TECHNICAL CONSTRAINTS TO CONDUCTING OPERATOR STUDIES IN A RECONFIGURABLE CONTROL ROOM SIMULATOR

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ABSTRACT

The Human Systems Simulation Laboratory (HSSL) at Idaho National Laboratory (INL) is a full scope, full scale, and reconfigurable digital representation of an analog nuclear power plant control room. The HSSL is used to conduct human factors research studies on digital technologies being introduced into legacy nuclear power plant control rooms. With the aging nuclear fleet approaching an average of 35 years, utilities are beginning to replace their analog systems with more modern technologies, and utilizing the HSSL to accomplish these tasks. This document will describe some of the constraints identified when conducting operator studies in the HSSL.

Key Words: Nuclear, Modernization, HSSL, Technology, INL

1 INTRODUCTION

The Department of Energy Light Water Reactor Sustainability (LWRS) program funds the Human Systems Simulation Laboratory (HSSL) at Idaho National Laboratory (INL) as well as the majority of the research activities conducted in the HSSL. One of the primary goals of the LWRS program is to sustain the current fleet of nuclear power plants (NPPs) in the U.S. for long-term operations in a safe, economical manner. The HSSL contributes to this effort by providing a digital replica of an analog NPP control room, which is representative of the aging fleet of .As the fleet continues to age, finding replacement parts is becoming increasingly difficult, and the need to upgrade to more modern technologies is becoming necessary. Because utilities in the U.S. need to continue to run due to economic purposes, they are unable to shut down for six months to replace the entire control room with a more modern one. There is also the issue of licensing and the time it takes to get the plant a renewal after the fact. The alternative effort that most are adopting is the piecemeal upgrade approach, where one or two components will be upgraded during scheduled outages that occur once every 18-24 months. This necessary down time is to refuel the reactors and conduct as much maintenance as possible in a very short amount of time.

Because the HSSL is a virtual representation of an analog main control room at a NPP, it makes for an ideal sandbox environment where vendors and utilities in collaboration with human factors researchers can validate and test new technologies in early stages of development without interrupting normal operations or training. To facilitate this process, vendors will often provide screenshots of their product, which allows for researchers at INL to recreate their product in a manner that allows it to communicate with the utility simulator.

This is beneficial to the nuclear industry because they are able to test new instrumentation, information, and control systems with human factors experts before they are implemented into their own control rooms. The simulator at the plant is primarily used for operator training, so it is easier on the engineers, operators, program managers, and researchers to conduct studies at INL's HSSL, where human factors researchers can validate the design concepts with the operators in real-world scenarios.

Researchers at INL use the HSSL to test and validate new technologies being introduced into these control rooms, enabling the current fleet to continue operating safely and efficiently [1]. Many utilities utilize the same hardware as the HSSL in their simulators, but not to the same scale (e.g., groups of one or two bays spread out throughout the facility). Technical engineers at INL were able to connect fifteen bays together to form one full scope, full scale environment. When a utility decides to collaborate with INL on a modernization project, one of the first steps is replicating their NPP control room in the HSSL.

The HSSL is a valuable tool for conducting research and development for NPP control room technologies. With its many components, there can be challenges and constraints to conducting operator studies. This document describes the technical constraints involved when conducting operator research studies in the HSSL, and how those constraints are mitigated.

1.1 Simulator Facility

The first step in conducting a workshop is setting up and configuring the plant-specific simulator. Typically, the introduction of a new simulator into the HSSL is the most time-consuming task, which involves various technical capabilities for smooth integration into the HSSL infrastructure.

Currently, the HSSL houses six different simulators .The simulators are provided by simulation vendors GSE, Western Services Corporation, and L-3 Mapps. Once the simulator software has been delivered, it is then installed onto a virtualized Microsoft Windows® instance and placed on a host server. This method is uncommon in industry, but it is a vital step for integration into the HSSL because it allows for rapid reconfiguration (e.g., more memory), nightly backups, and reduces corruption risk.

While reconfiguration of the virtualized instance is seldom, it may sometimes be necessary. For example, if during testing of a prototype, the simulator becomes bogged down or becomes unresponsive, it may be necessary to add more processing power to the virtual machine. This is more convenient than trying to find another physical machine to replace the current one.

Nightly backups provide peace of mind when there are many people doing development work on the simulator at once. Should one of the prototypes corrupt the simulator, reverting to a snapshot from the day before requires little time and effort.

In order to produce a more realistic environment for the operators, the HSSL is built as a full scope, full scale control room using near life-sized bays to display the simulator. There are fifteen total bays, each housing three, vertically stacked 47” monitors (Fig. 1). By physically representing the control room, research scientists can collect more accurate data, both qualitative and quantitative.

