alarms, the color of the Component Tile will change to yellow or Red, yellow indicating Low Alarms and Red signifies High Alarms.
c) Detail Pages: Detail Pages are the third level of the App. Here, the details of each individual components are displayed, format of which depend on particular type of component. The Detail Page consists of components details and functionality. For example, the Detail page has controls to Start and Stop the Pump or to change the level of the Hand Valve.
Figure 17: Different levels of information presentation in COP Mobile

Diagram showing different levels of information display in COP Mobile
The App bar is the primary command menu for the app. The App bar is used to present navigation to the users and is hidden by default. The App bar appears and partially covers the app contents when users swipe from top or bottom edge of the screen. Users can dismiss the App Bars by touching the screen at any other position or by interacting with the app. The bottom App Bar provides basic navigation features, including a “Back” button which redirects user to the previous page and a “Home Button” which navigates to App Hub or “Level 1” of the navigation hierarchy.

The Top App Bar provides “one click” access to any Component Section within the app.
1. **Alarm Management in the Mobile system**

In the mobile system, alarms on a component are indicated by change in color of the associated component tile. If any component has active Alarms, the Component Color in Scenario Page will change to Yellow or Red Depending on the nature of the Alarms [Yellow signifies a low alarms, and red signifies an High Alarm. If there are multiple low and high level alarms on a component (like 1 High alarm and 2 Low alarms), Component color will still change to Red]. Alarms in the app are caused by Pump failures. When a pump fails, the crude flow between the components will drastically drop. “Fixing “the alarms is an multi step process involving –

5. Opening the pump faceplate and restarting the pump.

6. Navigating to the component faceplate or corresponding scenario screen (There will be active alarms) and acknowledging the alarms.

**Step 1) Addressing a pump failure on COP Mobile (Restarting the Pump):**

1. Navigate to the Pump Faceplate

2. Click on “Start” button to start the pump.

3. Verify that the current status of the pump has been changed to “Started”.

55
Step 2) There are 3 Ways to Acknowledge Alarms in COP Mobile

1. Users can click on each individual alarm in Component Faceplate to Acknowledge (Fix) Alarms.

Figure 18: Starting pump in COP Mobile
2. Clicking on “Ack All” Button in Component Faceplate acknowledges all active alarms.

3. Alarms can also be acknowledged directly from “Scenario Page” by “Tapping and Holding” the Component. The “Tap and Hold” interaction will acknowledge all Active Alarms for that component.
Figure 20: "Tap and hold" to acknowledge alarms in COP Mobile
V. RESULTS

In the experiment, participants were introduced to the process schematic interface from the traditional process automation system ported on the mobile device along with the new interface developed specifically for the mobile system. Since both were mobile systems, for the sake of clarity, the two test systems will be addressed as process schematic interface system and mobile interface system. Participants were given a procedure training document with detailed instructions on plant operation basics including how to monitor the system performance, how to respond to alarms and how to control system components including pumps, flow controls and valves. After reviewing the document, participants were trained on a test scenario on both the systems for the above tasks including monitoring the system, fixing alarms and controlling different flow components like pumps and changing values of valves. The training module were untimed sessions and participants were encouraged to practice as long as they want till they were familiar with the system. Familiarity was based on a subjective measurement of the participant’s level of comfort in interacting with the interface and successful completion of a scenario similar to the testing and training scenarios. Once they had successfully completed the test scenario and were familiarized with both the systems, the participants were asked to fix a pump failure scenario on the process schematic interface display and the mobile interface display. The experiment was counterbalanced with respect to scenarios being tested and the type of system. Three different scenarios were tested on both the systems to collect the appropriate metrics. All the scenarios involved monitoring the system for alarms and fixing the pump and changing the valve flows to optimal values. For all the
scenarios, alarms were scheduled to appear after a pre-determined time interval (30-40 seconds) after the start of the scenario and the participants had to monitor five sections with each section having close to twelve components. Before the occurrence of the alarm, the participants were asked to monitor the components across multiple sections. In order to assess the performance of the system, situational awareness, and ease of use; metrics related to time taken to complete the task, time taken to identify components, mental workload, and subjective measures related to ease of use was collected. The following time for completion metrics were collected by the process schematic interface system and the mobile system display:

- **Identification Task:** This indicates the time when oral instructions were given to participants to read out a particular component value to time when participant correctly read aloud the component values by navigating through the different sections of the interface.

