

Simulation-Based Mock-Up Evaluation of a Universal Operating Room

Jonas Shultz, MSc EDAC

Health Quality Council of Alberta and University of Calgary

David Borkenhagen, MPlan BSc

University of Calgary

Emily Rose, MHSc MPH BAsC, Brendan Gribbons, EIT MEng, Hannah Rusak-Gillrie, BEng,

Shelly Fleck, MBA, Allison Muniak, MAsC BSc, and John Filer, RN

Vancouver Coastal Health

**Accepted for publications:** Shultz J, Borkenhagen D, Rose E, Gribbons B, Rusak-Gillrie H, Fleck S, Muniak A, Filer J. Simulation-based mock-up evaluation of a universal operating room, Health Environments Research & Design Journal (OnlineFirst) pp. 1-13. Copyright © 2019 (SAGE Publishing). DOI: 10.1177/1937586719855777.

### **Corresponding Author**

Jonas Shultz, MSc EDAC

Health Quality Council of Alberta, 210, 811 - 14 Street NW, Calgary, AB T2N 2A4

Phone:403.355.4440

Email: [Jonas.shultz@hqca.ca](mailto:Jonas.shultz@hqca.ca)

### **Funding**

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### **Declaration of Conflicting Interests**

The Authors declare that there is no conflict of interest.

## **Simulation-Based Mock-up Evaluation of a Universal Operating Room**

### **Abstract**

Designing or renovating a physical environment for healthcare is a complex process, and is critical for both the staff and the patients who rely on the environment to support and facilitate patient care. Conducting a simulation-based mock-up evaluation as part of the design process can enhance patient safety, staff efficiency, as well as user experience, and can yield financial returns. A large urban tertiary care center located in Vancouver, Canada followed a framework (Health Quality Council of Alberta, 2016) to evaluate the proposed design template for 28 universal operating rooms (OR) included within the OR Renewal Project scope. Simulation scenarios were enacted by nursing staff, surgeons, anesthesiologists, residents, radiology techs, and anesthesia assistants. Video and debriefing data were used to conduct link analyses, as well as analyses of observed behaviors including congestions and bumps to generate recommendations for evidence-based design changes that were presented to the project team. Recommendations incorporated into the design included relocating doors, booms, equipment and supplies, as well as reconfigurations to workstations. These recommendations were also incorporated into the mock-up and re-tested to iteratively develop and evaluate the design. Findings suggest that incorporating the recommended design changes resulted in better room utilization, decreased congestion and enhanced access to equipment.

*Keywords:* Mock-up evaluation, patient simulation, healthcare facility design, universal operating room, human factors

Designing operating rooms (ORs), which have been described as the “heart” of any major surgical hospital, requires paying specific attention to key outcomes, such as user safety, convenience of use, and efficiency as part of the design process (Harsoor & Bhaskar, 2007; Joseph, Bayramzadeh, Zamani, & Rostenberg, 2017). Designers need to address the “ergonomic nightmare” present in ORs and manage, for example, the abundance of cables, gas lines, and equipment to maintain patient access (Davies, 1994; Helmreich & Davies, 1996). Doing so, however, is difficult given the lack of evidence available regarding the optimal layout of an OR (Traversari, Goedhart, & Schraagen, 2013). Furthermore, understanding built environment factors alone is not sufficient to design an OR. Joseph and colleagues (2017) highlighted that an understanding of team member roles, tasks they perform, and how equipment and technology will be integrated is also required. **Simulation-based mock-up evaluations of OR spaces have been shown to minimize congestions and bumps through design modifications, potentially mitigating sources of contamination, infection, and equipment damage** (Biesbroek, Shultz, Kirkpatrick & Kortbeek, 2012; Kirkpatrick et al. 2014). It is not surprising, then, that clinical stakeholders are becoming increasingly involved in the design process to proactively identify latent conditions in the built environment that could have an adverse impact on efficiency and patient outcomes.

The Vancouver General Hospital, a large urban tertiary care center located in western Canada is following an initiative set forth by the Ministry of Health to improve the overall quality of patient care through the development and improvement of a sustainable health system (Ministry of Health, 2014). The OR Renewal Project, which aimed to refresh an aging perioperative footprint and optimize the current volume of surgical cases completed at this hospital, will establish a sustainable surgical delivery model, with the ability to accommodate the projected

expansion of both population and operational growth. Specifically, this involved renovating and expanding OR suites to include 28 universal ORs plus two hybrid ORs over three phases. Prior to the OR Renewal Project, the existing 21 ORs ranged in size from 300 square feet to 650 square feet and were of irregular shape. After the OR Renewal Project, the 28 universal OR's will be 650 square feet and square in shape.

The universal ORs are designed to accommodate an inclusive spectrum of procedural cases, based on the criterion "any case, any room." Given the diverse set of surgical procedures this would need to support, the project team made it a primary focus to embed the expertise of Human Factors Specialists in the design process to iteratively evaluate, verify and validate the universal OR design.

### **Simulation-Based Mock-Up Evaluation**

The Health Quality Council of Alberta's (2016) *Simulation-based Mock-up Evaluation* framework outlines an approach to developing recommendations centered on enhancing patient safety, staff efficiency and user experience. Specifically, the framework lists six guiding principles that cover planning, conducting, and analyzing evidence-based data from a mock-up evaluation (see Table 1).

The framework has been promoted through the Facilities Guidelines Institute (FGI, 2018) website as an FGI-supported resource to guideline users. It was also recently incorporated into the National Standards of Canada regarding the planning, design, and construction requirements for Canadian Health Care Facilities (Canadian Standards Association, 2018) as well as provincial standards in Alberta (Alberta Infrastructure, 2018). The framework has been used internationally for the design and evaluation of ORs (Joseph, Wingler, Allison, 2016; Bayramzadeh, Joseph,

Allison, Shultz, & Abernathy, 2018), and leverages lessons learned from prior simulation-based mock-up evaluations of hybrid operating theaters (Biesbroek et al., 2012; Kirkpatrick et al., 2014), ICU patient rooms (Chisholm et al., 2008), and assisted-living resident suites (Shultz & Chisholm, 2010).

