HQCA
Health Quality Council of Alberta

HEALTHCARE FACILITY MOCK-UP EVALUATION **GUIDELINES**

Using Simulation to Optimize Return on Investment for Quality and Patient Safety

OCTOBER 2020

The Health Quality Council of Alberta is a provincial agency that pursues opportunities to improve patient safety, person-centred care and health service quality for Albertans. It gathers and analyzes information, monitors the healthcare system, and collaborates with Alberta Health, Alberta Health Services, health professions, academia, and other stakeholders to drive actionable improvements. Our responsibilities are set forth in the *Health Quality Council of Alberta Act.*

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SYNOPSIS

This report makes recommendations to optimize return on investment (ROI) when evaluating healthcare facility designs for quality and patient safety. Specifically, it provides guidance on how to choose between simple, detailed, and virtual reality (VR) mock-ups for a simulation-based mock-up evaluation.

Human factors experts evaluated the three options with clinical caregivers (nursing and pharmacy) for a medication room mock-up and validated the results against findings from an evaluation of an existing medication room in a hospital (post-occupancy evaluation; POE). Eight data types were collected, including workflow, bumps, impediments, interruptions, task completion times, searching behaviours, selection errors, and equipment placement.

Simple mock-ups. The best ROI was achieved with the simple mock-ups (cheaper set up costs), but had significant limitations as five of the eight types of data collected were inaccurate or lacked sensitivity.

Detailed mock-ups. The detailed mock-ups had higher set up costs (less than VR), and accurately evaluated all data types examined.

VR mock-ups. The VR mock-ups, costliest of the three but still with a positive ROI, accurately evaluated five of the eight types of data. Technological advances will likely enhance the type of data which can be collected and make this a more cost effective option.

It is recommended that organizations should consider cost-effectiveness and the accuracy of data collection when considering or planning to conduct a simulation-based mock-up evaluation.

EXECUTIVE SUMMARY

There is a growing trend to conduct simulation-based mock-up evaluations as part of the process to design healthcare facilities. In 2016, the Health Quality Council of Alberta (HQCA) published the *Simulation-based Mock-up Evaluation Framework*[1] (available at www.hqca.ca/humanfactors) which outlines an approach to plan, collect and analyze data from full-scale mock-ups. However, little is known about the return on investment (ROI) from conducting these evaluations, and which types of mock-ups should be used to meet different evaluation objectives.

Objective

The intent of this document is to present evidence-based guidelines outlining which mock-up type would optimize cost effectiveness and outcomes (i.e., identified latent conditions and hazards) during the design of healthcare facilities. The findings pertain to organizations who are considering, planning, or are currently conducting simulation-based mock-up evaluations. Proactively identifying opportunities to enhance quality and patient safety through hospital design before construction can avoid costs associated with future renovations to achieve the same opportunities. ROI information will be reported using the Phillips ROI Methodology,[2] which provides a systematic measurement and evaluation process to generate a balanced set of data, intended to be believable, realistic and accurate.

Methods

A medication room was selected to evaluate the mock-ups given the safety implications, and applicability across healthcare sectors and caregiver roles. A post-occupancy evaluation (POE) of an existing medication room was conducted. Three mock-ups were developed replicating the design of the existing medication room. The mock-ups were designed to be reconfigured so a second layout could also be evaluated which incorporated design changes identified through the POE results. As such, the mock-up evaluations specifically compared two medication room layouts (existing and proposed) in three types of mock-ups: simple, detailed and virtual reality (VR). Simple mock-ups are typically very basic in design (i.e., tape on the floor). Detailed mock-ups are finished to a greater degree (i.e., wall, furniture, and equipment included). VR mock-ups are 3D, fully immersive, photorealistic, interactive virtual environments that are experienced using a head-mounted display. Scenarios were enacted within each of the three mock-up types by registered nurses, licenced practical nurses and pharmacy technicians to evaluate various types of data pertaining to workflow, efficiency and safety.

The evaluation also considered multiple points of view – those of end-users who enacted the scenarios (end-user participants), those of other design stakeholders who did not participate in scenario enactments (non-participant stakeholders), and those who received results of the POE and are operationally responsible for the existing medication room evaluated (decision makers). Surveys gathered subjective data from these three groups regarding the different mock-up types, scenarios, room layouts, and experiences.

Objective data collection from scenario enactments within the physical mock-ups (simple and detailed) involved two human factors experts independently reviewing video and audio recordings from four different camera angles to code workflow, bumps, impediments, interruptions, task completion times, searching behaviours, selection errors, and equipment placement. Data collection from scenario

enactments within the VR mock-ups coded most of these data types; however, the process was automated through specialized software modules (HyperMock).

Findings

The results suggest that conducting simulation-based mock-up evaluations (regardless of the mock-up type) is perceived by non-participant stakeholders to produce findings that are useful for future projects. Moreover, the process engaged end-users to the extent that they felt they were able to effectively evaluate the design of the room and make meaningful contributions to improve the design.

Return on Investment

Simulation-based mock-up evaluations can predict design opportunities which could prevent change order requisitions or future renovations. The findings provide a number of intangible (non-monetary) benefits which involve enhancements to quality and safety (patient and caregiver) and suggest that all mock-up types have the potential to produce a positive ROI. The potential savings reported here are intended to be very conservative; larger returns could be expected as technologies advance, or when evaluating multiple rooms of the same design.

Simple mock-ups

Simple mock-ups are inexpensive to create, and produced the largest ROI when used to conduct a simulation-based mock-up evaluation. For every dollar invested in a simple mock-up, $26.85 can be saved. When evaluating simple mock-ups, examining workflow (link analysis), bumps, impediments, interruptions, as well as equipment placement were found to be valid predictors (Figure 1).

Detailed mock-ups

Detailed mock-ups are more costly to construct, but still have a very high ROI. For every dollar invested in a detailed mock-up, $16.66 can be saved. All data types listed in Figure 1 were found to be valid predictors when using detailed mock-ups including workflow, bumps, impediments, interruptions, task completion times, searching behaviours, selection errors, and equipment placement.

VR mock-ups

VR mock-ups were the most costly option, however, still resulted in a positive ROI. For every dollar invested in a VR mock-up, $5.06 can be saved. Some types of data were not programmed for automated data collection (selection errors and equipment placement), and this highlights the importance of *a priori* measurement clarity when procuring or programing VR software. VR was able to accurately evaluate workflow, bumps, impediments, interruptions, and task completion times. Because data collection can be automated, VR mock-ups are particularly beneficial for projects where sufficient planning time is allocated but a short turnaround time between the scenario enactments and delivery of recommendations is desired. VR technologies are quickly evolving, and costs are decreasing. As such, it is anticipated that VR will become an increasingly cost effective mock-up type. Furthermore, what was not possible in 2017 when the VR evaluations occurred, will likely be possible in the near future (if not already).

Conclusion

Not all mock-up types are appropriate or effective to assess all evaluation objectives. Although there are various ways that mock-ups can be used, organizations considering a simulation-based mock-up evaluation should select the most appropriate mock-up type with consideration of:

- cost-effectiveness; and
- accuracy of data that would permit assessment of evaluation objectives of interest to the design team (Figure 1).

Selecting an appropriate mock-up type based on these considerations is anticipated to further advance the effectiveness of organizations who are considering, planning, or are currently conducting simulation-based mock-up evaluations as part of their design process.

Figure 1: Types of data which can be accurately assessed with each mock-up type as well as the return on investment realized.

TYPES OF DATA	Simple mock-up	Detailed mock-up	Virtual reality mock-up
Workflow	◎	◎	◎
Bumps	◎	◎	◎
Impediments	◎	◎	◎
Interruptions	◎	◎	◎
Task completion times	◎	◎	◎
Searching behaviours	◎	◎	◎
Selection errors	◎	◎	N|A
Equipment placement	◎	◎	N|A
Amount saved per dollar invested	**$26.85**	**$16.66**	**$5.06**

Legend: Data validity was used to categorize types of data as being:

◎ Accurate ◎ Accurate but less sensitive ◎ Not accurate/ possible N|A Not Assessed

BACKGROUND

The goal of using an evidence-based design (EBD) approach when designing healthcare environments is to achieve the best possible outcomes. The amount of research linking the design of healthcare environments to patient and staff outcomes is increasing with more than 4,500 citations listed in the Center for Health Design Knowledge Repository.[3] There is an increasing interest in improving the design process, with a growing trend to conduct simulation-based mock-up evaluations as part of the process to design healthcare facilities.[4,5,6,7,8,9]

A simulation-based mock-up evaluation involves creating a full-scale mock-up of a planned space and having end users enact realistic processes and procedures within the mock-up.[1] Evidence-based data collected from the scenario enactments is used to develop recommendations to optimize the planned design. Little is known about the return on investment (ROI) from conducting these evaluations and which type of mock-up should be used to conduct the evaluation. The intent of this document is to present evidence-based guidelines outlining which mock-up type would optimize cost effectiveness and outcomes (i.e., identified latent conditions and hazards) in the design process and report ROI-related information. Proactively identifying opportunities to enhance quality and patient safety through hospital design can avoid costs associated with future renovations to achieve the same opportunities.

INTRODUCTION

Simulation-based Mock-up Evaluation Framework

The Health Quality Council of Alberta (HQCA) published the *Simulation-based Mock-up Evaluation Framework*[1] (available at www.hqca.ca/humanfactors), which outlines an approach to plan, collect, and analyze data from full-scale mock-ups. The framework describes six guiding principles to conduct an evaluation (Table 1). The document and process has been incorporated into the National Standards of Canada regarding the planning, design, and construction requirements for Canadian Health Care Facilities (CSA Z8000-18).[10] It has also been incorporated into the Health Facilities Capital Program Manual,[11] which provides guidelines for the province of Alberta. The Facilities Guidelines Institute (FGI) website promotes the framework as an FGI-supported resource of interest to guideline users in the United States.[12] Moreover, institutions in both Canada and the United Stated have used the framework to evaluate room designs.[4,13,14,15]

Table 1: Guiding principles from the HQCA's *Simulation-based Mock-up Evaluation Framework*.[1, p4-5]

Guiding Principles of the Framework
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.

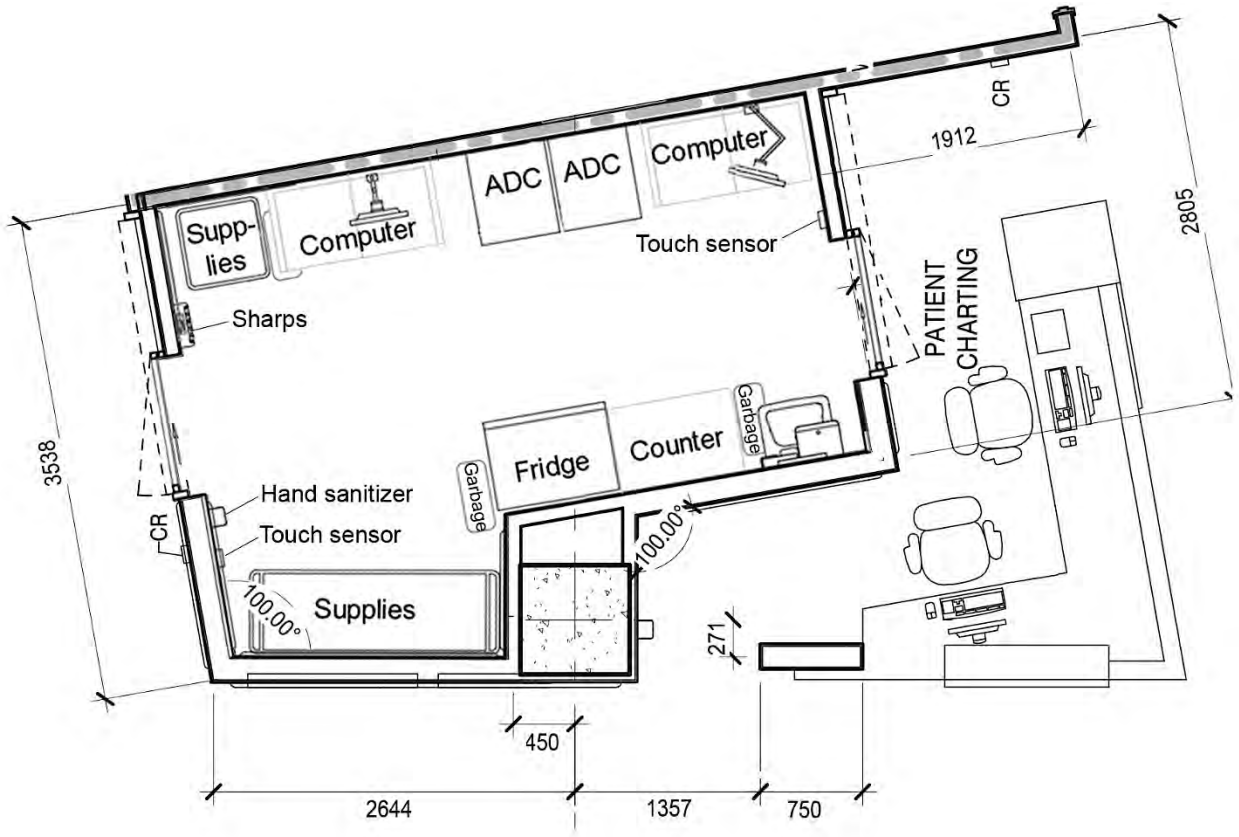
Setting Selection: Medication Room

Medications are administered to almost every patient in hospitals, as well as in other healthcare settings. Unfortunately, medication errors are the most common type of medical error,[16] and research studies have shown that medication errors may be occurring as frequently as one per patient, per day.[17,18] Most medication errors (58 per cent) have been found to occur during administration (providing patients with a prescribed medication),[19] but occur across all stages of the medication use process.[19,20,21] Although nearly half of medication prescribing errors are intercepted before reaching the patient, only two percent of errors occurring at the administration stage are intercepted.[20] In Alberta, Canada, an adverse event involving a medication substitution error resulted in two patient deaths. An external review of the circumstances recommended that the "adequacy of areas for medication preparation in patient care areas be assessed and renovations undertaken where necessary".[22, p81]