- **Navigational Task:** This indicates the time when oral instructions were given to participants to navigate to specific display to the time when participants navigated to the correct display by navigating through the different sections of the interface.

- **Fixing Pumps:** This indicates the system time when pump failure indication was displayed on interface to the system time when the pump was started.

- **Acknowledging Alarms:** This indicates the system time when the alarm was displayed on the interface to the system time when the participant acknowledged the displayed alarm by interacting with the interface.
The study involved testing using the Windows 8 Surface tablet. Participants were asked to interact with the device using touch interaction. The scenarios modeled were typical of an operator managing a petrochemical plant process. Participants were asked to monitor the system of a crude oil refining plant running within specified flow constraints. The participants had to a) start pumps and check for the range for flow to normal; b) verify the flow constraints across the pipeline of crude storage through the separation process.

The next section details the simulation system and the empirical design for testing the mobile system. The following two figures (Figure 21 and Figure 22) show the experimental setup of the process schematic interface ported on the mobile device and the mobile system. The average year of experience for expert to have interacted with the process schematic interface was 3 years. The range of years of experience for expert to have interacted with the process schematic interface was 1-6 years. The session was video-taped and system recorded using Camtasia ® for data analysis.

Figure 21: Process Schematic Interface of the Traditional Desktop System ported on Windows Surface 8
Result Analysis

A parametric analysis was conducted to test for statistically significant difference in the dependent variables across the process schematic interface and the mobile interface and also to understand the difference between novice users and expert users. A two way ANOVA was carried out for each of the different treatments.

5.1 Time taken for Identification task

Results(Figure 23) indicate that there was no significant difference between expert and novice participants (p-value=0.136325) and between process schematic interface and
mobile interface (p-value=0.080833). There was also no interaction effect (p-value=0.140). Among identification tasks, again both expert and novice participants required considerably less time on mobile systems than on traditional systems.

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Figure 23: Mean times for identification tasks

5.2 Time taken for Navigation task

In performing navigation tasks, results(Figure 24) indicate that there was no significant difference between expert and novice participants (p=0.217672) but there was a significant difference between process schematic interface and mobile interface (p-value=0.023995). The mean was 15.85 seconds for process schematic Interface and 3.3 seconds on mobile system for expert participants. Among novice participants, the mean was 7.15 seconds and 1.6 seconds on process schematic interface and 3.23 seconds on mobile system. There was no significant difference in the interaction effects (p-value=0.225).

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Figure 24: Mean times for navigational tasks
5.3 Time taken for Acknowledgement task

Results(Figure 25) indicate that for acknowledging alarms, there was no significant difference between expert and novice participants \((p = 0.059872)\), but there was significant difference between process schematic interface and mobile systems \((p =0.021855)\). The mean was 74.82 seconds and 88.69 seconds on process schematic Interface and 9.06 seconds on mobile system for expert participants. Among novice participants, the mean was 15.47 seconds on process schematic interface and 13.54 seconds on mobile system.

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<td>Mean Time (Seconds)</td>
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Figure 25: Mean times for acknowledging tasks

5.4 Time taken for Fixing Pumps Tasks

Results indicate that there was a significant difference between expert and novice participants \((p=0.03963)\) and between process schematic interface and mobile interface systems \((p=0.015734)\).
As seen in Figure 26 above, the difference between expert and novice was almost 50 seconds with the experts having a higher mean than novices for process schematic interface. This could be attributed to the fact that the process schematic interface was a traditional process automation system that would introduce spiral effects of multiple failures after a specified time of not fixing the pump. Most of the experts were cognizant of advanced functionalities within traditional system. Therefore, instead of following given instructions as novice participants did; the expert participants followed standard operational procedures that resulted in additional time in completing those tasks. The scenarios used in testing were simplified version of real time scenarios on which the experts usually operate. Figure 27 indicates the mean value for all the dependent variables.