*Table 1.* Guiding principles from the Health Quality Council of Alberta's (2016) Simulation-based Mock-up Evaluation framework (p. 4-5).

- 
1. A simulation-based mock-up evaluation should be considered, and if applicable, planned, as part of the pre-design stage for inclusion in the design stage.
  2. The mock-up evaluation should be thoroughly planned to maximize effectiveness.
  3. Building of the mock-up should align with evaluation timing and objectives.
  4. Roles and responsibilities for those involved in the evaluation should be clearly defined.
  5. The simulation scenarios that are created and enacted should test the evaluation objectives.
  6. Recommendations should be informed by evidence based data from scenario enactments.
- 

## Methods

The OR Renewal Project team engaged a Human Factors team, some internal to the local health system and some contracted from other organizations, to evaluate the planned design of the universal ORs. The evaluation methodology used followed the six guiding principles outlined in the *Simulation-Based Mock-Up Evaluation Framework* (Health Quality Council of Alberta, 2016). This section details the steps taken by the OR Renewal Project team in collaboration with Human Factors team to conduct the mock-up evaluations.

Planning for the mock-up evaluation was considered and initiated early in the pre-design stage. The business case for the OR Renewal Project allocated both time and budget resources sufficient to incorporate the evaluation into the design process. This was later included into the detailed design documents that specifically stated the costs involved - constructing a detailed mock-up and conducting simulation-based evaluations. The project schedule committed 22 months for the completion of design development and contract documents, which included three to six months for mock-up evaluations.

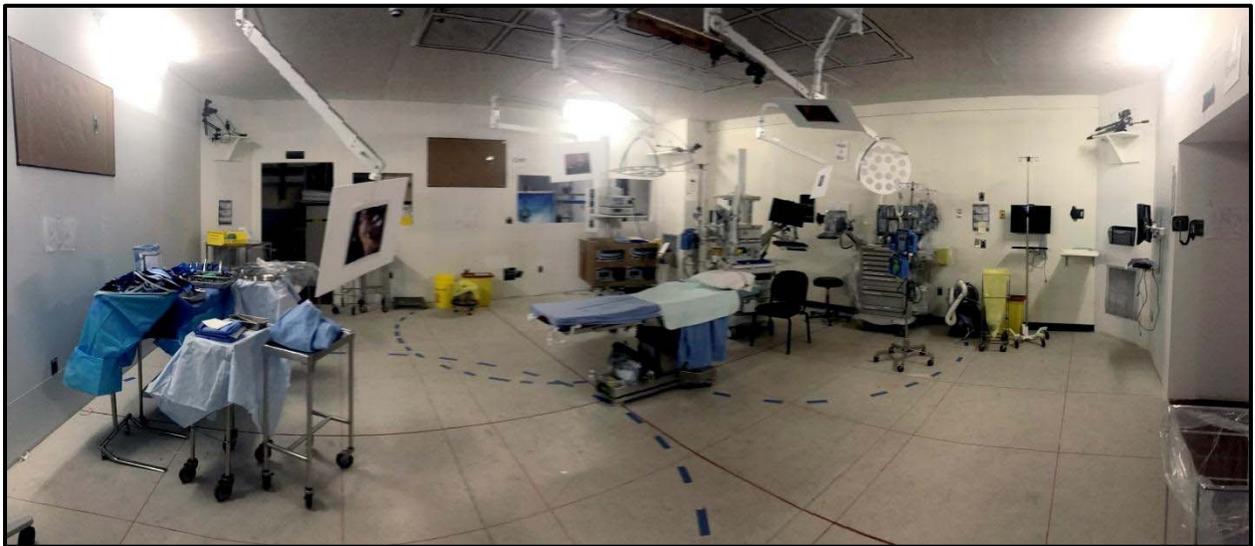
The project scope involved assessing the mock-up and providing recommendations to inform design decisions based on the evaluation of workflows, space requirements during set-up and the surgical procedure, access requirements, room configuration and visibility of the patient and monitors. Access requirements included clinicians' ability to access the patient, booms, equipment, and supplies as needed. Room configuration focused on the placement of doors, booms, equipment, supplies, data and electrical ports, as well as light switches.

A full-scale detailed mock-up was constructed (Figure 1) after schematic design with sufficient time to allow resulting recommendations to be incorporated prior to sign-off on the design and room data sheet. The mock-up included steel framed and drywall-constructed walls and ceiling. To evaluate accessibility of wall mounted items such as power outlets, code calls and sterile gloves, correctly proportioned images were fixed on the wall in their planned locations with the opportunity to change their location depending on evaluation results. OR booms, monitors and lights were mocked up through the use of cost effective materials including acrylic piping, cardboard, plywood and 3D-printed joints. Equipment and auxiliary booms were mocked up with cardboard and plywood; affixed photos illustrated the services provided on the booms (i.e., electrical, gasses, suction, and data). They were mounted on IV poles to allow repositioning. OR

lights and monitors were ceiling mounted and maneuverable. Ensuring the booms, lights and monitors were manoeuvrable allowed the functionality of boom placement, patient table placement, as well as OR light and monitor range of use to be tested. Case-dependent equipment was made available for each scenario to facilitate the level of detail required when enacting clinician work flow and process. Where possible, active or retired equipment (i.e., anesthesia workstation, anesthesia machine, surgical table, Bair hugger, LigaSure), carts (i.e., case carts, procedure carts) and supplies (i.e., drapes, gowns, surgical instruments) were used to furnish the mock-up.

**The mock-up was modified to incorporate and reflect design decisions resulting from learnings generated through the mock-up evaluations (following every three scenario enactments), which allowed for iterative testing of an evolving OR design.**

An observation area was set up to allow for live video and audio feeds of scenario enactments just outside the mock-up. This allowed stakeholders to watch and listen to the scenario enactments, engage in the evaluation and provide feedback during debriefing sessions.