Literature reviews have suggested that interruptions are the leading cause of medication errors.[23] Research suggests that interruptions occur frequently during medication preparation and are associated with procedural failures and clinical errors.[24] A recent study investigated the effect of separate medication preparation rooms on interruptions and errors.[25] This study found that after introducing separate medications rooms, the interruption rate decreased from 52 to 30 interruptions per hour, and the medication error rate decreased from 1.3 to 0.9 errors per day. And while progress in medication room design has been made, patient safety can further benefit from a more proactive approach to identify medication safety issues. For example, The Center for Health Design has identified a number of design considerations to enhance medication safety,[26] many attempting to decrease interruptions and distractions in these spaces.[27]

Given the patient safety implications, as well as its applicability across healthcare sectors and clinical caregiver roles, a medication room was selected to evaluate return on investment (ROI) when conducting simulation-based mock-up evaluations. Three different types of medication room mock-ups were created. Each mock-up type replicated the design of existing medication rooms from medical/surgical units at a large urban acute care hospital (Figure 2). This acute care hospital has four units, each with two medication rooms, all of which have the same design. Therefore the mock-ups replicated the design of these eight medication rooms.

Figure 2: Existing medication room design.



Mock-up Types

Simple mock-ups

Simple mock-ups are typically very basic in design, often created using a 2D footprint (or plan view) augmented by 3D items where possible (e.g., furniture, equipment). This can include using tape on the floor to indicate the location of walls and furniture in the room. In some instances, walls may be constructed using cardboard, plywood or foam-core. The location of furniture and/or equipment may be indicated using cardboard footprints or using boxes to represent furniture and equipment. Creating simple mock-ups to scale allows individuals to get a better sense of the room layout and space available.

For this evaluation, the simple medication room mock-ups were created to scale using tape and cardboard (Figure 3). Black tape indicated the location of walls. White tape indicated the location of doors. Cardboard cut-outs indicated the footprint and location of furniture or items in the room. Names were written onto the cardboard cut-outs indicating what each piece represented. Photos of the furniture and items, printed on 8x11 paper, were also taped onto the cardboard cut-outs to illustrate each item. A sharps container photo, printed onto an 8x11 paper, indicated its planned location in the medication room.

Mobile wireless medication (Wi-Med) carts, which are used to deliver medications from the existing medication room to the patients, were not available for use when evaluating the simple medication room mock-ups. Instead, two mobile ultrasound machines were used. Ultrasound machines were

selected as alternatives because they are also on wheels, included a small work surface, and utilized approximately the same space. A crash cart was used as a pharmacy cart, which was very similar in terms of its size, available workspace, and inclusion of drawers.

Figure 3: Photos of the simple mock-up (left), mobile ultrasound machines used as Wi-Med carts (top right), and crash cart used as a pharmacy cart (bottom right).

Detailed mock-ups

Detailed mock-ups are more realistic in their design because they are finished to a greater degree compared to simple mock-ups, and may include equipment, furniture, flooring, a ceiling, light fixtures, the headwall with electrical and gas outlets, functioning millwork, as well as other details.

To evaluate the detailed mock-ups, DIRTT, a company specializing in the prefab construction of interior spaces, was contracted to supply modular walls and cabinetry, and to construct the full-scale mock-ups (Figure 4). Supply carts were placed inside the mock-up and filled with common supplies. A lockable cart with drawers was used as an automated medication dispensing cabinet (ADC) and was filled with medications that were planned for use during scenario enactments. A cardboard box was used as a fridge, and was modified to include a shelf so items could be stored within it. Two Wi-Med carts and a pharmacy cart were also placed inside the mock-up.

Figure 4: Exterior (top left) and interior (bottom left) photos of the detailed mock-up along with the Wi-Med carts (top right) and pharmacy cart (bottom right).

Virtual reality (VR) mock-ups

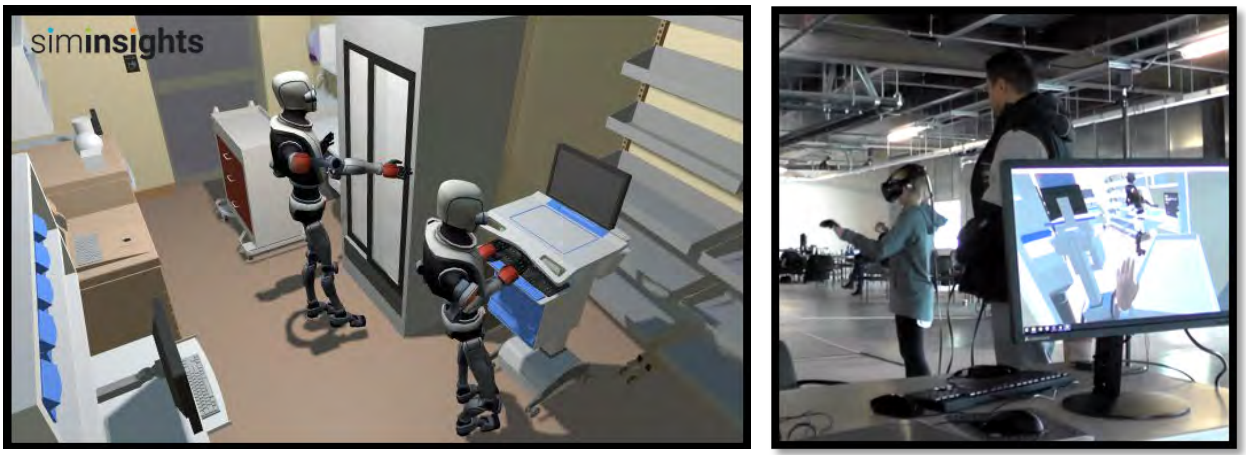
VR mock-ups are interactive environments that allow participants to move around inside a VR environment while also manipulating and interacting with the virtual world. Head-mounted displays, worn over the eyes of participants, allows location tracking and provides continuous visual updates based on the users' head position and orientation in the physical environment. This provides a 3D, fully immersive, photorealistic, and interactive environment.

VR mock-ups were not commonly used when the *Simulation-based Mock-up Evaluation Framework* (HQCA, 2016) was developed and, therefore, was not included in the framework. However, there has been a growing trend in both the use of VR mock-ups, as well as calls for research examining VR mock-ups for healthcare facility design.[7,15,28] With technological advances, the costs, capabilities, and usability of VR is improving and expected to continue.

To evaluate the VR mock-ups, SimInsights, a software company specializing in VR simulations, was contracted to develop the VR medication room mock-ups (Figure 5), program interactive capabilities

within the room, and automate data collection processes. The VR mock-ups included a functioning ADC, maneuverable and operable Wi-Med carts and pharmacy cart, stocked fridge, and supply cabinets, as well as intractable electronic medication administration records. Participants could virtually speak with each other, providing a sense of immersion and presence within the environment.

Figure 5: VR room mock-up (left). Head-mounted displays worn by participants allowed immersion and interaction within the VR environment (right).



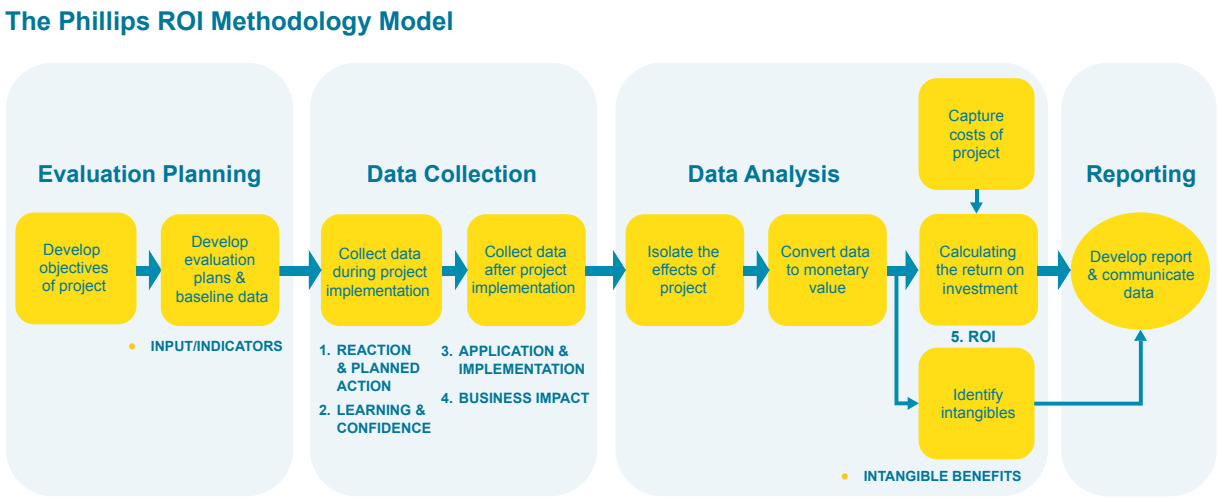
To develop the VR mock-ups, an AutoCAD 2D layout of the room along with photos of the room, equipment, and objects were supplied to SimInsights. A VR software product named HyperMock was used to develop the VR mock-ups. HyperMock includes the interaction capabilities necessary for enacting the scenarios within the virtual environment. Four HTC Vive headsets and controllers allowed four end-user participants to simultaneously immerse themselves as avatars and interact with each other as well as objects and equipment within the VR environment.

METHODS

Return on Investment (ROI)

The Phillips ROI Methodology[2] provides a systematic measurement and evaluation process that generates a balanced set of data, intended to be believable, realistic, and accurate (Figure 6).

Figure 6: Ten steps in the in the Phillips ROI Methodology.[29]



The Phillips ROI Methodology builds upon the four levels of evaluation developed by Kirkpatrick[30] and includes a fifth level, ROI, as well as intangible (non-monetary) benefits. The levels are summarized in Table 2. The five levels, plus associated intangible benefits, were used as a framework to describe the relative value of using each mock-up type when conducting a simulation-based mock-up evaluation. The ROI methodology also provides 12 guiding principles that guide how evaluation studies should be planned and conducted (Appendix III). These principles ensure that studies are conducted using a consistent and conservative approach. The principles were used when making methodological decisions for the ROI evaluation.

Table 2: Five levels of data, plus intangible benefits, collected as per the Phillips ROI Methodology.[2]

ROI Level	Measurement Focus
1. Reaction and planned action	Measures participant reaction to the program and captures planned action.
2. Learning	Measures change in knowledge, skills, and attitudes related to the program.
3. Application	Measures implementation, action, and changes in behaviour on the job.
4. Business impact	Measures changes in business impact variables.
5. Return on investment	Compares monetary benefits to the costs of the program.
Intangible (non-monetary) benefits	Measures benefits that are not converted to monetary values.

Post-Occupancy Evaluation (POE)

A POE is a structured approach to evaluate the performance of a new or existing facility when it is fully operational, typically after at least 12 months of occupancy.[10] The intention is to determine if the design achieved its anticipated outcomes and to identify and solve problems in the built environment so learnings can inform the design of future spaces. To proactively identify these learnings, simulation-based mock-up evaluations provide an approach to identify learnings and allow for design modification to enhance quality and patient safety before constructing the space. A POE was conducted to test the validity of data collected from the medication room mock-up evaluations. The results from the POE and the mock-up evaluations were compared. The medication room design assessed in the mock-up evaluations replicated the existing medication room design evaluated in the POE. Evaluating validity involved examining the degree to which data collected from each mock-up evaluation could predict (or be consistent with) data collected from the POE. Furthermore, this study also assessed whether incorporating design changes into the mock-ups based on the lessons learned from the POE (with a second mock-up layout) would enhance quality and patient safety through specific anticipated outcomes that the design changes were intended to improve.