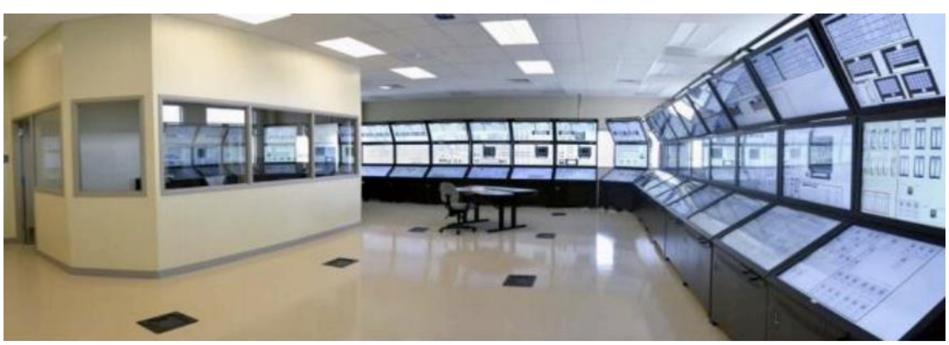

Figure 1. Human Systems Simulation Laboratory

The HSSL is a neutral location, meaning that there are often mixed technologies working in harmony. For example, the bays themselves are L3-Mapps, while the software they run can be from another vendor, such as GSE. This is because the base platform for the simulator is written to be run on Microsoft Windows. The bays each include a Dell desktop computer running Microsoft Windows, as well as a video card to support the three displays. The bays and other computers are all connected via Ethernet throughout the laboratory.

The HSSL uses a client-server model to run the simulators, meaning the bays are the clients being fed information from an instructor station (server). From the instructor station, the plant's initial condition is selected from a large list of possible conditions (e.g., turbine start-up, 100% power, and syncing to the grid). This is also the same machine that controls malfunctions and faults. For example, during an operator scenario, the instructor may insert a fault to where the turbine does not trip automatically as it should, and the operators have to manually trip the turbine instead. In operations training, exposure to this kind of scenario is prevalent and operators expect this kind of behavior. This keeps operators sharp and always aware of other possible faults in scenarios.

The networking architecture resides in its own room. This room consists of four Cisco switches that are needed to provide Ethernet to all of the bays, instructor stations, and other miscellaneous hardware. Because most client/server models operate and rely on TCP/IP connections, it is important that the networking infrastructure remains fully operational and does so reliably.

Ethernet ports are embedded into the floor in various places to support reconfiguration. The bays often need to be reconfigured to reflect the plant that it is representing (e.g., L-shaped and U-Shaped), and because nearly every NPP has its own, unique control room, this is an important step in physically representing each plant as close to reality as possible.

Physical reconfiguration requires at least two people due to the bays weighing over 700 lbs each; however, because they are perched atop wheels, moving them around requires fairly minimal effort.

1.2 Operator Studies

During operator studies, qualitative and quantitative data is gathered from operators involved in the research. Human error is a costly and common cause of accidents. The reason is humans are put at the head of all system operations in that they make the decisions, have the final say, or manipulate the system directly. Everything from driving a car to operating a nuclear power plant is analyzed by human factors researchers. Psychologists and human factors practitioners have found many reasons why humans may cause errors; increased or prolonged workload, lack of accurate and timely information, unclear information, lack of training (inversely system usability) among others are all factors considered when performing studies on NPP technologies in the HSSL. Measuring these performance qualities on the human side of a system indicate which design will most positively affect human performance.

Operator studies consist of operators, researchers, engineers, technicians, program managers, vendors, and support staff. Typically, studies are run for one week increments, with one set of personnel one week followed by another the next. Operators are usually available for weeklong stints before they have to go back to their plant, which is beneficial to researchers because it allows for data to be collected from rotating crews, ensuring that they stay long enough to become familiar with the HSSL. This also ensures that researchers and operators have enough time to run through multiple control room scenarios.

Before any human-machine interface (HMI) studies are conducted, researchers and engineers are provided "screen-by-screen" examples of a vendor product. For example, a vendor may want to implement a new Turbine Control System into an operating plant. The Turbine Control System is then mimicked using Microsoft Visio® where technicians and engineers can begin interfacing it with the simulator. This is made possible by the simulator vendors providing an Application Program Interface (API) that allows for third party products or programs to interface with the simulator platform. This ensures that the mimic operates identically to the vendor product in the actual control room (e.g., controlling turbine speed, opening or closing governor valves).