*Figure 1.* Full-scale mock-up of the universal OR suite constructed on site at the Vancouver General Hospital.

The Clinical Project Manager from the OR Renewal Project team led scenario development in collaboration with the Human Factors team and with front line clinicians including nurses, anesthesiologists, surgeons, and biomed. Consultation and feedback were obtained from the OR

Renewal Project team both before and during scenario development to determine the project scope, evaluation objectives and listing of surgical procedures to be enacted. Scenarios selected for enactment started with basic and frequently occurring surgical procedures and increased in complexity when additional equipment, personnel and processes were involved. For the purpose of analysis, the scenarios were scheduled chronologically by increasing levels of complexity/difficulty to incrementally test the space. Simulation scenarios were enacted by surgical teams including nursing staff, surgeons, anesthesiologists, residents, radiology techs, and anesthesia assistants. Fourteen scenarios were enacted by the surgical teams over a four-month period and all enactments were followed by facilitated debriefing sessions.

A decision was made to focus more detailed evaluation efforts on the basic and frequently occurring surgical procedures and, as such, a subset of surgical procedures was selected for video analysis by the Human Factors team. The results focus on simulation scenarios where video analysis was performed. As previously noted, modifications to the mock-up incorporated lessons learned as scenarios progressed.

Scenario development entailed listing the tasks to be enacted by each clinical team (nursing, anesthesia, surgery, other). The listed tasks helped identify potential challenges, and develop associated metrics to assess the potential challenges. Data definitions were then developed for each metric. Specifically, this involved identifying appropriate questions to ask during debriefing sessions and also noting what observations would be coded during video analysis of scenario enactments.

To evaluate design-change effectiveness, one scenario (laparoscopic cholecystectomy) was repeated and video analysis conducted to allow comparison between the initial and final mock-

up design iterations. The scenarios were separated into two parts. Part one included room set-up and ended after the patient entered the room and was intubated. Part two included the surgical procedure starting with the entry of the patient into the room and ended when the patient exited the room. Separating the scenarios into parts minimized time requirements for the surgeons and for anesthesiologists, who were not needed to participate in part one. It also permitted more attention to nursing set-up as well as workflow and room utilization during the surgical procedure.

Several days prior to each enactment, the scenario, debriefing questions and background information describing the evaluation process were circulated to participants and stakeholders. This enhanced awareness of the evaluation and clarified expectations of those involved.

Immediately before each scenario enactment, participants were briefed with a project overview, summary of the scenario and orientation to the mock-up (including where they could find equipment and supplies), along with instruction to enact the scenario as realistically as possible. All participants gave written consent for the collection of video and photographic recordings.

Data collection included feedback obtained through debriefing sessions following each enactment. Additionally, video analysis was conducted for a subset of scenario enactments. Four cameras were positioned within the mock-up that collectively captured the angles needed to observe workflow without visual obstruction.

Debriefing sessions gathered feedback from both scenario participants and observers. The Human Factors team facilitated these sessions through the use of semi-structured interview questions developed to specifically evaluate metrics intended to assess potential challenges and

gather feedback on the room design. This provided direct end-user feedback and was used to fine tune and strengthen the video analysis.

Video analysis involved a number of analytic strategies. The first was conducting link analyses that were used to show all participant movements (color coded by clinical role) as they completed scenario tasks within the mock-up. The analyses provided a visual representation of areas within the OR that were subject to congestion, high volume or underutilization. The second element of video analysis entailed coding the video and audio recordings for relevant observations (Table 2) and was used to assess the potential challenges identified during scenario development. Noldus (The Observer XT 11.5©) software was used as a coding platform. Each scenario enactment was independently coded by two members from the Human Factors team. Discrepancies were resolved by having both individuals review the video timestamps together to reach consensus and correct the discrepancies. During data analysis, the frequency of occurrence and spatial mapping (typically overlaid onto a link analysis) of the observation categories were examined. **This provided an evidence-based foundation for the assessment of potential challenges and resulting recommendation of specific design changes to optimize clinician workflow and room utilization while minimizing the potential for bumps and congestion.**

The third element of video analysis involved plotting the locations where various booms, boom mounted monitors, and some equipment (anesthesia machine, anesthesia workstation) were placed during scenario enactments. This was examined for particular scenarios and also across scenarios to better visualize room utilization and to compare desired placement relative to the potential range of motion for booms and boom mounted monitors.

*Table 2.* Observation categories and associated measurement definitions used to code the video and audio recordings.

<b>Observations</b>	<b>Measurement definition</b>
Bump	Physical contact between two objects (people and/or equipment) that were not intended to make contact.
Comment	Verbalized comment regarding positive design features or identified challenges.
Congestion	An object (person or equipment) was in the way.
Cord/cable snag	Unintentionally applied force to a cord (for power supply or patient monitoring) being used as part of patient care.
Ducking	Person ducked under an item.
Excessive reach	Accessed something beyond "one's reach envelope," which is the length of an extended arm.
Line snag	Unintentionally applied force to an IV line being used as part of patient care.
Re-adjustment	Re-adjustment made to an equipment or monitor.
Space constraint	During a task, a person needed to move to a different location in the room because of space constraints.
Task Time	Time it took to complete a task.
Tripping hazard	Object (people or equipment) required to move over another object, cord, or line. It also included when an item hit a person at a point (i.e., below the knee) where it could have caused them to trip.
Visibility	Needed to see something (i.e., patient, monitor, equipment, etc.) that was not in view of the individual who needed to see it.