Comparing mock-up data to POE data from an actual design process would be problematic because the design is often modified based on the results from the mock-up evaluations. The final design therefore would differ in comparison to the mock-up. These differences prevent the interpretation of comparisons, because it would not be known whether any observed differences were due to the mock-up evaluation process or attributable to the design modifications. To isolate the effect so that findings were specific to the mock-up evaluation process, all three mock-up types were created to replicate the exact design of the existing medication room. This created a basis for comparison to evaluate the accuracy of data collected through the mock-up evaluations. Ultimately, this was to assess the overall value of conducting a simulation-based mock-up evaluation prior to construction.

POE data collection

The POE involved conducting interviews with eight nursing staff and three pharmacy technicians, all of whom work in the medication room being evaluated. Four video cameras were set up in the medication room and recorded individuals working in the medication room over two days during peak medication administration times (6 a.m. until 12 p.m.). Video analysis involved conducting link analyses and coding instances of bumps, impediments, interruptions, task completion times, selection errors, and searching behaviours. Descriptions of how each of these metrics were defined is described on page 17, scenario enactment data.

POE recommendations

Qualitative and video analysis data led to the identification of issues as well as the development of recommendations to address them. Specifically, the POE identified three recommendations that aimed to enhance quality and patient safety through specific design changes intended to achieve certain anticipated outcomes (Table 3). Anticipated outcomes were derived from the issues that the recommendations intended to address.

First, the POE revealed a number of issues encountered by individuals working within the existing medication room related to the location of the automated medication dispensing cabinet (ADC) and

caregiver's ability to move between medication preparation areas and medication supplies. Relocating the ADC would minimize congestion in the center of the room, thereby allowing better movement throughout the room and minimizing the following identified issues:

- Accessing the ADC (or getting past someone working at the ADC) was one of the most common causes of interruptions during medication preparation activities.
- When preparing or stocking medications, there was no convenient place to store a wireless medication (Wi-Med) cart or pharmacy cart that did not disrupt workflow. The carts were often stored in the center of the room.
- Workflow was disrupted by congestion when multiple people or Wi-Med carts were in the medication room making it difficult to exit, as well as access the sharps container and supplies.
- Workflow and access to the fridge was hindered when the ADC drawers were open.

Second, the POE revealed that when selecting medications from the ADC, the Wi-Med cart placement blocked access to the only sharps container.

Third, the POE revealed that the storage of patient bins above both medication preparation areas resulted in congestion when searching both locations, because care providers then needed to maneuver around Wi-Med carts and open drawers on the ADC.

Table 3: Recommended design changes and anticipated outcomes.

Recommendations	Anticipated Outcomes
1. Switch the location of the medication supplies with the automated medication dispensing cabinet (ADC) and medication preparation area.	▪ reduce the number of interruptions ▪ more effective cart storage ▪ reduce congestion ▪ better access to the fridge ▪ reduce time for medication preparation
2. Include a sharps container within arm's reach of medication preparation areas.	▪ reduce congestion when accessing the sharps container
3. Store all patient bins together.	▪ make it easier to find patient bins ▪ reduce congestion when accessing patient bins ▪ reduce likelihood of selecting the wrong patient bin

Simulation-based Mock-up Evaluation

Following the POE, simulation-based mock-up evaluations were planned for each of the three mock-up types: simple, detailed, and virtual reality (VR). A methodology overview comparing the POE and the three mock-up evaluations can be found in Table 4. The mock-up evaluations are described in greater detail in the subsequent sections.

Table 4: Methodology overview for the evaluations conducted.

<table>
<tr><th>Post-occupancy evaluation</th><th colspan="3">Simulation-based mock-up evaluation</th></tr>
<tr><td>Existing medication room</td><td>Simple mock-ups</td><td>Detailed mock-ups</td><td>Virtual reality mock-ups</td></tr>
<tr><td>Existing layout evaluated</td><td colspan="3">2 medication room layouts evaluated (existing + proposed layouts; Figure 7)</td></tr>
<tr><td>12 hours of medication room usage over 2 days</td><td colspan="3">4 scenarios x 3 evaluation days = 12 scenarios enacted within each layout (Appendix I for scenarios) for each mock-up type</td></tr>
<tr><td>25 medication room users</td><td colspan="3">5 simulation participants x 3 evaluation days = 15 participants for each mock-up type (45 total individual participants)</td></tr>
<tr><td>Direct observation to collect data as part of patient care (Noldus):
workflow (link analysis)
bumps
impediments
interruptions
task completion times
searching behaviours
selection errors
Not evaluated:
equipment placement</td><td colspan="2">Direct observation to collect scenario enactment data (Noldus):
workflow (link analysis)
bumps
impediments
interruptions
task completion times
searching behaviours
selection errors
equipment placement</td><td>Automated collection of scenario enactment data (HyperMock):
workflow (link analysis)
bumps
impediments
interruptions
task completion times
searching behaviours
Not evaluated:
selection errors
equipment placement</td></tr>
<tr><td>Interviews
8 nursing staff
3 pharmacy technicians</td><td colspan="3">Survey data
end-user scenario enactment participants (234 post-scenario enactment surveys + 45 end-of-day surveys received from 45 participants)
other hospital design stakeholders (non-participant stakeholders; 20 surveys from 43 meeting attendees)
recipients of POE recommendations (decision makers; 10 surveys from 10 committee members)</td></tr>
</table>

Scenario development

Various simulation scenarios comprised of up to four roles were developed for enactment within each of the mock-up types (Appendix I). The same scenarios were enacted within each mock-up type. Tasks were selected for scenario enactment which reflected those that are the most frequent (preparing and stocking medications), urgent (STAT medications), and challenging (multiple people working simultaneously) tasks to be performed in the medication room. Scenarios were designed to replicate realistic workflow while interacting with most design elements of the medication room. The scenarios were reviewed by various unit managers and clinical caregivers to ensure realism.

Two of the simulation roles (RN1 and RN2) involved nurses preparing multiple medications for four patients as part of a morning medication pass. A third role (RN3) involved a nurse preparing a STAT (urgently needed) medication for one patient. The fourth role (Rx) involved a pharmacy technician stocking multiple medications and supplies in the medication room. The scenarios varied in the number of people and roles enacted simultaneously within each mock-up type:

- Scenario 1 involved enactment of RN1, RN2, RN3, and Rx roles (one person at a time).
- Scenario 2 involved enactment of RN2 and Rx roles (enacted simultaneously).
- Scenario 3 involved enactment of RN1, RN3, and Rx roles (enacted simultaneously).
- Scenario 4 involved enactment of RN1, RN2, RN3, and Rx roles (enacted simultaneously).

Two different medication room layouts (existing layout and a proposed layout which incorporated POE recommendations) were evaluated through each mock-up type. The same four scenarios were enacted within both of the layouts to allow for direct comparisons. Furthermore, the process was repeated for three days (eight scenarios per day) with new end-user participants each day. Each day, five people were recruited to enact the scenarios, which included registered nurses, licenced practical nurses, and pharmacy technicians. Individuals could only participate in the evaluation of one mock-up type, but everyone enacted scenarios within both room layouts. The order that participants experienced each room layout was counterbalanced such that half of the people experienced one layout first and half experienced the other layout first. In total, 45 people participated (15 people per mock-up type) with no people participating in multiple days or mock-up types.

Scenario enactment data

Various types of data pertaining to workflow, efficiency, and safety were collected from the scenario enactments for analysis to assess the design of the medication room.

Workflow

Movement paths for each individual involved in the scenario enactments were transcribed onto a room layout diagram. This is also referred to as a link analysis. Combining various link analyses allowed for visualization of room utilization, movement patterns, and assisted in identifying high traffic areas within the room.

Bumps

Instances of physical contact between two objects (people and/or equipment) that were not intended to make contact were coded. Both the number of bumps and the frequency to which each object (i.e., the fridge) was involved in a bump were examined.

Impediments

Instances where an individual experienced an object or person that obstructed their path were coded. More specifically, an impediment was defined as an instance where a path travelled between two objects was more than 20 per cent longer and at least one metre longer, because that individual needed to go around a person or moveable object. Both the number of occurrences of impediments as well as impediments experienced while performing specific subtasks (i.e., while disposing of a used needle into the sharps container) were examined.

Interruptions

Instances where an individual's attention, while performing a task, was diverted away from the task at hand by another person were coded. The number of interruptions were examined. Additionally, the location of where the interrupted person was standing when they were interrupted was examined. Location data was plotted onto a room layout diagram to identify areas that were more prone to interruptions. However, the spatial mapping of location data was identified post-hoc (after the scenarios were enacted), and therefore, was not programmed into the VR software for automated data collection.

Task completion times

The time used to perform all tasks for each of the scenario roles was calculated. This time started when the individual entered the medication room mock-up and ended when they exited.

Searching behaviours

Instances where an individual did not know the location of a supply or equipment were coded, and the time spent searching for the supply or equipment was calculated. Although searching behaviours associated with all items were coded, analysis focused on the number of instances and total duration of time spent searching for patient specific bins. The VR software could not be programmed to collect data on searching behaviours. This data was only collected in the simple and detailed mock-ups.

Selection errors

Instances where a nurse mistakenly selected the wrong patients' bin were coded. These bins were patient specific, labelled with a patient identifier, and used to store medications retrieved from the ADC for that patient. At the start of the each scenario, the bins were stored on a shelf in the medication room. During the scenarios, the nurse would select the appropriate bin, fill the bin with the patient's medications, and place the bin into the Wi-Med cart. Selecting the wrong bin has patient safety implications as it could contribute to an adverse event involving the administration of medications to the wrong patient. The number of bin selection errors was examined. This measure was identified post-hoc (after the scenarios were enacted) through participant debriefing sessions, and therefore, was not programmed into the VR software for automated data collection. This data was only collected in the simple and detailed mock-ups.

Equipment placement

The locations where both Wi-Med and pharmacy carts were stored after they were brought into the room during scenario enactments were plotted onto a room layout diagram. This allowed for a visualization of cart placement and frequency count for how often the carts were placed in different locations within the medication room mock-ups. Collecting data regarding equipment placement was identified post-hoc (after the scenarios were enacted), and therefore, was not programmed into the VR software for automated data collection. This data was only collected in the simple and detailed mock-ups.

Scenario enactment data collection

Data was collected following the same process for both physical (simple and detailed) mock-ups as described in the *Simulation-based Mock-up Evaluation Framework*.[1] Introducing the use of VR technology allowed for advances through automation of data collection in the VR mock-ups so that manual coding through direct observation of video recordings was no longer performed.

Simple and detailed mock-ups

Data collection from scenario enactments within the physical mock-ups (simple and detailed) involved two human factors experts independently reviewing video and audio recordings from four different camera angles to code scenario enactment data. Noldus (The Observer XT 11.5©) software was used as a coding platform for most of the data collection. Discrepancies were resolved by having both individuals re-review the video timestamps together to reach consensus and correct the discrepancies. The link analyses were performed by manually drawing out the motion patterns for all participants over an architectural plan within a PowerPoint file while watching video recordings of the scenario enactments. This was the only component of data collection performed by only one human factors expert.

VR mock-ups

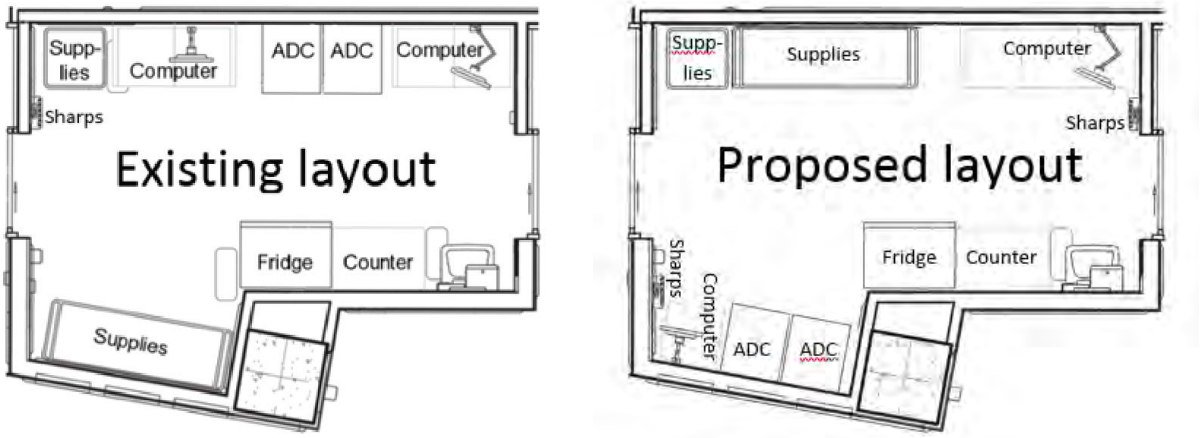
Data collection from scenario enactments within the VR mock-ups were automated through specialized software modules (HyperMock). This took telemetry data (timestamped events of fine-grained activities performed) to identify and automatically code the same scenario enactment data that was manually coded through video analysis with the physical mock-ups. The link analyses were performed through an automated process where the X and Y coordinates of the head-mounted displays were captured during the scenario enactments and used to generate the drawings.