Once complete, the operators are then put through several real-world scenarios (e.g., steam generator tube rupture, turbine manipulation, and chemical volume control tank scenarios). While their performance is measured to a degree, the researchers are more concerned with the HMI design of the vendor product. Therefore, a screen-by-screen evaluation is conducted with the operators to determine what was distracting, or not in the right place, and that input is then analyzed and the vendor is presented with a report detailing these types of findings.

2 CONSTRAINTS TO OPERATOR STUDIES

Workshops bring together many different groups, typically filling the HSSL with twenty or more people. Researchers and support staff need to be prepared to address and to adapt to a wide variety of surprises and challenges including, power outages, hard drive failures, heating or air conditioning issues, display issues, networking issues, and program crashes. While these are less than ideal when conducting an operator study, for the most part they have only caused minimal downtime and recovery was possible within minutes. It is important to foresee any conditions that might obstruct the workshop and have a plan in place.

2.1 Simulator Constraints

The HSSL currently houses six different plant models. Implementing the individual plants can require considerable time and effort, because the simulator models were not designed to run on a fifteen-bay configuration out-of-the-box. Technical staff needs to figure out how many bays are required for each panel, as well as determine which panels will be necessary for the operator study based on the specific scenarios that will be used. For example, if the panel needed for the study is the far left-most panel in the control room and is labeled "Panel A," and takes up 5' of lateral space, it will probably take up two bays in the HSSL. The next step would be to carve half of Panel A from the world view, create a new panel, and paste individual parts so that they match as close to the actual plant as possible. This often means that scaling becomes an issue, because while ideally 100% scale would be best, it does not always fit on the bays that way. The panels are scaled down so that they fit properly, but are also legible. Typically, this number is between 60-70% scale of the actual simulator.

2.2 Time Constraints

Time constraint is one of the most common constraints to be experienced before the operator study takes place. There is a fairly time consuming legal process needed to allow INL access to a utility's simulator model, hence, time quickly becomes a factor. In many cases, most of the needed paperwork is completed only a couple of weeks before a workshop, which can add quite a bit of stress to the technical staff preparing for the study. Ideally, getting the simulator a month or two beforehand can ease a lot of this as it provides ample time to implement the simulator into the HSSL.

2.3 Eye Tracking Technology Constraints

One technology researchers use to obtain quantitative measures is eye tracking. Researchers use eye tracking to determine if the operator distracted by something that has been poorly designed, as well as using fixations, saccades, and pupillometry to measure attention and workload and serval other psychological constructs [1]. The researcher using mobile eye tracking glasses (ETGs) which in and of itself can be quite a complicated process to set up; however, coupled with operators and a physically represented NPP control room, it can sometimes be daunting due to the complex nature and sometimes rapid pace of scenarios (e.g., the longer the scenario, the more opportunity for a connection to come loose, battery to die, button accidentally getting pressed). Operator scenarios can last for hours, so preparing the

ETGs to stay operational and fully charged is one key step. Another is ensuring that the three plugs going into the glasses, the battery pack, and the eye tracker hardware (Android phones running proprietary software) do not come loose in the slightest as the operators are ping-ponging around the boards. Being very gentle with the ETGs mostly mitigates this and packing them in a manner that will minimize the chances of them coming loose. The other issue is the battery life of the ETG system. It is imperative that all spare batteries and devices be charged in and ready the night before a workshop.

Other issues that can impede eye tracking are things like lighting, astigmatism, or people who wear glasses. Lighting can sometimes interfere with the infrared cameras on the ETGs, and astigmatisms can make it difficult for the ETGs to get a good reading off of the fovea. Although the eye tracking system used at INL states that it works with glasses, data collected reflects otherwise a lot of the time.

2.4 Networking Constraints

The networking of the HSSL needs to be fully functional and without interruption for the simulator to behave as expected. Because the HSSL is separated from the corporate network and is on its own, independent network, implementation of independent safeguards such as intrusion detection and prevention are the responsibility of technical staff. The HSSL houses information that needs to remain confidential, so several protective measures and a strong security posture have been implemented. To accomplish this, software and hardware is used to protect and defend against outside threats to protect these assets. A common theme among these technologies are false positives – meaning that although something might look nefarious, it is not, and the software automatically blocks the TCP/IP communication from happening. The simulators rely on this type of communication, so active policing of the network traffic and unblocking what would simply be the server communicating with the clients is sometimes necessary. Often times, temporarily disabling the intrusion detection technologies and isolating the network is easier and less time consuming during workshops.

In lieu of a raised floor to facilitate network needs, Ethernet ports reside in flush-mounted floor compartments, which also provide power as needed [3]. This allows for the physical reconfiguration to be possible, and creates ample opportunity to facilitate different plant shapes. While this does allow for multiple network locations, the ports themselves are not pre-patched. This is due to the limited network ports available on the switches in the server room. In the future, additional switches will be added to mitigate this. This means that every time a bay is moved, the old patch has to be moved to the new jack location in the server room. Plans are in place to acquire more equipment to accommodate this dilemma and move towards a fully pre-patched network infrastructure.