## Results

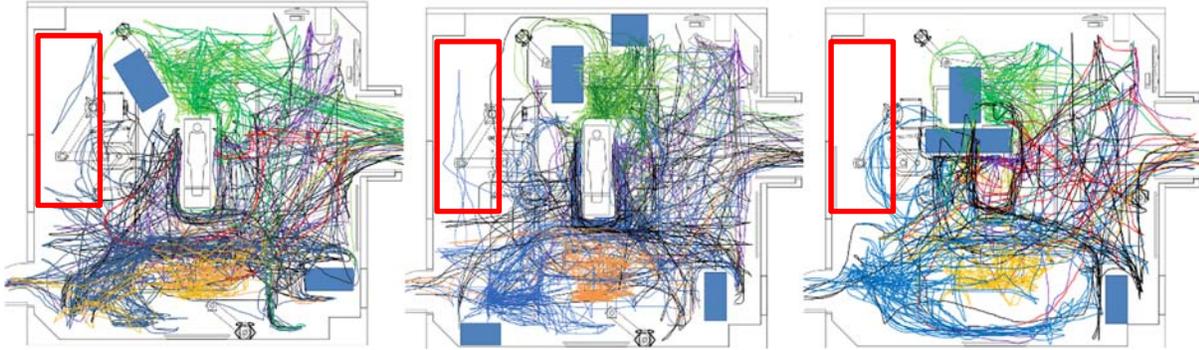
The results and recommendations generated were based on themed debriefing data as well as the various elements of video analyses. Moreover, the results presented here are specific to the three scenarios where video analyses were conducted:

- Total abdominal hysterectomy: Open abdominal approach for complete removal of uterus, ovaries, fallopian tubes and cervix.
- Laparoscopic cholecystectomy: Gall bladder removed laparoscopically.
- Thyroidectomy: Removal of the thyroid gland from a patient with known difficult intubation going into the case.

As previously noted, the mock-up was iteratively modified to incorporate the project team's recommendations into the universal OR design. This allowed for iterative testing of an evolving OR design. Repeating the laparoscopic cholecystectomy scenario allowed for comparisons between the initial mock-up design iteration and the final mock-up design iteration. Some limitations to be aware of when interpreting these comparisons are noted in the limitations section.

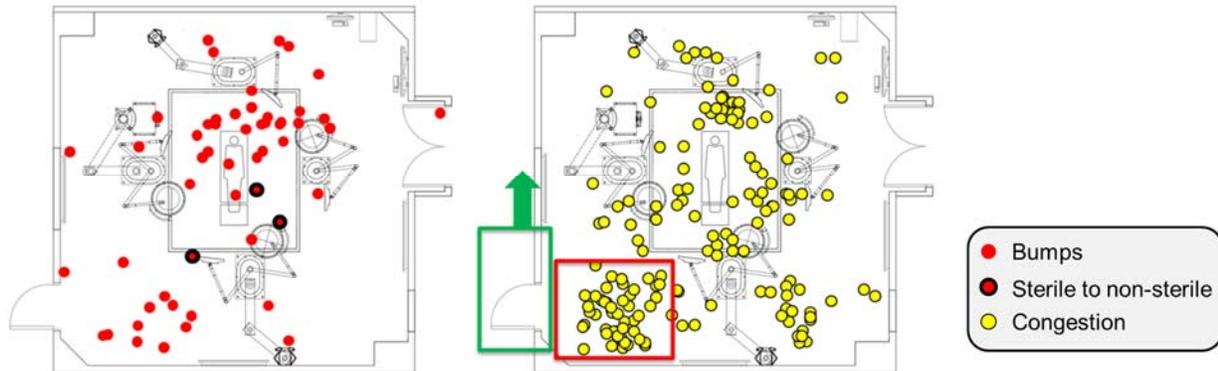
### **Room Utilization, Bumps, and Congestion**

Link analysis data (Figure 2) from the initial mock-up design iteration indicated that most of the room was utilized during scenario enactments. However, one corner of the room, indicated by the red box, was under-utilized. Recommendations discussed later intended to enhance utilization of this area of the room.



*Figure 2.* Link analysis illustrating motion patterns of each person participating in the scenario enactment of the total abdominal hysterectomy (left), laparoscopic cholecystectomy (center), and thyroidectomy (right) surgical procedures from the initial mock-up design iteration.

Bumps and congestions were two of the observation categories that were coded as part of the video analysis. The bump analysis (Figure 3, left) illustrates the frequency and location of physical contact between two objects (people and/or equipment) that were not intended to make contact. A subcategory of bumps was also examined. It included instances where sterile and non-sterile items unintentionally made contact. This subcategory is important because it can help to identify whether the room design might be contributing to compromises in sterility. Analysis of the bump data indicated there were very few sterile to non-sterile bumps. The congestion analysis (Figure 3, right) illustrates the frequency and location of where an object (person or equipment) was in the way. **Instances of bumps and congestions were primarily clustered inside the door leading to the sterile core, revealing an opportunity for improved design of this area** (Figure 3, red box).

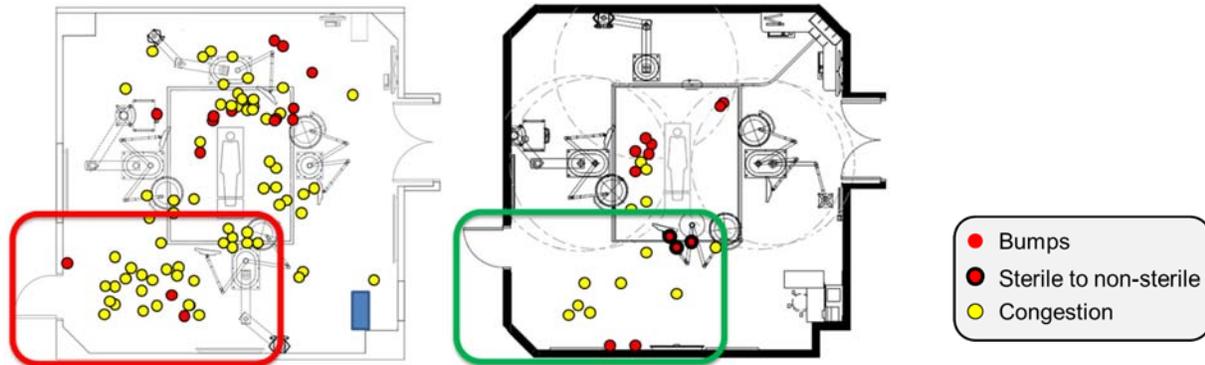


*Figure 3.* Bump analysis (left) and congestion analysis (right) are based on observations coded during the video analysis across the three scenarios. Congestion near the entrance (red box) informed the recommendations to relocate the door and pass-through (green box and arrow).