Assessing scenario enactment data validity

The POE findings were used in two ways to assess the validity of mock-up evaluation data. The first involved comparing whether data collected within each of the three mock-up types was consistent and predictive of data collected from the POE. The second was to examine whether the anticipated outcomes from implemented recommendations could be detected through mock-up evaluation data. This occurred by testing two different medication room layouts. One layout replicated the design of the existing medication room that was evaluated through the POE (existing layout); the other layout incorporated the design-based recommendations that came from the POE (proposed layout). Figure 7 illustrates both layouts tested. All three mock-up types were created so that they could be reconfigured to replicate both

layouts. Accuracy of data collected from the mock-up evaluations was assessed by examining if there were differences between the two layouts regarding the anticipated outcomes when enacting the same scenarios within each of the layouts.

Figure 7: The existing medication room layout (left) replicated the design of the medication room evaluated in the POE. The proposed medication room layout (right) incorporated recommendations from the POE.



Switching between the two layouts in the simple mock-ups involved reconfiguring the cardboard pieces representing room furnishings and photos of sharps containers. The detailed mock-ups were constructed with modular furniture supplied by DIRTT. Workstations and sharps containers were unmounted and remounted onto the walls in different locations to switch between the two layouts. Supply carts, on wheels, were moved between two locations. The VR environment was programmed to include both layouts. Participants entering the VR environment used an interactive menu and selected which layout to upload for the scenario enactments.

Survey Data

Paper-based surveys captured subjective feedback regarding the different mock-up types, scenarios, room layouts and experiences/applicability of the evaluation process. Three different user groups were surveyed at various points in the project. The full surveys can be found in Appendix II.

End-user scenario enactment participants (participants)

Post-scenario enactment surveys were completed immediately after each scenario by all participants. In total, 234 surveys (one for each role in every scenario enacted) were completed by the 45 registered nurses, licenced practical nurses, and pharmacy technicians who enacted the scenarios. This captured feedback regarding the room design based on the specific scenario enacted. Another survey, completed at the end of the day by the 45 participants, captured reflections across all scenarios enacted as well as perceptions about the utility of the process to evaluate various aspects of room design. Both surveys were completed and returned by all participants (100 per cent response rate).

Other hospital design stakeholders (non-participant stakeholders)

Approximately 43 individuals attended one of two stakeholder meetings to learn about this project and the different mock-up types being evaluated. These individuals included members of a capital planning team (leadership and project managers), architecture firms, hospital construction companies, clinical leadership, human factors specialists, process improvement consultants, and VR experts. Twenty of the non-participant stakeholders completed and returned a survey regarding perceptions about the ability of each mock-up to inform various aspects of room design (47 per cent response rate).

Recipients of POE recommendations (decision makers)

Recommendations from the POE (including the proposed layout which incorporated the recommendations) as well as findings from the mock-up evaluations were presented to the Medication Management Committee. This committee of decision makers consisted of 10 people, and included leadership from the various hospital units, Pharmacy Services, and Patient Safety at the hospital site where the POE was conducted. This was also the committee which granted approval to conduct the POE. A survey was administered and returned by all decision makers (100 per cent response rate). The survey inquired about whether the POE recommendations would address the identified issues, whether implementing the recommendations would be beneficial, and if they intend to implement the recommendations.

FINDINGS

ROI Level 1: Reaction and Planned Action

Level 1 of the ROI methodology describes desired immediate reactions, highlights issues that are important to success, and emphasizes planned actions that individuals may take based on the results. Given that the goal of the mock-up evaluations was to proactively predict the post-occupancy evaluation (POE) recommendations, it is important to ensure that the recommendations are perceived to be of value. Specifically, the POE recommendations should be perceived as being relevant and beneficial, warranting implementation. Secondly, the mock-ups and scenarios should be realistic. Mock-up and scenario realism is important because these two elements have an effect on what can be discovered as part of a simulation-based mock-up evaluation. And third, hospital design stakeholders (non-participant stakeholders) should perceive the mock-up results to be useful for future projects. Each of these three elements were assessed.

Reaction to POE recommendation

Recommendations from the POE, along with a proposed medication room layout, were presented to the decision makers. Via a paper-based survey they were asked to rate their level of agreement with the following statements:

- The recommendations delivered from the POE are relevant to medication room design.
- Implementing the recommendations would be beneficial.
- I intend to implement the recommendations.

Survey findings indicated that the decision makers strongly agreed that the recommendations are relevant to medication room design (Figure 8). Furthermore, they agreed or strongly agreed that implementing each of the recommendations would be beneficial and they intend to implement the recommendations (Figure 9). These findings suggest that decision makers see value in the recommendations and the proposed layout. It also provides a level of evidence that the recommendations were appropriate and that the two layouts being tested provided a strong foundation to assess the validity of the data gathered through the mock-up evaluations.

Figure 8: Average ratings regarding the relevance of the POE recommendations from decision makers.

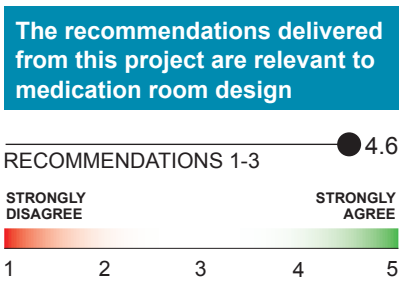
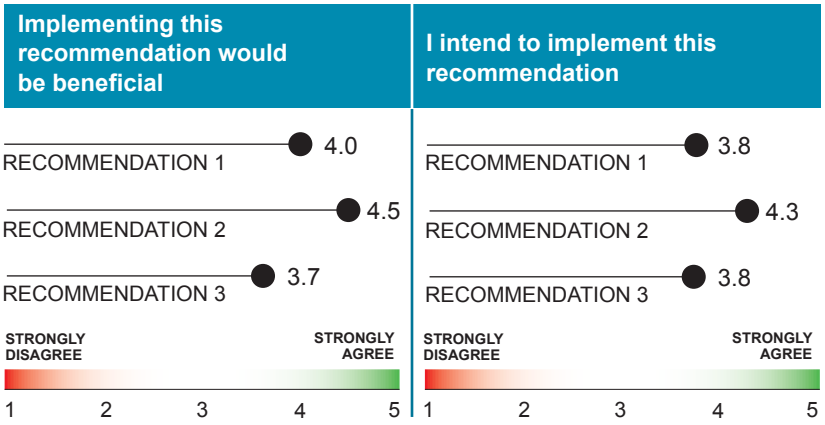


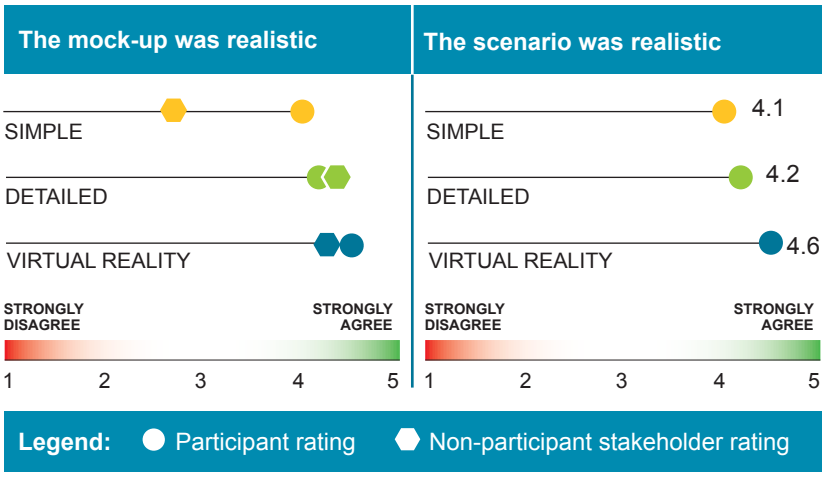
Figure 9: Average ratings from decision makers regarding the degree to which it would be beneficial to implement recommendations (left) and their intention to implement recommendations (right).



Realism

Participants and non-participant stakeholders were asked to rate the degree to which the mock-up was realistic for each mock-up type. Participants were also asked to rate the degree to which the scenarios they enacted were realistic. The results are summarized in Figure 10. Both participants and non-participant stakeholders agreed or strongly agreed that the detailed and VR mock-ups were realistic. Participants also agreed that the simple mock-ups were realistic; however, non-participant stakeholders did not agree that the simple mock-ups were realistic. Participants agreed that the scenarios they enacted were realistic across all three mock-up types; even strongly agreeing, on average, that the VR mock-up scenarios were realistic. Except for the realism of the simple mock-ups (as rated by non-participant stakeholders), this pattern of results suggests that the mock-ups and scenarios enacted were perceived to be realistic.

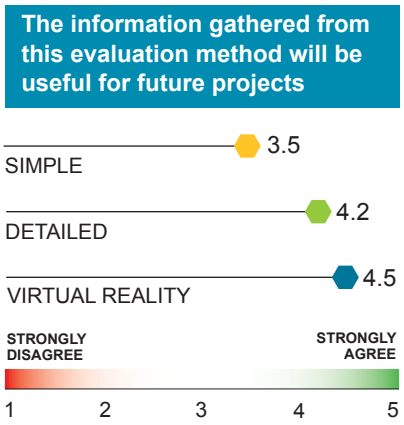
Figure 10: Average ratings regarding the perceived realism of the mock-ups (left) and scenarios enacted (right) within each mock-up type.



Evaluation utility

Non-participant stakeholders were asked to rate whether they thought the information gathered from an evaluation within each mock-up type would be useful for future projects. Results indicated that non-participant stakeholders agreed that all three mock-up types would be useful; however, they rated simple mock-ups lowest, while VR mock-ups were rated the highest (Figure 11).

Figure 11: Average ratings from non-participant stakeholders regarding the degree to which information gathered would be useful for future projects.



ROI Level 2: Learning and Confidence

Level 2 of the ROI methodology describes the ability to obtain new information, skills, and knowledge. This was assessed in three ways. First, decision makers were surveyed about whether they thought the recommendations would result in each of the anticipated outcomes, if implemented. This is important because the anticipated outcomes were used to assess the data validity of the mock-up evaluations. Second, end-user participants assessed their ability to contribute to a better medication room design through the simulation-based mock-up evaluation process. Finally, end-user participants and non-participant stakeholders were surveyed to assess what design considerations could be accurately evaluated within each mock-up type.

Likelihood that recommendations would produce anticipated outcomes

Each of the three POE recommendations had anticipated outcomes (Table 3). Decision makers were asked to rate the degree to which they thought each recommendation would result in the anticipated outcomes. There was agreement that all anticipated outcomes would occur (Figures 12-14), with one exception. Decision makers neither agreed nor disagreed that storing all patient bins together (recommendation 3) would reduce the likelihood of selecting the wrong patient bin (anticipated outcome of recommendation 3; Figure 14). There was strong agreement towards recommendation 2; including a sharps container within arm's reach of medication preparation areas would reduce congestion when accessing the sharps container.

Figure 12: Average ratings from decision makers regarding the anticipated outcomes resulting from switching the location of medication supplies with the automated medication dispensing cabinet (ADC) and medication preparation area (recommendation 1).

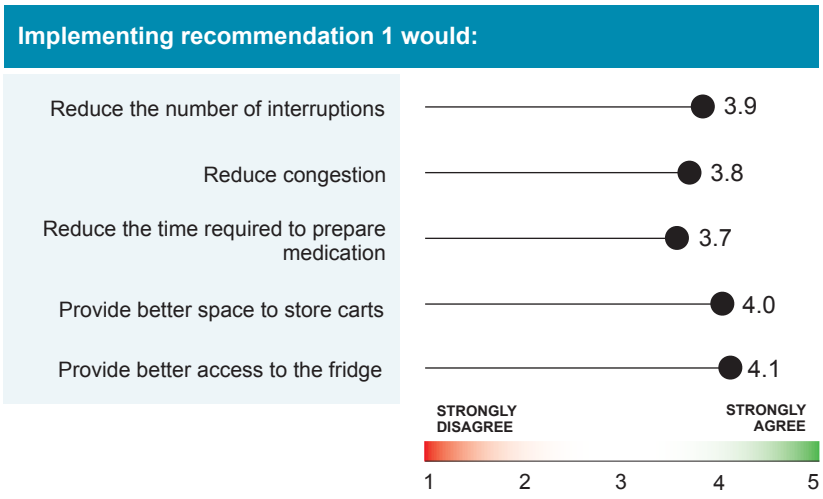


Figure 13: Average ratings from decision makers regarding the anticipated outcomes resulting from having the sharps container located within arm's reach of medication preparation areas (recommendation 2).