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Figure 26: Mean times for fixing pump failures
NASA TLX Scores

NASA TLX scores are used to measure the subjective workload assessments on operators working with human machine systems. It is a multi-Dimensional rating procedure that derives an overall workload score based in weighted average of ratings on six subscales—mental demands, physical demands, temporal demands, performance, effort and frustration (NASA TLX,”NASA TLX: Task load index”).

As shown in Figure 28, the NASA TLX Scores for process schematic interface and mobile interface on the mobile system. Participants testing the process schematic interface experienced consistently higher workload than the mobile system across both the groups. The average workload experienced by participants for testing the process schematic interface was 54.30 and for the mobile system was 35.50. These results indicate that navigating and identifying components and performing process operations generate more workload when users were using a process schematic interface. Statistical
difference between the values is not calculated, as there are not enough degrees of freedom to estimate the coefficients for the grouping variables.

Figure 28: NASA TLX scores among expert and novice participants
5.6 SUS Scores

The participants were asked to rate the use of the mobile interface across System Usability Score (SUS) score. SUS provides a quick reliable tool to measure usability and learnability. It consists of a standardized ten Item questionnaire with five response options (Measuring Usability, 2011). The usability score was tested only for the mobile system and not for the process schematic interface because it is more meaningful to get data on the current system design as the usability issue of the process schematic interface on mobile device was already identified as a challenge. They were also asked qualitative questions on the ease of use of the system. Many of the participants indicated that the mobile system was easy to use and was very intuitive. Figure 29, presents the mean score from novice users and experts. As indicated, the SUS score from novice users was much higher than the SUS score of the experts. This could be attributed to the fact that the experts were familiar with the process schematic interface and therefore they could have some initial bias on the ease of use of the mobile system. The parameter of “Net Promoter Score” indicates the value after which people are likely to recommend a system or product to a friend or colleague and any usability score above 68 is considered average (Measuring Usability, 2011). The net promoter score for this study was 82 and this indicates a wide user acceptability of the system. Although the novice users group recorded 86.1 in usability (surpassing the net promoter score), and the experts average score of 67.5 in usability. The scores were not statistically significant.
Figure 29: SUS Score for the mobile system – by experts and novice users
VI. RESEARCH IMPLICATIONS

Results indicate that the mobile system was easy to use and was effective for the operator to control the elements while maintaining situational awareness of the process information. This is indicated by the time taken for identification tasks and time taken for navigation tasks. This is a non-traditional method of assessing situational awareness. Based on the context of the user, this method of real-time probing technique was used since it is not realistic to assume that the operator would be able to recall from memory or that the system will become blank and the operator has to recall the variables from a different screen. The situational awareness aspect is related to the relative position of the screen or the user’s attention to the object that needs their attention. The focus is to understand how easily can they navigate to the problem area that may not be present on that particular screen and fix the problem area. Especially, in the mobile interface system this is important, as the user has to navigate through various screens to access information based on the limited real estate available on the mobile device.

The results were based on evaluation of user performance in fixing pump failures in three different scenarios. In real world process control operations they can be multiple failures, which need to be addressed by the operator simultaneously. NASA TLX scores can conclusively state that operating mobile system generates far less mental workload than Process Schematic Interface. With less mental workload, user can remember and recall
more information when performing operations, and having access to more information will enable operators to evaluate the environment and the situation more effectively, thus increasing the situational awareness of the operator.

One of the major limitations of this study is the oversimplification of the operator task to controlling one pump failure. This is not a typical workload of the operator. They have to manage multiple components to even control one component. Future study should focus on testing the aspects of access to multiple screens or components for pump failure.