When congestion was observed, both the item in the way and the planned destination of the person experiencing the congestion were coded. Examination of this data indicated that the most frequent obstructions involved tray tables and other surgical prep tables. This was partly because people who were using the door between the OR and the sterile core needed to navigate through the surgical preparation area for entry and exit. Based on this data, a recommendation was made to relocate the sterile core door and pass-through further towards the head wall (Figure 3, green box and arrow), which would allow workflow to and from the sterile core to occur without needing to pass through the surgical preparation area.

Re-enactment of the laparoscopic cholecystectomy scenario after relocating the door and pass-through allowed for an evaluation of the frequency of bumps and congestions before and after making the design change (Figure 4). The findings suggested that there was a **58% reduction in the number of instances of congestion that involved the items placed in the surgical**

**preparation area** (surgical tables, back tables, tray tables, foley tables, ring stands, recycling carts, garbage cans, or kick buckets).

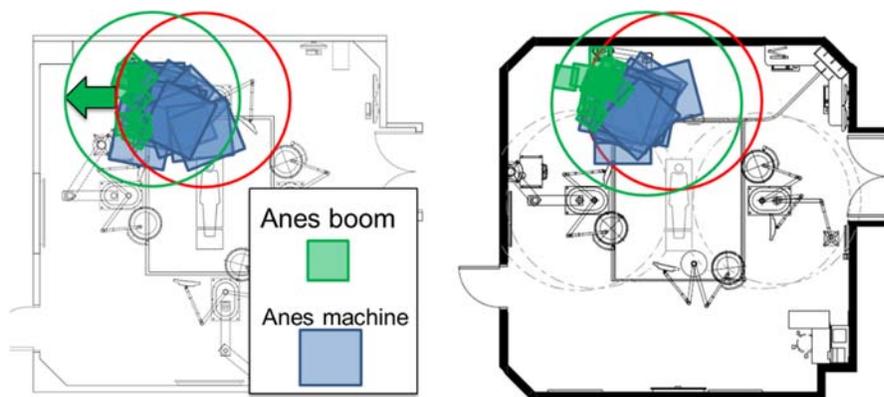


*Figure 4.* Comparison of bumps and congestions between the initial mock-up design iteration (left) and final mock-up design iteration (right) when enacting the laparoscopic cholecystectomy scenario.

### **Boom Placement**

Debriefing data revealed that anesthesia personnel were unable to push the anesthesia machine far enough back to create additional space in the anesthesia area that may be needed, for example, if a patient were to code. This was occurring because the anesthesia boom at the head of the bed was placed behind the anesthesia machine and could not be pushed further back. The placement of the anesthesia machine and anesthesia boom was examined across scenarios as part of the video analysis process. This confirmed that the anesthesia boom, located directly behind the anesthesia machine, was almost always placed at the end of its potential range of motion, indicated by the red circle in Figure 5. Given that the anesthesia boom was (1) only used on one side of its potential range of motion, (2) debriefing comments indicated it likely will not be used on the other side, and (3) the space behind the boom was underutilized, a recommendation was

made to shift the anesthesia boom mount towards the sterile core wall. The potential range of motion of recommended placement is indicated by the green circle in Figure 5. Re-enactment of scenarios after relocating the anesthesia boom mount in the mock-up showed that the boom was less likely to be placed at the end of its potential range of motion. Debriefing comments indicated that this **design modification allowed for better placement of the anesthesia machine and anesthesia boom and also permitted better use of the space in the underutilized corner of the room.**



*Figure 5.* Placement of the anesthesia boom and anesthesia machine was examined by plotting their various locations across scenarios in the initial mock-up design iteration (left) and final mock-up design iteration (right).

A second auxiliary boom was located near the foot of the OR table and was stored along the wall when not in use. Analysis of congestion indicated that the proximity between the auxiliary boom and the nursing workstation in the initial mock-up design iteration (Figure 6, left) made it difficult to walk behind the nursing workstation. Furthermore, the auxiliary boom when in use was generally placed at the end of its full range of motion (indicated by the red circle in Figure 6). Moving the auxiliary boom from its storage to use locations involved moving the boom

through the sterile preparation area, which was noted during debriefing sessions to be a possible source of contamination. Furthermore, participants said the ideal range of motion for this boom extends along the full length of the OR table from head to foot. Consequently, a recommendation was made to relocate the boom to the mount by the corridor entrance. The potential range of motion of the recommended placement is indicated by the green circle in Figure 6. Additional recommendations were made to reconfigure the nursing station, which also specified a number of design features to be incorporated. Re-enactment of scenarios after relocating the auxiliary boom to its optimal location resulted in better access to the nursing station and better positioning of the auxiliary boom along the length of the OR table.