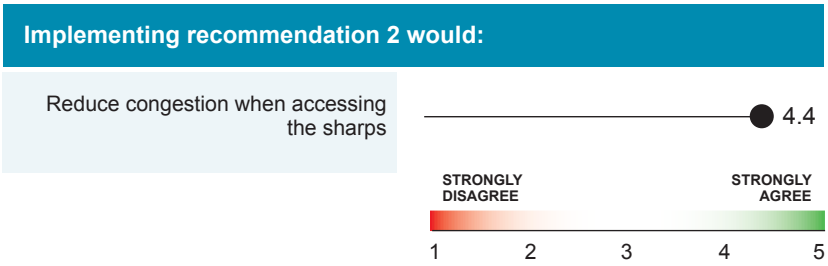
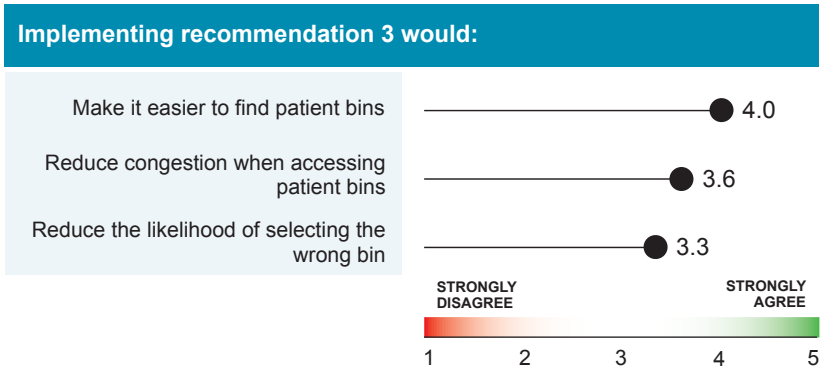


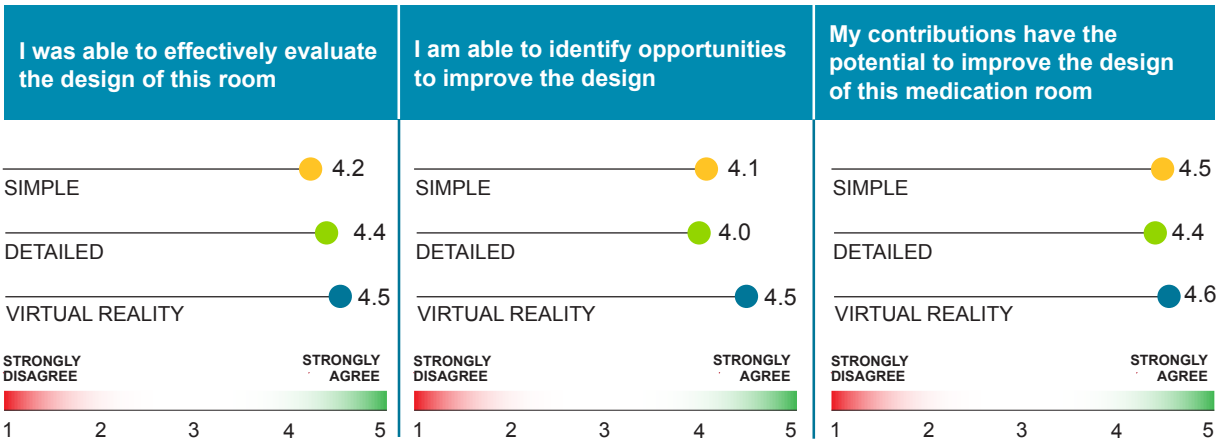
Figure 14: Average ratings from decision makers regarding the anticipated outcomes resulting from having all patient bins stored together (recommendation 3).



Perceived contributions from participants

Scenario enactment participants were asked to rate their perceived ability to contribute to a better medication room design through the simulation-based mock-up evaluation process. Participants agreed or strongly agreed that their involvement in the mock-up evaluation process allowed them to effectively evaluate the design of the room (Figure 15, left) and identify opportunities to improve the design (Figure 15, centre). Furthermore, they strongly agreed that their contributions have the potential to improve the design of the medication room (Figure 15, right). Although ratings were high across all mock-up types, participants in the VR mock-ups consistently rated the effect of their contribution higher than those who participated in the detailed and simple mock-ups.

Figure 15: Average ratings from scenario enactment participants regarding their contributions to improve the design of the medication room.



Perceived applicability of evaluation results

End-user participants and non-participant stakeholders were asked to rate the degree to which they felt a simulation-based mock-up evaluation would provide accurate feedback regarding various potential design considerations. The list of potential design considerations were those which were listed in the *Simulation-based Mock-up Evaluation Framework*.[1] It's important to note that this list is not intended to be exhaustive. Furthermore, mock-ups may be used for reasons beyond design assessments. The results are summarized in Figure 16.

Simple mock-ups were generally rated lower than detailed and VR mock-ups, especially when rated by non-participant stakeholders. End-user participants and non-participant stakeholders agreed that two design considerations could be accurately evaluated through simple mock-ups; room size as well as design or design feature comparisons. However, neither of these two received strong agreement from both groups. Although the actual reasons for the limited perceived accuracy are unknown, it may be related to non-participant stakeholder perceptions that simple mock-ups were not realistic.

Detailed mock-ups were rated by both participants and non-participant stakeholders as being able to provide fairly accurate feedback regarding all design considerations evaluated. Specifically, both participants and non-participant stakeholders either agreed (four design considerations) or strongly

agreed (11 design considerations) that simulation-based mock-up evaluations conducted in detailed mock-ups would provide accurate feedback. Furthermore, non-participant stakeholders and participants both indicated the accuracy of feedback would be better with detailed mock-ups than other mock-up types when evaluating room size as well as design or design feature comparisons.

VR mock-ups were also rated by both participants and non-participant stakeholders as being able to provide fairly accurate feedback. Specifically, participants and non-participant stakeholders either agreed (five design considerations) or strongly agreed (10 design considerations) that simulation-based mock-up evaluations conducted in VR mock-ups would provide accurate feedback.

Figure 16: Average ratings regarding perceived accuracy to evaluate various design considerations.

ROI Level 3: Application and Implementation

Level 3 of the ROI methodology describes the intermediate outcomes that provide the foundation to evaluate job performance changes, and often identifies the behaviours which are observable and measurable. This was assessed by examining the predictive validity of data gathered from the mock-up evaluations. It was also assessed by examining the consistency between subjective ratings from participants and objective behavioural data collected from the scenario enactments.

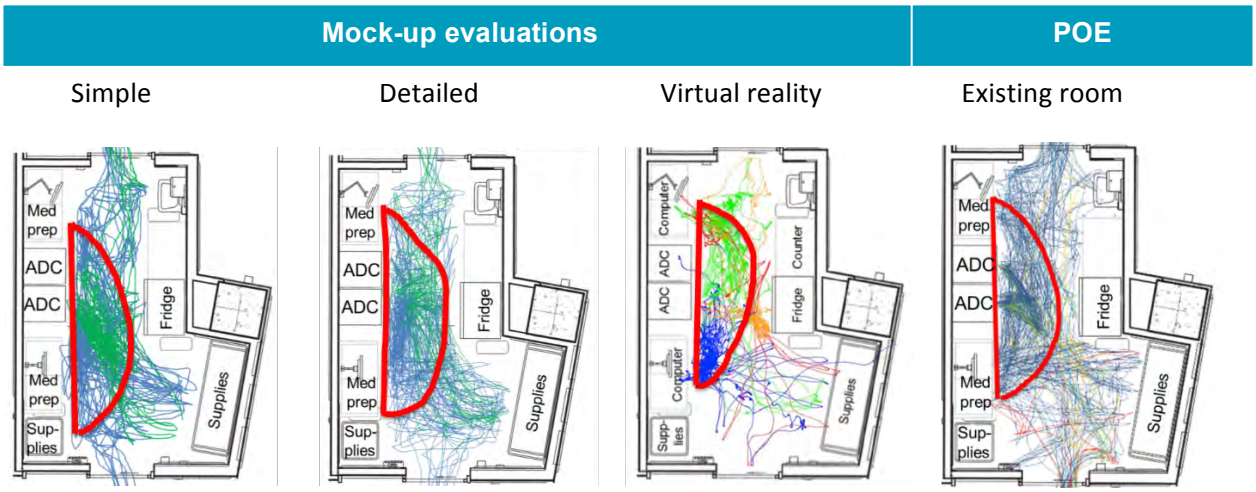
Predictive validity

Comparisons were made between behavioural data collected from the mock-up evaluations and the POE. Specifically, predictive validity was assessed by examining the degree to which there was consistency with respect to workflow, task completion times and the location of interruptions. These comparisons are important to allow for accurate generalizations from scenario enactments within the mock-ups to real-world workflows.

Workflow

Link analysis data was used to identify high traffic areas within the medication room based on both the mock-up evaluations and the POE. Although a link analysis was performed for all scenarios enacted, only a subset (a link analysis for one scenario from each mock-up type) has been included here for illustrative purposes (Figure 17, simple, detailed, virtual reality). This subset was chosen because they represent fairly typical workflows when comparing across scenarios. Each depiction illustrates the motion patterns for end-user participants enacting a scenario involving four people utilizing the medication room simultaneously. This includes workflow from the time each person entered the medication room until they completed the scenario and exited the room. Consistent across all mock-up types, the link analyses suggest that the medication room was fully utilized and the areas in front of the ADC and medication preparation areas were subject to the most traffic. This observation was consistent with existing medication room usage data collected over two days from the POE (Figure 17, existing room). Therefore, this supports the notion that workflow within each of the three mock-up types accurately represents realistic workflow in a medication room.

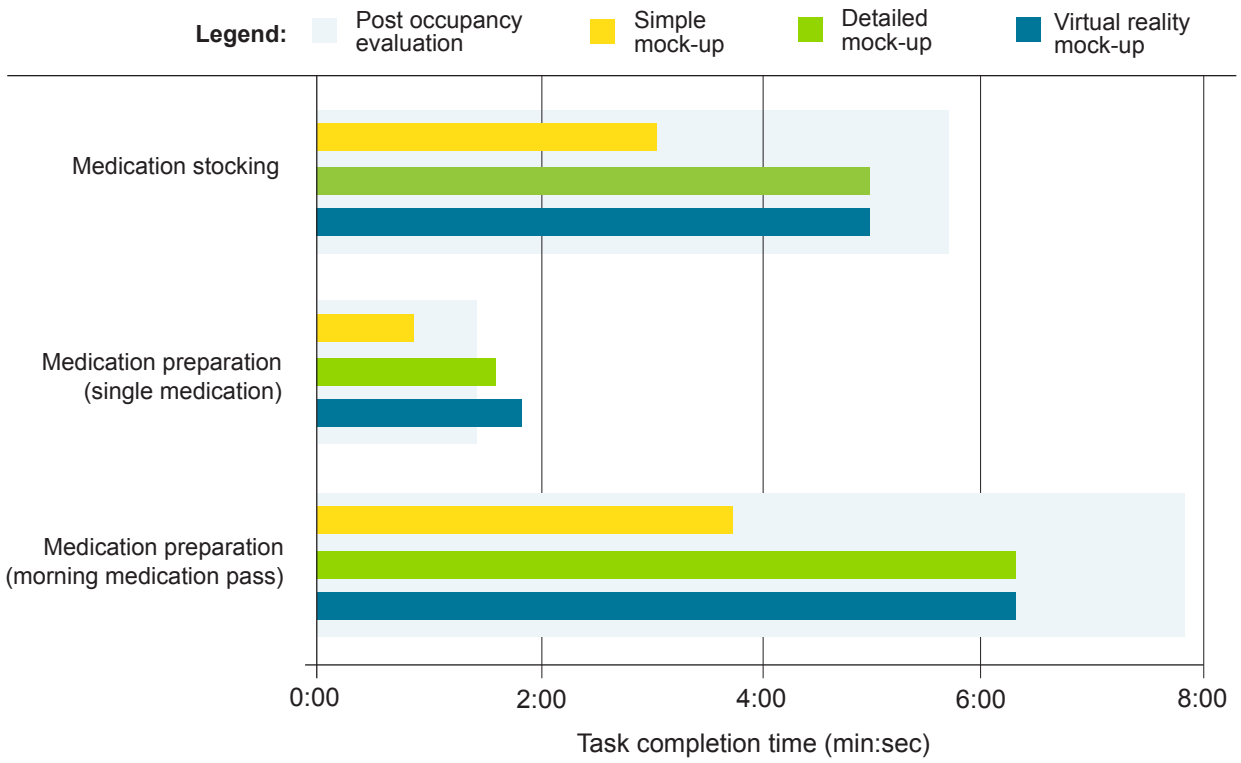
Figure 17: Sample link analyses illustrating workflow from mock-up evaluation scenarios which involved four people using the medication room simultaneously (simple, detailed, virtual reality) as well as from the POE of the existing medication room. The red line indicates the area with the highest volume of traffic.



