

## Human Factors Evaluation of an Interventional Trauma Operating Room Mock-up

Susan Biesbroek, M.Sc., Jonas Shultz, M.Sc.  
Human Factors Safety Specialists  
Alberta Health Services  
Calgary, AB, Canada

Dr. Andrew Kirkpatrick, CD, MD, MHSc, FRCSC, FACS,  
Dr. John Kortbeek, MD, FRCSC, FACS  
Alberta Health Services  
Calgary, AB, Canada

A state-of-the-art Interventional Trauma Operating Room (ITOR) combining the techniques of traditional surgery and interventional radiological procedures was designed to address major hemorrhage in the operating room. A Human Factors evaluation using video capture and patient simulation was conducted within a full scale mock-up environment to examine staff workflow and team integration to maximize the multi-user potential of the physical space and identify issues or barriers that would impact patient care during procedures. Recommended changes based on the evaluation included increasing the available space in the ITOR, re-organizing equipment to maximize workflow and relocating patient monitors for maximal visibility.

### INTRODUCTION

Traumatic injury is Canada's leading public health problem, constituting the leading cause of death between the ages of 15 to 44 in the developed world and is currently responsible for 16% of the world's burden of disease (Krug, Sharma, & Lozano, 2000; Anderson, & Smith, 2005; Hameed, et al. 2010). Until the later part of the previous century, direct surgical exploration was considered the mainstay of therapy for essentially all serious injuries. Traditional approaches to such life-threatening bleeding involved operative exploration exposing large areas of body cavities to identify the bleeding site. However, the use of less invasive transcatheter therapeutic techniques, known as interventional radiology, have become increasingly valuable to diagnose and treat vascular injuries throughout the body either to minimize the operative side effects or to access bleeding that is inaccessible surgically (Scalea & Sclafani, 2001; Zealley & Chakraverty, 2010).

Unfortunately, in a typical hospital the trauma operating room (OR) and angiography procedure suites are physically separate. When an unstable trauma patient presents in the emergency department, quick decisions must be made to use traditional surgical techniques or interventional radiology procedures to identify and stop the bleeding and often unstable patients are transferred between the two areas for treatment. To mitigate potential risks some institutions have upgraded and equipped their interventional radiology suites to function

as active resuscitation areas (Pryor, et al., 2005), and others have used mobile angiography technology in the Emergency department to stabilize patients in a rapid trauma situation (Morozumi, et al., 2009; Morozumi, et al., 2010). Neither situation is ideal when treating critically injured patients. The design team felt a better solution was to create a "hybrid" OR by including high-quality multi-purpose angiography equipment within a trauma OR. This would allow for a wide range of image-guided endovascular and interventional radiology procedures, on-table diagnostics and quality assessments, or formal open surgery as required, expediting patient care (ten Cate et al., 2004).

To date, the majority of research in Human Factors in the OR have focused mainly on training surgical and teamwork skills (e.g., Aggarwal, Undre, Moorthy, Vincent, & Darzi, 2004; Hurlbert & Garrett, 2009; Gaba, 2004) rather than physical space design for maximum safety and efficiency. The traditional OR had been described as an "ergonomic nightmare" given the abundance of cables, gas lines, equipment and lights in the room (Helmreich & Davies, 1996; Davies, 1994) contributing to injuries and making it difficult to move equipment around. To mitigate these difficulties and hazards the new revolution in equipment organization is to introduce ceiling mounted equipment carriers that would allow flexibility in equipment placement, ease movement issues, and reduce the "spaghetti" (i.e. tubing and cables) entanglement and tripping hazards on the floor. However, some considerations need to be

addressed when including ceiling mounted equipment in hospital spaces, especially with multiple boom arms being installed within a single space. It is essential to maintain a full range of motion with each boom arm to maximize the flexibility and mobility of equipment within the space without conflict (i.e. hitting other booms, hitting the wall, etc). As well staff must be able to easily position and access equipment where it is required within the room with little impact on the patient.

Therefore, the primary goals of this evaluation were to determine how the design of the physical space impacts staff workflow, access to equipment and the patient, to understand the integration of the teams during hybrid scenarios, and to identify any issues or barriers that would impact patient care in the ITOR space. Previous Human Factors projects have successfully tested mock-up evaluations in other clinical areas including intensive care unit patient rooms, emergency and outpatient exam rooms, supportive living resident suites, and acute care patient rooms (Chisholm et al., 2008; Shultz & Chisholm, 2010; Caird, Shultz, Mayer, Chisholm, & Teteris, 2010). Patient simulation is ideal in creating and maintaining realism in simulated environments and has been a valuable tool in usability evaluations of medical equipment (Lamsdale, Chisholm, Gagnon, Davies, & Caird, 2005).