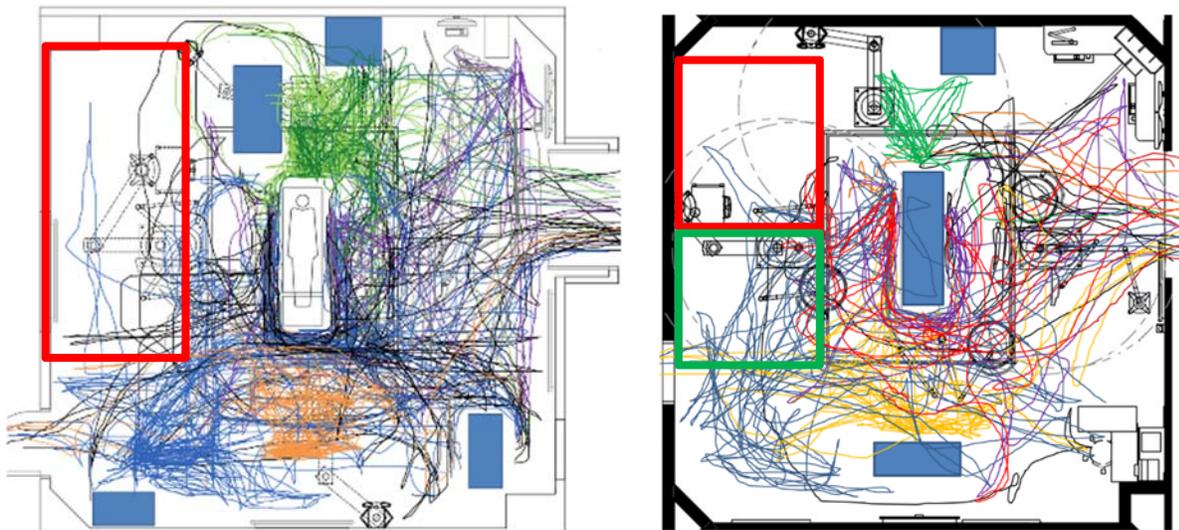


*Figure 6.* Comparison of congestions in the initial mock-up design iteration (left) to the final mock-up design iteration (right) suggested that access to the nursing station was improved; there was less congestion in the space around the nursing station. Furthermore, the potential range of motion of the auxiliary boom in the final mock-up design iteration (green circle), included the full length of the OR table, which was not the case in the initial design (red circle).

### Room utilization in the final mock-up design iteration

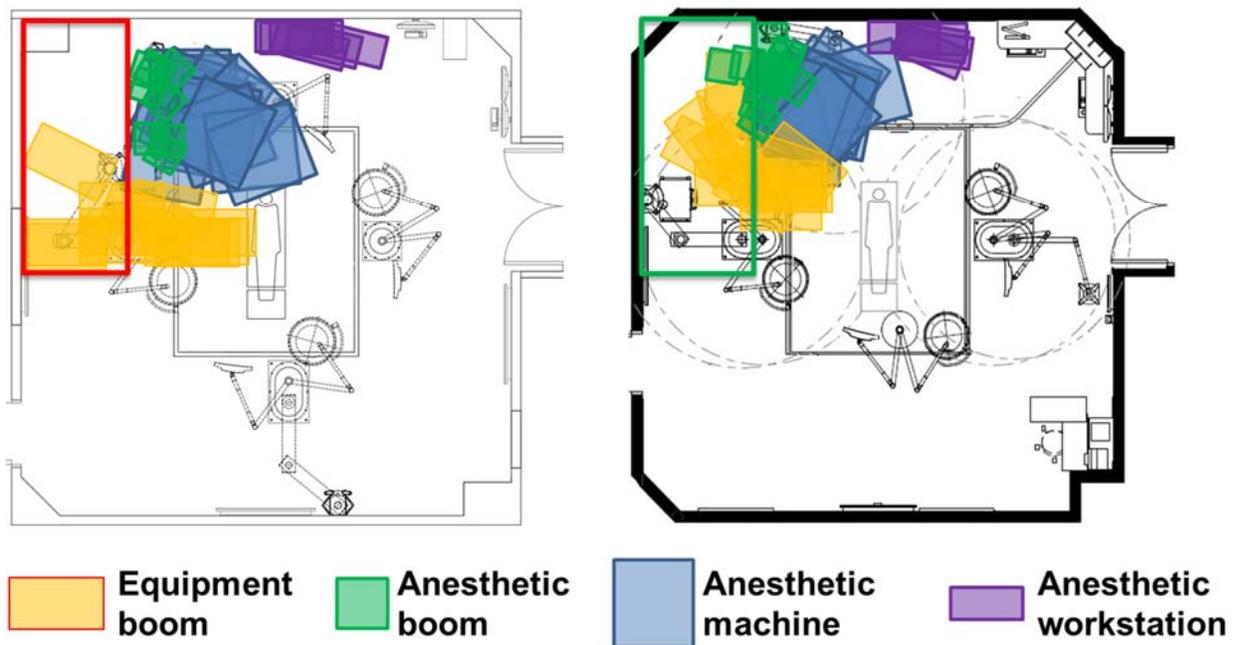
Although only a subset of the implemented recommendations was discussed above, additional modifications were made based on the recommendations put forward by the Human Factors team from the simulation-based mock-up evaluations (see supplemental material) and through other sources of feedback to the design team. To more fully examine the effect that all design modifications in general had on workflow and room utilization, the workflow of people enacting the scenarios, and placement of booms and equipment during scenario enactments were compared.

The link analyses comparing movement patterns of staff enacting the laparoscopic cholecystectomy scenario in the initial and final mock-up design iterations suggested that a greater portion of the room was being utilized for personnel workflow (Figure 7).



*Figure 7.* Link analysis of the laparoscopic cholecystectomy scenario enactment indicated that the amount of under-utilized space in the room (red box) decreased in the final mock-up design iteration (right) compared to the initial mock-up design iteration (left).

Furthermore, the placement of equipment and booms provided additional evidence that changes in where the booms were mounted (affecting the potential range of motion) also made better use of that area while simultaneously allowing the surgical teams to create more space around the surgical table when needed (Figure 8).



*Figure 8.* Visual representation of equipment and booms placement across scenarios where video analyses were conducted in the initial mock-up design iteration (left) and final mock-up design iteration (right).

## Discussion

The design process for the OR Renewal Project at the Vancouver General Hospital utilized the guiding principles described in the Simulation-Based Mock-Up Evaluation Framework (Health

Quality Council of Alberta, 2016). Specifically, a dynamic team of clinical staff enacted scenarios within a mock-up and enabled the collection of workflow and process data that provided a strong foothold for evidence-based recommendations. The iterative nature of the mock-up evaluations allowed for a diverse set of surgical procedures with a variety of stakeholders to evaluate the design as well as validate design changes made. Compared to design processes that do not utilize simulation-based mock-up evaluations, **this represents a significant advancement in understanding how design elements can and should be tailored to support team member roles, tasks they perform, and the integration of equipment** (Joseph et al., 2017).