Task completion times

The average time required to perform various tasks in the mock-up evaluations was calculated and compared to the average time to perform equivalent tasks within the existing medication room from POE data. Using detailed and VR mock-ups obtained higher levels of accuracy in task completion times compared to simple mock-ups (Figure 18). Times are likely shorter when performing tasks in simple mock-ups because items such as medications and supplies were intentionally not included to best reflect the level of fidelity of most simple mock-ups. Because these items were not included, medication preparation and stocking processes tended to be abbreviated. Findings suggest detailed and VR mock-ups should be used when time-based measures are of interest.

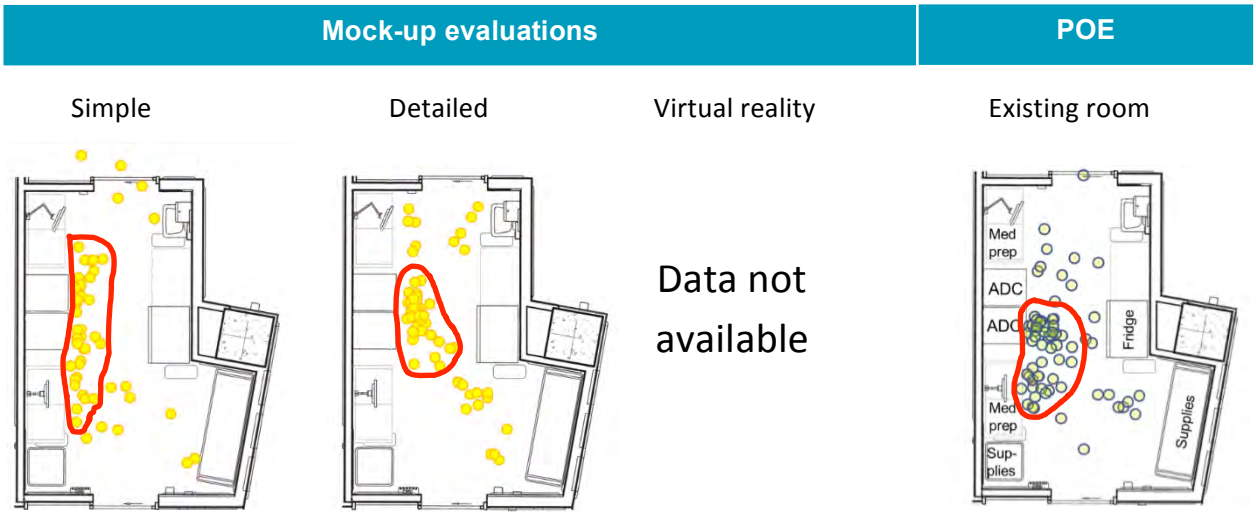
Figure 18: Average task completion times comparing mock-up evaluation data to POE data of the existing medication room.



Interruptions

Interruption data was aggregated across all scenarios enacted within each mock-up type (Figure 19, simple, detailed, virtual reality) as well as the POE (Figure 19, existing room). Yellow dots depict the location of where individuals were interrupted. Most interruptions occurred to coordinate or prioritize who was accessing the ADC, others occurred because of space constraints and needing to get past someone, and a small per cent were social in nature or to access various items in the room (i.e., patient bins, supplies, etc.). The pattern of results for the simple and detailed mock-ups revealed that most of the interruptions occurred in close proximity to the ADC, consistent with POE data. One subtle difference was that the detailed mock-ups did not reveal a clustering of interruptions in front of the medication preparation areas. This occurred in the simple mock-ups and the POE. It is not clear why this occurred. Data from the VR mock-ups was not available because spatial mapping of interruption data was not specified in the procurement process and, therefore, was not programmed into the software capabilities. In an exploratory mock-up evaluation, post-hoc analyses are likely to occur as participant debriefing comments are used to inform data analytic strategies.

Figure 19: Interruption data aggregated across scenarios comparing mock-up evaluation data to POE data of the existing medication room.



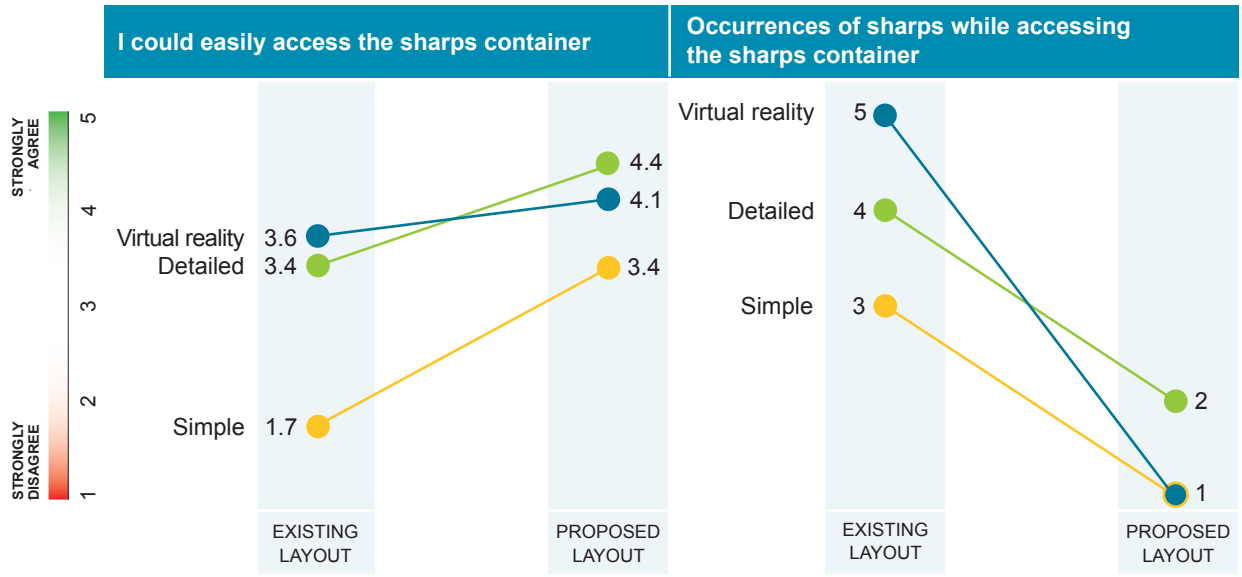
Subjective and objective measurement consistency

After enacting each scenario, end-user participants rated various aspects of their experience while working within each layout. In addition to subjective participant experiences, objective behaviours corresponding to their subjective experiences were coded. Pairings included subjective and objective measures which focused on access to the sharps container and congestion within the room. Comparisons were made to determine if the direction that each of these measures changed was consistent between the subjective and objective measures when comparing the existing to the proposed layouts.

Access to the sharps container

Congestion when disposing of a used needle is a safety issue, as it increases the probability of a needle-stick injury. Nurses who used the sharps container were asked to rate ease of access. Behavioural data was also examined to see how often individuals experienced impediments (needing to go around something) when disposing of a used sharp. Results suggested that participant perceptions of sharps container access were consistent and inversely related with observed occurrences of impediments while accessing the sharps container across all mock-up types (Figure 20). Specifically, access was rated lower (subjective measure) and more impediments were observed (objective measure) for the existing medication room layout across all mock-up types. This suggests that subjective and objective measures of congestion when accessing the sharps container were consistent.

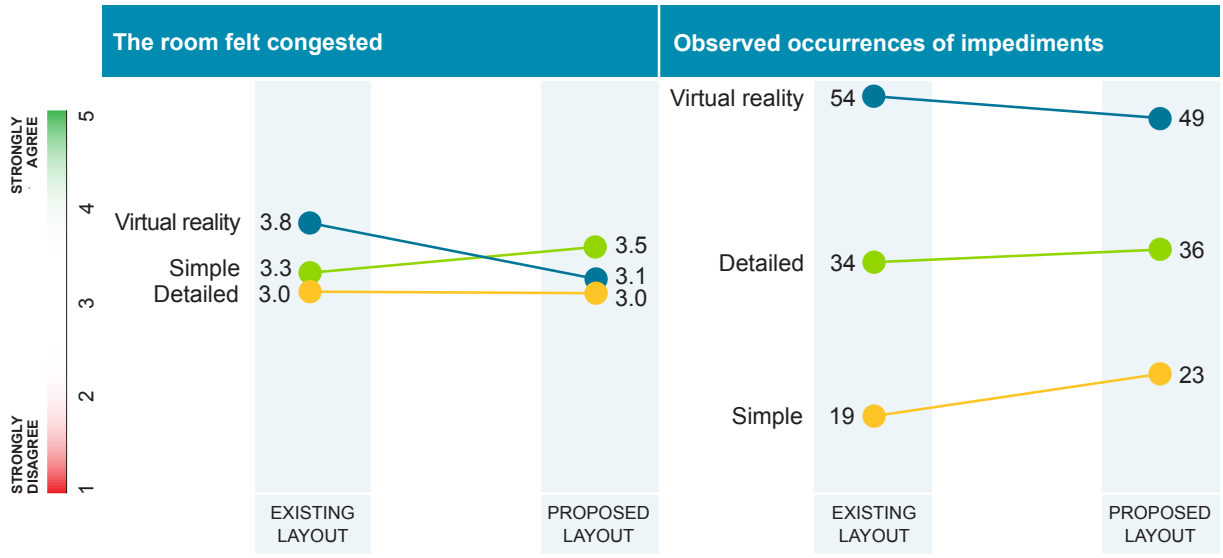
Figure 20: Subjective (left) and objective (right) measures regarding access to the sharps container.



Room congestion

After enacting every scenario, end-user participants were asked to rate the degree to which they felt the room was congested (subjective measure). Behavioural data regarding room congestion was also examined and included the total number of occurrences of impediments, defined as when an individual experienced an object or person obstructed their path (objective measure). Subjective and objective findings consistently identified the proposed layout as being slightly more congested when using the simple mock-ups, equally (or nearly equally) congested in the detailed mock-ups, and less congested when using the VR mock-ups. This suggests that objective and subjective measures of room congestion were consistent across all three mock-up types (Figure 21), although patterns were not. This is discussed later in the document (Reduce congestion, page 38).

Figure 21: Subjective (left) and objective (right) measures regarding room congestion.



ROI Level 4: Business Impact

Level 4 of the ROI methodology describes the expected outcomes from implementation and is typically expressed as output, quality, cost, and time. This was assessed by looking at whether the data collected from the mock-up evaluations was capable of detecting measurable differences in anticipated outcome measures when comparing the existing layout to the proposed layout.

As previously noted (Table 3), the proposed layout incorporated three recommended design changes from the POE. Each of the recommendations was expected to result in specific anticipated outcomes as identified through the POE. Decision makers agreed that the recommendations would result in eight of the nine anticipated outcomes (Figures 12-14). Furthermore, decision makers were in agreement that the recommendations were relevant to medication room design (Figure 8), and would be beneficial if implemented (Figure 9, left). To assess whether mock-up evaluations are capable of detecting measurable differences, the anticipated outcomes were measured in both the existing and proposed layouts; the same scenarios were enacted in both layouts. Using the anticipated outcomes, the two room layouts were compared. Results, with differences in support of the anticipated outcomes between the two layouts, were interpreted to indicate a level of accuracy in the data collected from the mock-up evaluation for that mock-up type.

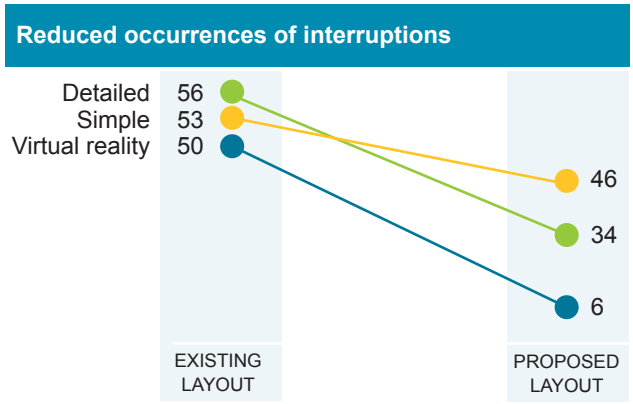
Recommendation 1:

Switch the location of the medication supplies with the ADC and medication preparation area. Data regarding interruptions, wireless medication (Wi-Med) and pharmacy cart storage, congestion, access to the fridge, as well as medication preparation time was examined, because implementing this recommendation was expected to affect these areas.