## METHODS

To ensure that this revolutionary design would meet the needs of the end users and provide adequate space for all equipment and personnel who would be required to function within the space, a full-scale mock-up was built within the shelled ITOR space (Figure 1) and Human Factors specialists were enlisted to evaluate the proposed design using patient simulation and scenario enactment. Both real and mocked-up surgical equipment (case carts, supplies, tools, surgical lights and tables), medical equipment (infusion pumps, cell savers, anesthetic machines, etc), ceiling mounted angiography, and patient monitoring equipment were installed in the mock-up environment as per the design specifications. Three clinical scenarios were developed with the assistance of frontline surgical staff to encompass a number of different patient situations (trauma patient with abdominal bleed, cardiac arrest during an angiography procedure, and a head injury) and equipment requirements. All scenarios included a brief patient description, relevant personnel and equipment required, and interventions that needed to be carried out. These scenarios were then used to direct more than 30 frontline staff (surgeons, anesthesiologists, nurses, and

interventional radiology staff, etc) on the simulation day. Each scenario took between 30 and 60 minutes to complete. A low fidelity patient simulator mannequin was used during the evaluation to increase the realism of the situation and maintain appropriate staff interactions with the patient. All equipment such as infusion pump tubing and airway circuits were connected to the patient simulator introducing the appropriate limitations and risks when moving around the operating table and adjusting the patient's or equipment positions.

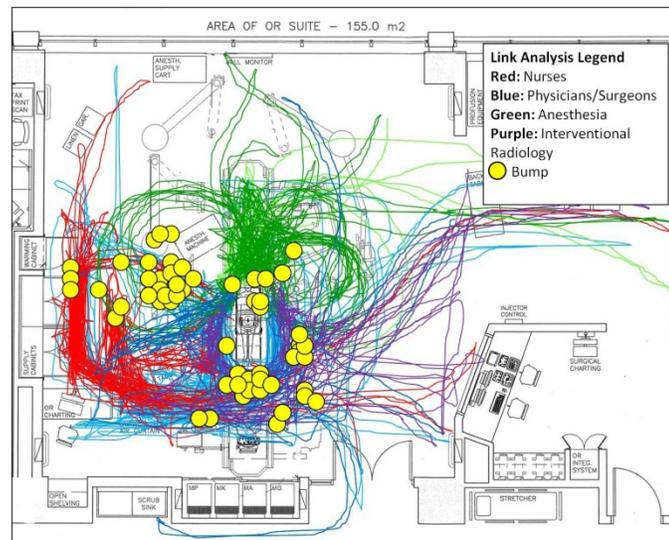


**Figure 1.** The ITOR suite mock-up with surgical equipment, angiography c-arm and frontline healthcare personnel

Eight digital video cameras positioned throughout the space captured all staff interactions and verbalizations during the scenario enactments. During each scenario participants were instructed to use think aloud protocol (Ericsson & Simon, 1993) whereby they verbalized all interactions or difficulties encountered. These verbalizations were captured on the video recordings and analyzed further. At the conclusion of each scenario focus group discussion sessions were performed with all of the participants in that scenario to gather additional feedback and generate suggestions for design changes.

Video analysis techniques involved reviewing each scenario from the eight vantage points, tagging and categorizing staff interactions, movements, difficulties, collisions and verbalizations into a data analysis spreadsheet which was used to highlight recurring issues. Approximately 32 hours of video were reviewed by two Human Factors specialists. Participant movement throughout the space were tracked using link analysis (Stanton, Salmon, Walker, Baber, & Jenkins, 2005; Wickens, Gordon & Liu, 1998) and superimposed onto a schematic of the ITOR to visualize staff workflow, congestion, and overall space usage (Figure 2). Bumps (collisions) between staff members and/or equipment

were also tracked during the scenarios and included in the overall link analysis results to determine where in the physical space potential contamination risks or equipment damage might occur.



**Figure 2.** Link analysis of participant movements

## RESULTS

The simulation scenarios focused on the operative, diagnostic imaging and hybrid tasks that were expected to occur within the ITOR. The primary goal with performing these scenarios was to determine if the proposed space was sufficient to accommodate staff workflow and team integration to maximize the multi-user potential of the physical space and identify issues or barriers that would impact patient care. A number of issues regarding physical space, equipment access, inefficiencies in staff workflow, and patient monitoring visibility were identified during the video analysis and will be discussed below. In total, 56 recommendations were identified during this evaluation and presented to the design committee. Only three requested recommendations were rejected due to equipment functionality or flexibility, 29 were deemed to be feasible and adjusted in the final design of the ITOR. Another 24 were determined to require additional follow-up with equipment vendors or manufacturers, or should be further tested before making a final decision.