2.5 Development Constraints

In order to keep development work (e.g., prototype turbine control system) separate from the production environment, another network is segmented into the mix. This network is yet another isolated network from the outside and inside world for property protection, and is used solely for testing purposes. While it is just a test bed, it still utilizes the same backup and recovery solutions as the other networks in the HSSL. This segment of the network is to ensure that new technologies will not disrupt the simulator's behavior and is essential because it allows for developers to test their code without any implications to the production simulator. Should the code somehow interfere with the simulator behavior, a restore point is loaded to a point before the code was introduced, and the debugging begins.

The development network is also used during operator studies for quick changes made to HMIs. For example, if the consensus of the operators is that a button is too small or in an area that is not desired, developers can make quick changes to the HMI, test it, and then push it to production with little-to-no downtime to the operators or the study.

2.6 Data Collection

One key feature of all simulator models deployed in the HSSL is the ability to log and trend events. From the instructor station, researchers are able to collect actual plant variables after each scenario. These variables give researchers exact plant statuses including current plant power, megawatt output, valve positions, and various tank levels. It also provides operator events, such as when a valve was opened or closed, or when a level was adjusted. This provides researchers with the details needed to determine if the scenario was a success, as well as key information about whether or not the plant should have been in the state it was in at any given time. While operator performance is not necessarily measured itself, these details can provide further insight as to whether the design of the new HMI improved the operator's ability to conduct these scenarios as effectively as the legacy equipment.

In addition to the eye tracking data, the simulator logs, and observation, audio and visual data is collected from several cameras scattered throughout the HSSL, as well as lapel microphones attached to the operators. These videos have assisted researchers who may have a question about what was found in a simulator log during a scenario. For example, if a valve was supposed to be closed in a certain procedure, and the simulator log shows that it was not, it is fairly easy to determine if the operator overlooked the step, was unable to do so using the HMI, or attempted to but the simulator did not respond. This could determine if the component was not clearly visible using the HMI, or if it was a fault with the HMI or simulator.

Synching all of the data together is a time consuming, manual process. Because these methods are all collected separately, there is no one technology to bring it all together. Researchers at INL have taken a time-stamp everything approach, which applies to nearly everything during an operator scenario. Notes, malfunctions, audio/video start and stop times, scenario events, and everything else involved requires a time stamp to coordinate all the data together. This is especially helpful for hour-long scenarios and needing to go back to retrieve a piece of information from a given event.

2.7 Introducing New Technologies

As new technologies become available to NPPs, workshops provide a great opportunity to showcase them in the HSSL, giving operators first-hand experience. The HSSL is furnished with advanced overview displays, advanced alarm systems, computer based procedure systems, and future thinking technologies like advanced diagnostic tools. Implementing each item provides its own unique challenges; however, because the base operating system is Microsoft Windows®, the challenge is usually minimal. Historically, simulators were originally run on Unix or Linux systems before Windows became the platform of choice sometime in the mid 1990s. Having a single Windows operating system as a base has proven to be very helpful for the simulator side of things; Linux and other operating systems are implemented to handle backbone infrastructure (e.g., firewalls and name servers).

If the installation of a new technology requires proprietary steps or requires vendor visits, the HSSL accommodates for in-house installations that are completed by the vendors providing the technology. This is also helpful if further development is needed before it can be incorporated to the HSSL's environment.

3 CONCLUSIONS

Operator studies can be a complex undertaking. Adapting each simulator to the HSSL is not a simple task; having a team assist in implementation is extremely helpful and time saving. Writing down the steps taken to construct the simulator and represent it on the bays is crucial as the process, while somewhat simple, is easy to forget if it is not done frequently.

All technologies used in operator studies should often be tested to make sure it is in proper working order. Going into a study with broken or misconfigured equipment can waste precious time with NPP operators. This testing should be done on all equipment involved: simulators, network equipment, clients, data collection devices, personal computers and tablets, and even surge protectors and power outlets. This not only keeps equipment healthy and up-to-date, but it will save on unexpected down time down the road.

When conducting operator studies in the HSSL, preparedness is paramount. Further, it is important to always have a backup plan should something go awry. For researchers and technical staff at INL, having a detailed approach to address all challenges in workshops and studies is vital to a successful study. Through teamwork and strong communication within the department, INL staff has conducted several successful studies in the HSSL. These efforts and the results continue to be valuable to the utilities that have partnered with INL for control room modernization.

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