The evaluation resulted in 29 recommendations that were presented by the Human Factors team to the OR Renewal Project team. The full listing of recommendations is available online as supplemental material for design teams to consider in future OR design projects. The vast majority of these recommendations were incorporated into the final design. The recommendations offer applicable considerations to others working on OR design projects. For example, one consistent finding demonstrated that the surgical preparation area, located just inside the door leading to the sterile core, was more prone to bumps and congestions than other areas of the room. The recommendation to re-locate the door and pass-through further towards the head wall allows workflow to and from the sterile core to occur without needing to pass through the surgical preparation area. **This highlights the importance for design teams to consider door placement (and associated traffic) in relation to other workflows within the OR, echoing the findings from prior OR mock-up evaluations targeting the placement of doors** (Bayramzadeh et al., 2018).

A number of recommendations targeted the placement of boom mounts, including the anesthesia and auxiliary booms. These recommendations were based on the maximal ranges of motion for each boom, boom placement during the various surgical procedures enacted, access and visibility requirements to equipment on the booms, as well as workflow and overall room utilizations data. This highlights some of the factors to be considered when deciding where booms should be mounted. More importantly, it highlights that the **design needs to build upon a detailed understanding of workflow within the planned OR design, achievable through simulation-based mock-up evaluations**. Collecting evidence-based data from mock-up evaluations rarely occurs, but can significantly enhance OR design (Traversari, Goedhart, & Schraagen, 2013; Bayramzadeh et al., 2018).

### **Limitations**

The surgical procedures selected for scenario enactment represent only a subset of procedures that will occur. Variability exists between clinicians in how they work. Equipment and technologies are constantly evolving. As the procedures, clinicians and technology change, the observed workflows and space requirements will likely also change. A number of steps were taken (i.e., enacting a variety of surgical procedures) to mitigate these limitations while focusing the detailed video analysis on frequently occurring procedures.

A number of comparisons were made between the initial and final mock-up design iteration. Ideally, all aspects of scenario enactment would be identical, allowing the results to be fully attributable to modifications between the two design iterations. Differences in the roles included and tasks performed during the two enactments of the laparoscopic cholecystectomy were likely confounding factors in the results. Staff shortages in the actual OR during the final mock-up

design iteration prevented the anesthesiologist from participating in room set up portion of the scenario, but was able to participate in the surgical procedure portion of the enactment.

Similarly, an anesthesia resident and anesthetic room nurse were not available to participate in the surgical procedure portion of the scenario enactment. With respect to tasks performed, a LigaSure and Bair Hugger were used within the initial but not the final mock-up design iteration.

There was also a decrease in the amount of patient charting that occurred between iterations.

Despite these differences, the vast majority of tasks performed were consistent between the two scenarios. Specifically, both scenario enactments included the use of surgical team introductions, prepping surgical tables, positioning monitors and OR lights, scrubbing and gowning, draping the patient, the surgical procedure, performing post-surgical counts, undraping the patient and transferring the patient out of the OR. Furthermore, careful considerations were made to ensure that data comparisons were appropriate given the differences. For example, congestion analyses around the surgical table were affected because the Bair Hugger was not present, and therefore were not interpreted as part of data analysis. Instead, congestion analyses were used to assess the surgical preparation area where the equipment and supplies used were consistent between the two enactments.

### Conclusions

Iterative simulation-based mock-up evaluations of **this OR design provided evidence for decision-making that resulted in better room utilization, decreased congestion, and enhanced access to equipment.** Indeed, this required dedicated time and resources be incorporated into the projects schedule along with time commitments from a diverse group of stakeholders. This may present as an obstacle for use in other capital projects. However, the benefits that resulted from the process should allay such concerns.

### **Implications for Practice**

- The use of simulation-based mock-up evaluations allows healthcare design teams to optimize spatial utilization while providing a design that supports improved flow for the tasks being performed.
- Collecting evidence-based data from mock-up evaluations can identify opportunities to improve design and save costs by discovering these opportunities before constructing the space.
- Evaluating the locations of where booms are mounted within an operating room and the range of motion for each boom is important to optimize access to the booms (and equipment on the booms) as well as space utilization in the room and around the surgical table.

### **Acknowledgments**

The authors thank Jasleen Aujla, who provided administrative support for the mock-up evaluation, the individuals who participated or observed the scenario enactments, OR management and staff who were instrumental in furnishing the mock-up and recruiting staff to participate, bio-medical engineering personnel who constructed and supported the mock-up evaluated, DYS architecture, and everyone else who assisted with many different aspects of this study.

### References

- Alberta Infrastructure (2018). Health facilities capital program manual. Retrieved June 28, 2018 from <http://www.infrastructure.alberta.ca/3782.htm>
- Bayramzadeh, S., Joseph, A., Allison, D., Shultz, J., & Abernathy, J. (2018). Using an integrative mock-up simulation approach for evidence-based evaluation of operating room design prototypes. *Applied Ergonomics*, 70, 288-299. doi:10.1016/j.apergo.2018.03.011
- Biesbroek, S., Shultz, J., Kirkpatrick, A., & Kortbeek, J. (2012). Human factors evaluation of an interventional trauma operating room mock-up. *Proceedings of the 2012 Symposium on Human Factors and Ergonomics in Health Care*. doi:10.1518/hcs-2012.945289401.012
- Canadian Standards Association. (2018). Z8000-18: Canadian health care facilities. Standards Council of Canada.
- Chisholm, S., Shultz, J., Caird, J., Lord, J., Boiteau, P., & Davies, J. (2008). Identification of intensive care unit (ICU) system integration conflicts: Evaluation of two mock-up rooms using patient simulation. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 52(12), 798-802. doi:10.1177/154193120805201207
- Davies, J. (1994). Complications of general anaesthesia. In Nimmo WS, Rowbotham D. J., & Smith, G. (eds) *Anaesthesia* (2nd Ed) pp 758-787. Boston: Blackwell Scientific Publisher.