Reduce the number of interruptions

Interruptions were defined as an event where a person's attention, while performing a task, was diverted away from their task at hand by another person. Interruption data indicated that fewer interruptions occurred in the proposed layout, compared to the existing layout (as anticipated) in all mock-up types (Figure 22). However, the difference observed in the simple mock-ups was minimal (13 per cent reduction) when compared to findings from the detailed and VR mock-ups (39 per cent and 88 per cent reduction, respectively). This suggests that all mock-up types can be considered by design teams interested in assessing interruptions, but detailed and VR mock-ups may be better suited / more sensitive in detecting potential differences.

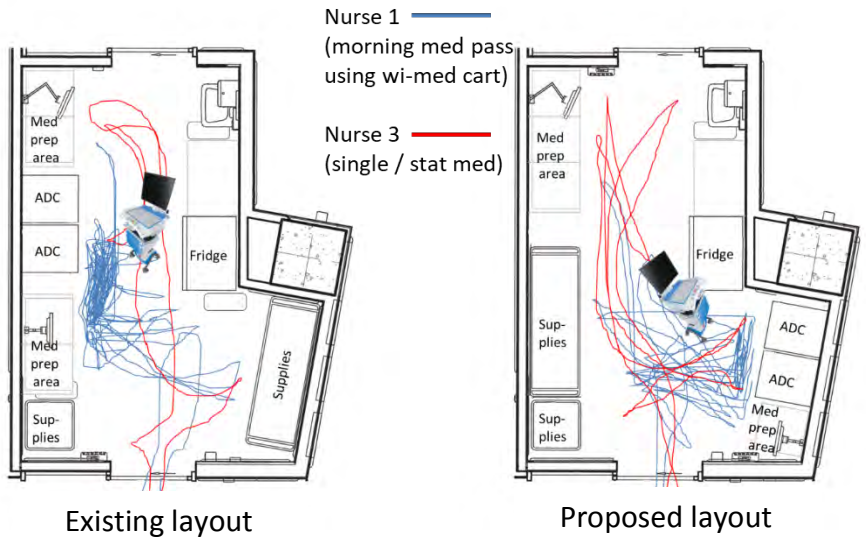
Figure 22: Total occurrences of interruptions across scenario enactments. A reduction of interruptions was an anticipated outcome.



More effective cart storage

Cart storage in the centre of the room was found to hinder workflow and cause interruptions. The workflow data (link analyses; Figure 23) illustrates typical workflow. The blue lines show movement for one nursing role (RN1) who was tasked with preparing multiple medications using a Wi-Med cart. The red lines show movement of a second nurse (RN3) who was tasked with preparing a single STAT (urgently needed) medication. In both the existing and proposed layouts, RN1 typically stored the Wi-Med cart in close proximity to the ADC to easily transfer medications from the ADC into the Wi-Med cart. When stored in the center of the room (existing layout; Figure 23, left), the Wi-Med cart impeded movement of RN3 between the available medication preparation area and the supplies. In the proposed layout, the workflow data illustrates how the Wi-Med cart storage location is less obstructive, enabling movement behind the Wi-Med cart while preparing the STAT (urgently needed) medication.

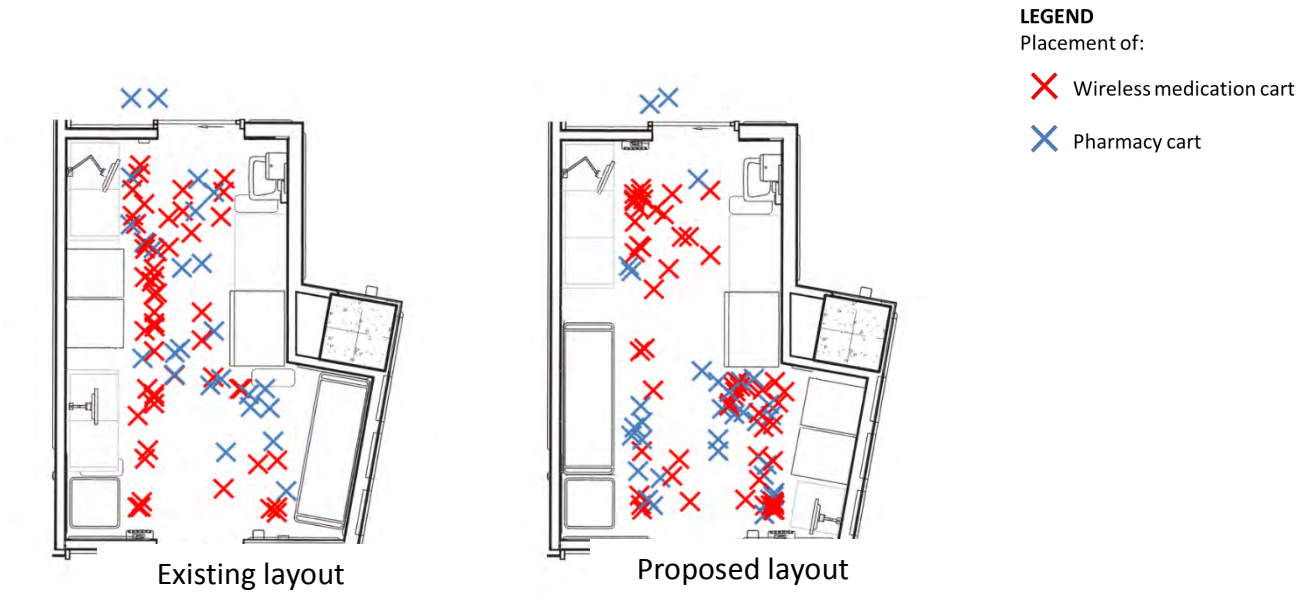
Figure 23: Typical cart placement during medication preparation. A less obstructive cart storage location was an anticipated outcome.



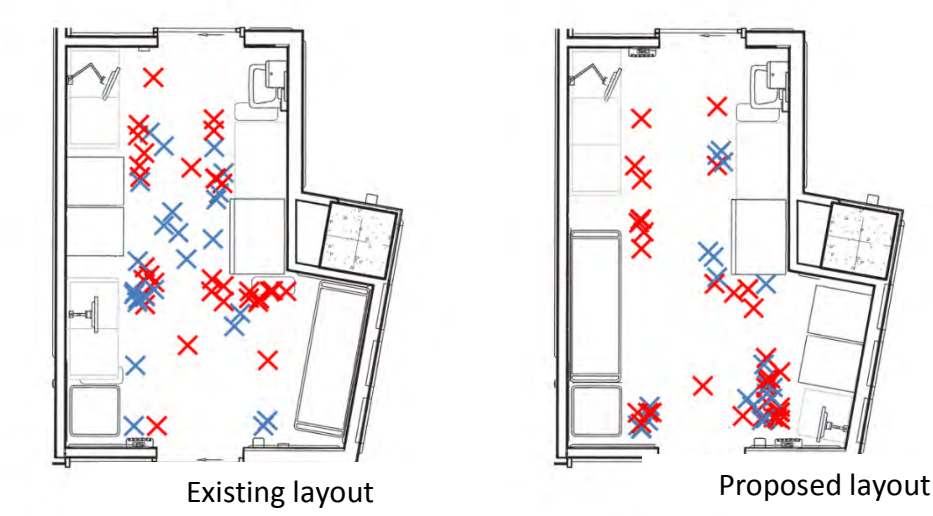
To more directly examine how design changes affected cart placement, the location where both Wi-Med carts and pharmacy carts were placed or stored during scenario enactments were plotted onto a room layout diagram (Figure 24). This comparison was identified after the scenario enactments had occurred based on workflow data, interruption data, and debriefing comments. The results suggest that the carts were more likely to be stored in the alcove area in the proposed design of the medication room, enabling better workflow throughout the rest of the room when compared to the existing design (as anticipated). Specifically, end-user participants in the simple mock-ups stored their carts in the alcove 51 per cent of the time in the proposed layout, and only 21 per cent of the time in the existing layout. The same pattern occurred in the detailed mock-ups; participants stored their carts in the alcove 49 per cent of the time in the proposed layout, and only 23 per cent of the time in the existing layout. This suggests that simple and detailed mock-ups can be considered by design teams interested in assessing equipment placement. The VR mock-ups were not programmed to identify equipment placement as part of the automated data collection process because this was not identified *a priori* and therefore not included as a requirement in the procurement process.

Figure 24: Cart placement across all applicable scenario enactments. A less obstructive cart storage location was an anticipated outcome.

Simple mock-up



Detailed mock-up



Virtual reality mock-up

Data not available

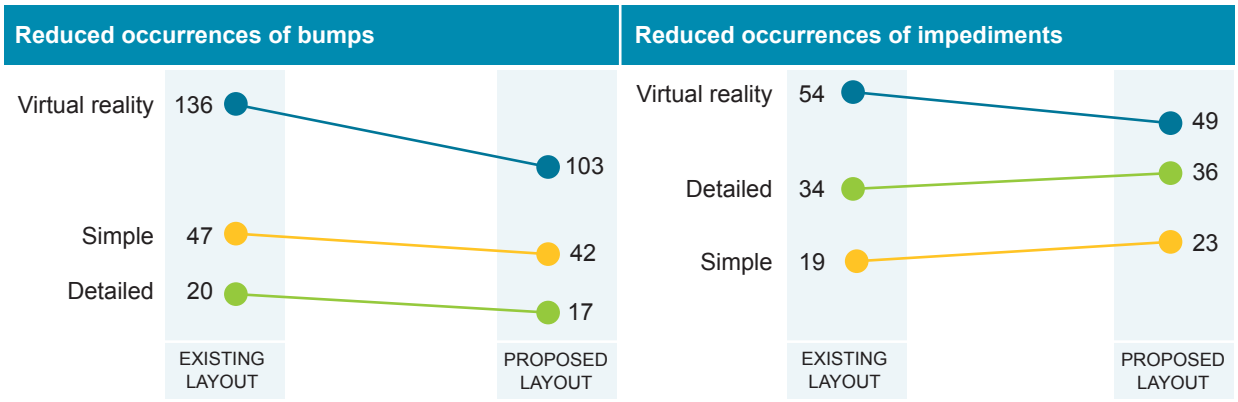
Reduce congestion

Congestion was assessed by examining occurrences of bumps (when a person or object unintentionally makes contact with another person or object) and impediments (needing to go around a person or object to access something). Bump data suggested that there was a reduction in the total number of bumps (as anticipated) across all mock-up types (Figure 25, left). The decrease was minimal for simple and detailed mock-ups (11 per cent and 15 per cent reduction, respectively), whereas a moderate reduction occurred in the VR mock-ups (24 per cent reduction). In summary, this suggests that all mock-up types can be considered by design teams interested in assessing bumps, but VR mock-ups may be better suited / more sensitive in detecting potential differences.

Only the VR mock-ups indicated a reduction in the frequency of impediments (as anticipated), although the reduction was minimal (nine per cent; Figure 25, right). The simple mock-ups indicated the opposite of what was anticipated – an increase in the amount of impediments (21 per cent increase). Almost no change was indicated in the detailed mock-ups (six per cent increase). Upon further inspection of the impediment data, many instances of impediments in both designs involved circling around the carts. Interestingly, many individuals working in the proposed design parked their carts beside the fridge as noted above (Figure 24). Placement of the carts beside the fridge was not anticipated. Instead, the design was based on an assumption that the carts would be placed in front of the medication preparation area beside the ADC (which also occurred, but less frequently). When individuals parked their carts beside the fridge, they would then need to circle around the cart (coded as impediments) in order to access supplies or items stored in the fridge, explaining why more impediments were experienced in the proposed design.

Although contradicting the anticipated outcome, the data revealed an important, and likely accurate, unintended consequence of the proposed design. Given this inconsistency, and possible explanation, impediment data will be further examined through other congestion data collected.

Figure 25: Total occurrences of bumps (left) and impediments (right). A reduction of bumps and impediments were anticipated outcomes.