### Physical Space Issues

The link analysis (Figure 2) was a very valuable analysis tool to highlight workflow patterns and issues in the physical space. From this analysis we were able to determine that there is not enough physical space within the nursing area as illustrated by the red links on the left side of the room along with the clustering of bumps in

this space to accommodate all of the equipment required. Difficulties were observed in accessing the surgical equipment, case carts and other supplies without increasing contamination risk for the surgical tools.

### Equipment Access and Workflow Inefficiencies

Supply and warming cabinets were installed along the left side of the room, impacting the efficiency of workflow for nursing staff and increased congestion around the surgical supplies. Nurses were forced to walk back and forth repeatedly from the foot of the operating table to the supply cabinets and case carts to gather the needed surgical supplies throughout the case. The surgical tables and case carts restricted access to the supply and warming cabinets and made it difficult to maintain the sterile field when gathering supplies. This was further exacerbated when the surgical tables and case carts were moved closer to the operating table during the surgical procedures as highlighted by the numerous bumps with surgical equipment during the scenarios. The link analysis highlighted a natural path for nurses to exit the surgical area at the foot of the operating table, a route that was less congested than the current layout. By relocating the surgical supply and warming cabinets to the wall at the foot of the operating table it would improve access to the cabinets, reduce the amount of traffic on the left side of the room and reduce contamination risk during surgical procedures. Another benefit to relocating these cabinets was that it opened up the wall space to increase the width of the ITOR and with permission from the design committee we were also able to incorporate adjacent OR office space into the ITOR footprint and increase the physical size of the room itself to alleviate space issues in the nursing area.

Ceiling mounted boom arms to hold patient monitors, surgical lights, and equipment carriers (cauterizing equipment, suction canisters and a variety of other tools required during surgery) were installed into the ITOR space. These boom arms are designed to reduce the “ergonomic nightmare” issue of traditional OR spaces by reducing the abundance of cables and gas lines running across the floors. The arms also group equipment for quick adjustments and access to a number of pieces of equipment rapidly. While these boom arms are beneficial in reducing the clutter within the space, they do compete for ceiling space with the angiography c-arm equipment and required additional considerations to reduce flexibility issues. For example, tubing and cable length of the equipment mounted on these boom arms dictates their flexibility and forced the boom arms to be positioned in close proximity to the patient. When bringing in the angiography c-arm equipment this caused

some difficulties as the equipment carriers were not able to be pushed out of the way and increased the risk of tubing being pulled and becoming disconnected from the patient. Longer tubing was recommended for the majority of equipment that is connected to the patient to maximize the flexibility of these boom arms.

Because the equipment carriers were placed close to the patient it also impacted access to both the equipment and patient, creating inefficiencies in workflow and increasing contamination risks. The anesthesia team was forced to circle around the equipment carrier boom arms to start IV's and administer fluids to the patient. Unfortunately, in some cases this resulted in the contamination of the sterile field around the surgical tables as they brushed past the equipment (Figure 2, bumps). Increasing the length of tubing will allow the equipment carriers to be positioned further away from the patient, opening up space around the operating table, improving patient access and reducing the contamination risk.

### **Patient Monitoring**

Maintaining adequate patient monitoring is essential during surgical procedures. Multiple monitors were installed throughout the ITOR space to ensure that proper patient monitoring could be maintained throughout a procedure. However, with the abundance of staff in the ITOR requiring visual access to monitors, a number of issues arose. The majority of patient monitors were mounted on the boom arms where in theory it should allow for flexible placement to optimize visibility. Unfortunately, due to tubing length the equipment carrier arms were placed in close proximity to the patient and reduced the available space for the monitor arms around the operating table. This reduced the visibility, flexibility and use of the monitors in the ITOR. Participants were not able to properly position the monitors where desired. Furthermore, the mocked-up monitors were positioned too low for optimal visibility and did not allow for adequate clearance when moving around the room resulting in a number of head bumps during the scenario enactments. Rather than use these monitors they tended to be pushed out of the way during the scenarios. Increasing the height of the monitors was recommended to improve visibility and reduce the risk of injury.