Facilities Guidelines Institute. (2018). Simulation-based tool for evaluating health care designs.

Retrieved March 16, 2018, from <https://www.fgiguideelines.org/resource/simulation-based-tool-evaluating-health-care-designs/>

Harsoor, S. & Bhaskar, S. (2007). Designing an ideal operating room complex. *Indian Journal of Anesthesia*, 51(3), 193-199.

Health Quality Council of Alberta (2016). Simulation-based mock-up evaluation framework.

Calgary, Alberta, Canada: Health Quality Council of Alberta.

Helmreich, R. & Davies, J. (1996). Human factors in the operating room: Interpersonal determinants of safety, efficiency, and morale. *Bailliere's Clinical Anaesthesiology: Safety and Risk Management in Anaesthesia*, 10(2), 277-295.

Joseph, A., Bayramzadeh, S., Zamani, Z., & Rostenberg, B. (2017). Safety, performance, and satisfaction outcomes in the operating room: A literature review. *Health Environments Research & Design Journal*, 11(2), 137-150. doi:10.1177/1937586717705107

Joseph, A., Wingler, D., & Allison, D. (Eds.). (2016). *Realizing improved patient care through human-centered design in the operating room* (Vol. 1). Retrieved March 15, 2018, from [https://issuu.com/clemsonchfdt/docs/ripchd.or\\_volume\\_1](https://issuu.com/clemsonchfdt/docs/ripchd.or_volume_1)

Kirkpatrick, A. W., Vis, C., Dubé, M., Biesbroek, S., Ball, C. G., Laberge, J., Shultz, J., Rea, K., Sadler, D., Holcomb, J.B., & Kortbeek, J. (2014). The evolution of a purpose designed hybrid trauma operating room from the trauma service perspective: The RAPTOR (resuscitation with angiography percutaneous treatments and operative resuscitations).

Injury, *International Journal of the Care of the Injured*, 45(9), 1413-1421. doi:Injury,  
Corrected proof. doi:10.1016/j.injury.2014.01.021

Ministry of Health (2014). Setting priorities for the B.C. health system. Retrieved March 6, 2018,  
from [http://www.health.gov.bc.ca/library/publications/year/2014/Setting-priorities-BC-  
Health-Feb14.pdf](http://www.health.gov.bc.ca/library/publications/year/2014/Setting-priorities-BC-Health-Feb14.pdf)

Shultz, J., & Chisholm, S. (2010). Supportive living resident suite evaluation: Using simulation  
to evaluate a mock-up. *Proceedings of the Human Factors and Ergonomics Society  
Annual Meeting*, 54(12), 937-941. doi:10.1177/154193121005401228

Traversari, R., Goedhart, R., & Schraagen, J. M. (2013). Process simulation during the design  
process makes the difference: Process simulations applied to a traditional design. *Health  
Environments Research & Design Journal*, 6(2), 58-76.

## Supplemental material: Listing of recommendations

**Simulation-Based Mock-Up Evaluation of Universal Operating Room Recommendations****Room Utilization**

1. Consider how to better utilize the space along the sterile core wall (e.g., move anesthesia boom mount, equipment storage, supply storage).
2. Relocate the sterile core door and pass through further towards the head wall.
3. Include a window on sterile core door.

**OR Lights**

4. Extend arm length of OR light (foot).
5. Review OR light arm lengths if mount locations change.

**Equipment Boom**

6. Use longer line/cord/tube lengths for devices connected to equipment boom.
7. Include minimum cord length as an equipment procurement criterion (use future simulations to determine minimum length).

**Anesthesia Boom - Head of OR Table**

8. Shift the anesthesia boom mount towards the sterile core wall.

**OR Table Positioning**

9. Consider moving OR table towards the foot and how this impacts the clean suite ceiling.

10. Validate that shifting the OR table location does not negatively impact nursing setup.
11. Include a visual indicator marking center of sterile field.

#### **IV Poles**

12. Consider the use of ceiling / bed mounted hooks instead of IV poles.
13. Test the use of ceiling / bed mounted hooks in future mock-up evaluations.

#### **Anesthesia Area**

14. Wall mounted items behind AWS area (and behind anesthesia boom) should be relocated closer to physician workstation.
15. Add anesthesia assist button and phone to head wall.

#### **Auxiliary Boom - Foot of OR table**

16. Relocate auxiliary boom to mount by corridor entrance. Ceiling mounted gasses may be an alternative.
17. Purchase in-field monitors with electrical plugs (gather electrical requirements for devices expected to be plugged in here).
18. Consider design features (size, storage height, storage location) when procuring the auxiliary boom to minimize congestion at the entrance.
19. Test auxiliary boom placement after procuring boom.

#### **Nurse Workstation**

20. Having the nurse workstation parallel to the corridor is preferred (if auxiliary boom is at foot). Consider and test an L-shaped workstation.
21. Ensure the nurse workstation is usable while facing towards and away from the patient (i.e., rotatable computer).
22. Accommodate charting while sitting and standing (i.e., standing desk with stool or sit-stand desk).
23. Recommended design features:
  - Allow visibility of patient while charting.
  - Computer should be rotatable.
  - Desk corners should be rounded.
  - Support multiple users simultaneously.
  - Increase the amount of available workspace provided.
24. Specimen supplies should be co-located near nurse workstation.

### **Physician Workstation**

25. Increase the amount of available workspace provided (chart, laptop).
26. Provide locked cupboards for personal items near OR.

### **Ceiling Lift**

27. Consider parking ceiling lift near nurse workstation.
28. Test both locations after selecting ceiling lift vendor with consideration for access and contamination of surgical prep area.

### **Validating Recommendations**

29. Continue to conduct mock-up evaluations to validate design changes.

- Incorporate design changes into the mock-up.
- Incorporate characteristics and functionality of equipment / devices into mock-up after selecting vendors.