As advances in mobile devices and secure communication of the devices are made, it should be easier to implement the mobile devices for field operation controls. There still needs to be further research on the form factor of the devices to understand the environmental factors and their effect on the adoption of the mobile devices. This research can be extended to integrate sensor information for device information and for intelligent information presentation based on location based services. This can help the display to be adaptive and provide information such that the operator can view the right content in the right way based on the context. This would reduce the cognitive workload and provide better situational awareness to the operator. This research can also be extended to the area of overview displays. Many of the petrochemical industry operator control is moving towards large overview displays where different operators can view the information instead of distributed control room operators. Hence overview displays are designed to provide the operator with a full span of control, require re-work in order to be useful in a mobile form factor.
APPENDIX A

A. NASA TLX Pre–Test Questionnaire

NASA-TLX Pair-wise Comparison Sheet (administered pre-test)

For each pair of demands, circle the demand that you feel will be a greater source of workload in the task you are about to complete. Please refer to the description sheet for each demand if needed.

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<th>Mental Demand</th>
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B. NASA TLX Post Test Questionnaire

**NASA Task Load Index**

Hart and Staveland’s NASA Task Load Index (TLX) method assesses workload on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

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<th>Very High</th>
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<td>How hurried or rushed was the pace of the task?</td>
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<td>Very High</td>
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<td>How hard did you have to work to accomplish your level of performance?</td>
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<td>Very High</td>
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<tr>
<td>Frustration</td>
<td>How insecure, discouraged, irritated, stressed, and annoyed were you?</td>
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<td>Very High</td>
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VII. Appendix B

A. SUS Usability Scale
VIII. Appendix C

A. Consent Form

Project Title: Intelligent Information Presentation on Mobile Devices

You are asked to participate in a research study being conducted by Raghavendra Rao Polakonda and Subhashini Ganapathy from the Biomedical, Industrial and Human Factors Department at Wright State University. Your participation in this study is entirely voluntary. Please read the information below and ask questions about anything you do not understand before deciding whether or not to participate.

The purpose of this study is to investigate whether COP Mobile can provide more accurate and timely access to the information needed by an operator to perform daily
operational tasks as compared to the traditional process control system (which in this study is the DeltaV System). We are also investigating if the mobile application will result in better decision making and improved operator safety and performance. The study will take approximately an hour to complete.

In the experiment, you will be introduced to the traditional DeltaV desktop display and the experimental mobile display and will be trained on how the controls work in each system. Once you are familiar with both the systems, you will be asked to fix a pump failure scenario on the traditional DeltaV desktop display and the mobile display. The following metrics will be collected by the traditional DeltaV desktop display and the mobile display through built in event logs -

1. Time Taken to address each pump failure
2. Total number of steps correctly executed and total number of events correctly addressed.

The results of these tests will be available to all organizations participating in the Centre for Operator Perfromance(COP), however any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.
You can choose whether or not to be in this study. If you volunteer to be in this study, you may withdraw at any time without negative consequences of any kind or loss of benefits to which you are otherwise entitled. You may also refuse to answer any questions you do not want to answer. There is no penalty if you withdraw from the study. There are no direct benefits or remuneration provided to you if you choose to participate in this study.

If you have any questions about this study, you can contact the principal investigator, Raghavendra Polakonda, at Polakonda.3@wright.edu, or Subhashini Ganapathy, at Subhashini.ganapathy@wright.edu, or at 937-775-5044. If you have any questions about your rights as a subject participating in research, you may contact the Wright State University Institutional Review Board at 937-775-4462.

Your signature below means that you have freely agreed to participate in this investigational study.

______________________________
Signature of Participant
IX. Appendix D

Statistical Analysis results for navigational tasks among Traditional and Mobile systems for Expert and Novice users

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Statistical Analysis results for Identification tasks among traditional and mobile system for expert and novice users.

Anova: Two-Factor With Replication

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Statistical analysis results for acknowledging alarms among traditional and mobile systems for expert and novice users

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Statistical analysis results for fixing pump failures among traditional and mobile systems for expert and novice users

### Anova: Two-Factor With Replication

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