A second large monitor was included in the ITOR for additional monitoring. This was located along the back wall behind the anesthesia equipment. While positioned high enough for visibility, its placement forced the staff at the head of the patient to turn

completely away from the patient and procedure in order to view the monitor. During debriefing sessions staff felt that the monitor was too far away from the surgical area and would not be useful during procedures.

Recommendations to relocate the monitor closer to the operating table to maximize visibility and ensure it was within their line of site around the operating table would allow for quick glances at the monitor without losing sight of the patient. An additional monitor was placed closer to the operating table above the control room window in the final design plans to accommodate this requirement.

### **CONCLUSIONS**

Patient simulation historically has been used for staff training where through training scenarios staff are able to practice basic skills, invasive procedures, and teamwork training without risk to patients (Croskerry, Cosby, Schenkel, & Wears, 2009; Good, 2003). It can be an effective tool to create realism and provide feedback to staff during these educational training scenarios. However, patient simulation is also essential to evaluate physical design through the enactment of intentionally developed clinical scenarios within a mock-up as part of the design process. Patient simulation in mock-up environments have previously proven to be beneficial in a number of different healthcare areas including ICU and acute care patient rooms, emergency department exam rooms, and outpatient exam rooms (Caird, et al., 2010; Chisholm et al., 2008). By including the patient in the scenarios frontline staff focus on the patient and are not as self conscious during the scenario enactments. The use of standardized patients (actors) has assisted in testing out guidelines for resident suite design in assist living environments (Shultz & Chisholm, 2010) and is particularly useful to gather patient centered feedback as part of the evaluation. High or low fidelity patient simulators are particularly useful when simulating more invasive procedures.

There is a variation in the degree of completeness or fidelity of mock-up environments ranging from high fidelity or fully complete with real and fully functioning vendor installed equipment (Chisholm et al., 2008) to low fidelity built to scale wooden mock-ups of equipment. The added benefits of evaluating a higher fidelity environment is that usability issues with specific equipment design can also be evaluated at the same time and recommendations for user friendly equipment can be made. The trade off is that lower fidelity mock-ups can often occur earlier within the design process when greater changes are still possible. During this evaluation many of the physical

aspects of the space including OR lights, the angiography c-arm, and equipment carriers were mocked-up to scale out of plywood, but was capable of moving in the same way as the real equipment would. This reduced the cost of the mock-up, but still allowed for evaluation of their physical footprint, movements and how staff would interact with them. Even with the low fidelity physical design, this evaluation was worthwhile and beneficial. If this evaluation had not been performed the final outcome would have been a space that did not function efficiently for staff, one that forced them to adjust their workflow to conform to the environment rather than have a space that was designed with their workflow in mind. By allowing the staff an opportunity to provide feedback and be engaged in the development of their work environments, we were also able to improve buy-in and reduce anxiety surrounding the use of the ITOR.

Regardless of the technologies or fidelity of the environments used during the evaluations, these evaluations have the added benefit of allowing the staff an opportunity to provide feedback and be engaged in the development of their work environments, which can improve buy-in and reduce anxiety. Frontline staff are the expert users of their environments, they live and breathe in it and know what works for them and what doesn't. By engaging them in these endeavors we can enhance patient safety and staff efficiency.

Similar to prototyping, mock-up environments are essential tools in evaluating new environments and determining design requirements and flaws prior to building the actual space. Unexpected design issues can arise and be adjusted easily early on in the design phase rather than later where changes are costly and may not be possible. The average person would never buy a car without driving it first, but we will often design buildings without ever stepping foot in them and consequently may result in an environment that does not function optimally. By mocking-up the proposed design we were able to "test drive" the ITOR before making any final decisions, giving the staff the ability to kick the metaphorical tires.

When designing healthcare environments it is important to ensure that the best possible design is used. Specifically, that it meets the current user needs and is flexible enough to grow and adapt as new technologies are introduced. The life span of healthcare spaces is decades, so perfecting the design prior to building it is essential and will save frustration and money in the long term. While on paper the space looked adequate, when all of the personnel and equipment were added it quickly

became apparent that there were significant adjustments that needed to be made if the ITOR was going to work as needed. The design team was open to suggestions and took feedback and recommendations into account when finalizing the design plans. Having open discussions with both the frontline staff as well as the evaluation team allowed them to implement evidence based design changes into the ITOR space. In healthcare environment evaluations it is rare to be able to increase the physical dimensions of spaces, however through this endeavor we were able to increase the size of the ITOR space to accommodate staff and equipment and have decreased contamination risk for the patient. While there are upfront costs associated with building the mock-up spaces, evaluation costs and staff time, the benefits and cost savings in the long term far outweigh the initial expenditure.

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