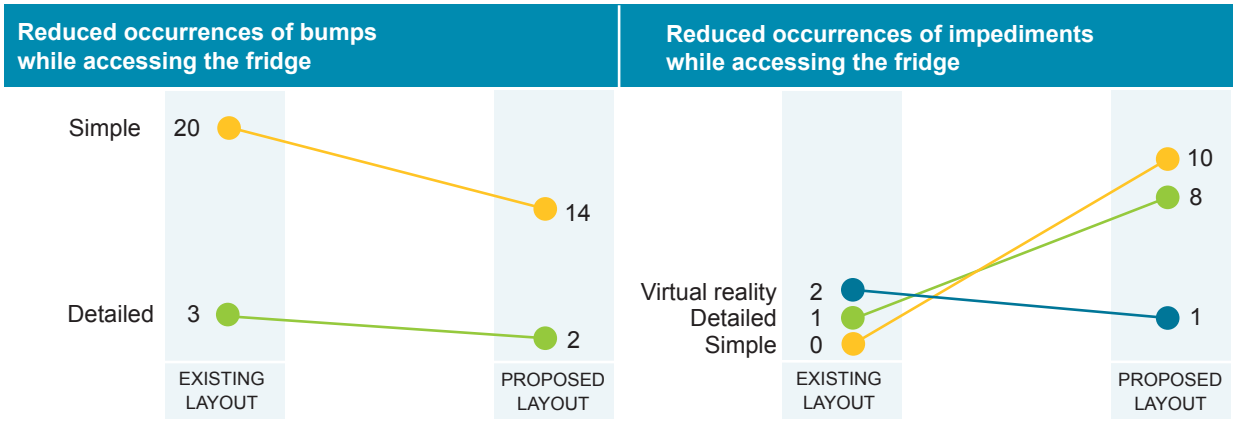


Better access to the fridge

Access to the fridge was assessed by examining the total number of occurrences where people or objects bumped into the fridge, as well as the total number of occurrences of impediments (needing to go around a person or object) while trying to access the fridge. Bump data from the simple and detailed mock-ups indicated that the proposed layout resulted in a reduction in the number of bumps while accessing the fridge (as anticipated), compared to the existing layout (30 per cent and 33 per cent reduction, respectively; Figure 26, left). The VR mock-ups were not programmed to identify bumps involving the fridge and, therefore, could not be assessed. These results provide further support for design teams to use simple and detailed mock-ups when interested in bump data. It also highlights the need for *a priori* measurement clarity when procuring or programming VR software.

Data from the VR mock-ups suggested the proposed layout resulted in a reduction in impediments (as anticipated), compared to the existing layout (50 per cent reduction; Figure 26, right). However, data from the simple and detailed mock-ups suggested that more impediments were experienced while accessing the fridge in the proposed layout, which is the opposite of what was anticipated. As previously noted, the Wi-Med and pharmacy carts were most often placed beside the fridge while working at the ADC in the proposed layout. Consequently, participants then needed to circle around the cart in order to access the fridge, which is an unintended outcome. As previously noted, impediment data will be further examined through other data collected regarding congestion, given this inconsistency and possible explanation.

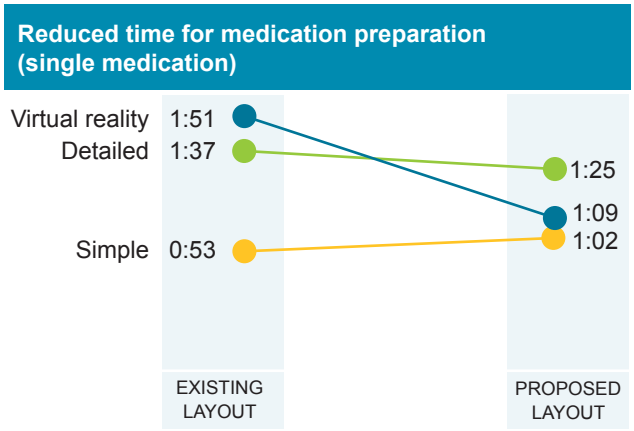
Figure 26: Total occurrences of people or equipment bumping into the fridge (left). Total occurrences of impediments while accessing the fridge (right). A reduction of bumps and impediments while accessing the fridge were anticipated outcomes.



Reduce time for medication preparation

Medication preparation time was assessed by examining how long nurses were in the medication room to prepare their medications. One of the scenarios involved selecting and preparing medications for a patient requiring a single STAT (urgently needed) medication. This scenario was specifically used for this measure because of the importance of task completion time in an urgent situation. Data suggested that the proposed layout resulted in a reduction in the time required to prepare medications (as anticipated) for both the detailed and VR mock-ups (12 per cent and 38 per cent reduction, respectively); however, the opposite was found to occur for the simple mock-ups (17 per cent increase; Figure 27). As such, detailed and VR mock-ups can be considered by design teams interested in assessing time-based measures, whereas simple mock-ups may not produce accurate results. This is consistent with the predictive validity data for task completion times (Figure 18).

Figure 27: Average time to prepare a single medication (min:sec). A reduction in time for medication preparation was an anticipated outcome.



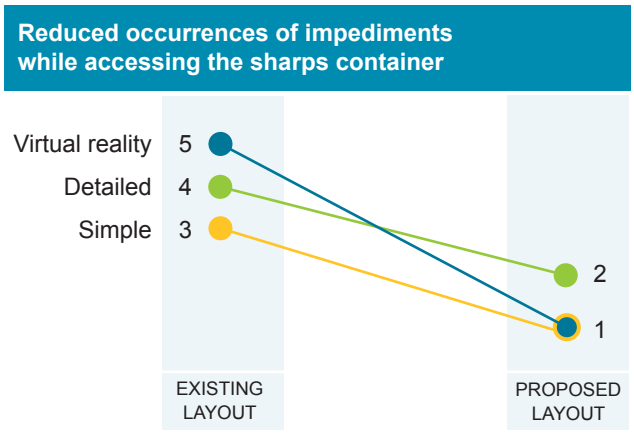
Recommendation 2:

Include a sharps container within arm's reach of medication preparation areas. Data regarding impediments when accessing the sharps container was examined.

Reduce congestion when accessing the sharps container

Congestion was assessed by examining the occurrences of impediments (needing to go around an object) while carrying a used needle to the sharps container after preparing an injectable medication. Data suggested that the proposed layout resulted in a reduction in the occurrences of impediments when accessing the sharps container (as anticipated), and this reduction was observed across simple, detailed and VR mock-ups (67 per cent, 50 per cent, 80 per cent reduction, respectively; Figure 28). This provides evidence towards the use of impediment data when evaluating any mock-up type.

Figure 28: Total occurrences of impediments while placing a used needle in the sharps container. A reduction of impediments while accessing the sharps container was an anticipated outcome.



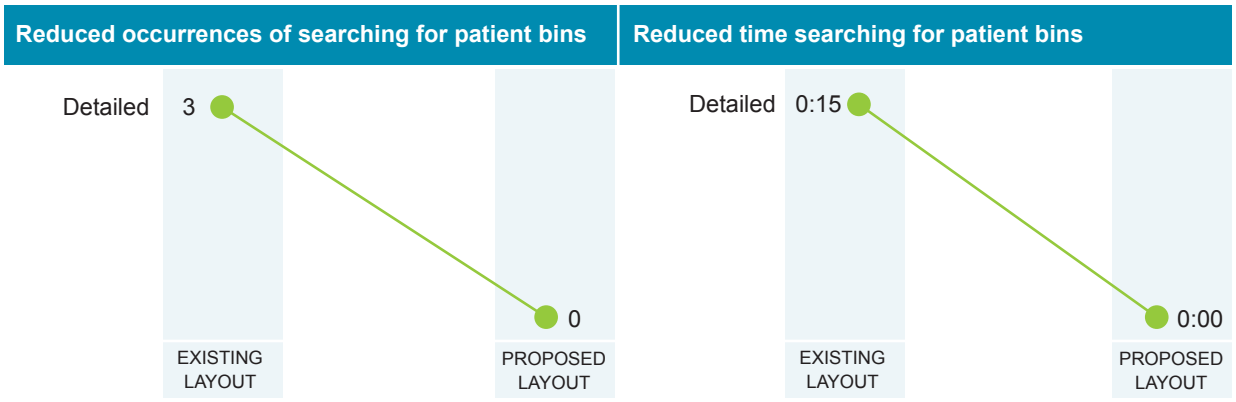
Recommendation 3:

Store all patient bins together. Data regarding participants searching for patient bins, impediments while accessing patient bins, and the time spent waiting to access patient bins was examined.

Make it easier to find patient bins

Patient bins were labelled with the patient's name in the detailed and VR mock-ups. Patient bins were not included in the simple mock-ups because simple mock-ups typically do not include this level of detail. The VR software could not be programmed to identify searching behaviours as part of the automated data collection process. Therefore, it was not possible to assess this anticipated outcome in the simple or VR mock-ups. Searching for a patient bin was defined as looking in the wrong location for a specific bin and needing to search another location. Time searching started when a participant looked in the wrong location and ended when they found the bin. Ease of finding patient bins was assessed by examining the total number of occurrences of searching for patient bins, as well as the total time spent searching for patient bins. Data from the detailed mock-ups suggested that it was easier to find patient bins in the proposed layout (as anticipated; Figure 29). Specifically, the number of occurrences and time spent searching for bins decreased (100 per cent reductions). There were no instances of searching for patient bins and no time spent looking in the wrong locations for patient bins in the proposed layout, when the bins were co-located. This provides support for the use of searching data in detailed mock-ups. It also highlights that collecting searching data is likely not possible in simple or VR mock-ups.

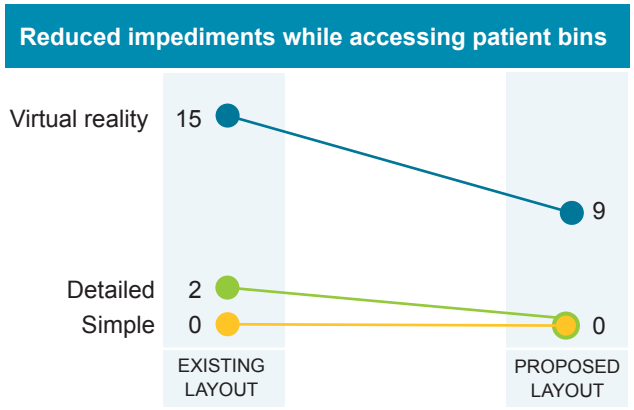
Figure 29: Total occurrences searching for a patient bin (left). Total time spent searching for patient bins (min:sec; right). A reduction in occurrences and time searching for patient bins were anticipated outcomes.



Reduce congestion when accessing patient bins

Congestion was assessed by examining impediments (needing to go around a person or object) while trying to access a specific patient's bin. Data suggested that the proposed layout reduced the occurrences of impediments when accessing patient bins (as anticipated) for both detailed and VR mock-ups (100 per cent and 40 per cent reduction, respectively; Figure 30) when compared to the existing layout. This provides further evidence for the use of impediment data for detailed mock-ups. It also provides the first evidence towards the use of impediment data for VR mock-ups. There were no instances of impediments within the simple mock-ups while accessing patient bins in either the existing or proposed layout. Although patient bins were not used in the simple mock-ups, participants still pretended to retrieve the bins. Because of this, participants could retrieve the bins from either storage location as well as the most accessible position at that location. This made it less likely that participants would experience congestion. Finding that there was no impediments while accessing the patient bins in either layout is more likely due to the fidelity of the mock-ups than their ability to access the bins. For this reason, it is important to consider how fidelity might affect measurement.

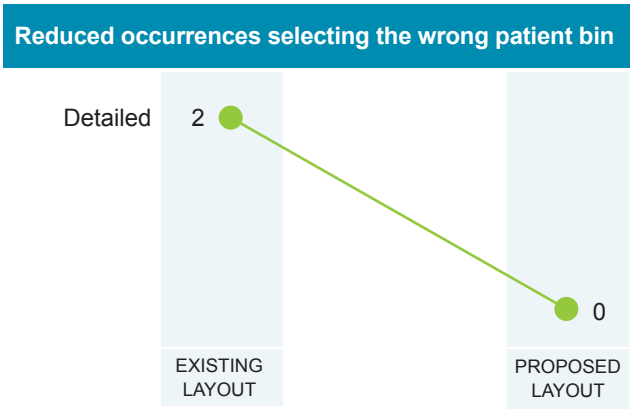
Figure 30: Total occurrences of impediments while accessing patient bins. A reduction of impediments while accessing patient bins was an anticipated outcome.



Reduce likelihood of selecting the wrong patient bin

This measure was assessed by examining occurrences where end-user participants mistakenly selected the wrong patient's bin. This has patient safety implications as it could contribute to an adverse event involving the administration of medications to the wrong patient. Because patient bins were not included in the simple mock-ups, participants were pretending to select patient bins and, therefore, selection errors could not be detected. Data from the detailed mock-ups suggested that the proposed layout resulted in a reduction in the total number of occurrences where the wrong patient bin was selected (as anticipated), compared to the existing layout (100 per cent reduction; Figure 31). The VR mock-ups were not programmed to identify when the wrong patient bin was selected because this behaviour was not identified *a priori* and, therefore, was not included as a requirement in the procurement process. This reinforces the need for *a priori* measurement clarity when procuring or programming VR software. The results provide evidence supporting detailed mock-ups when human error data is of interest, whereas simple mock-ups may not produce accurate results.

Figure 31: Total occurrences of selecting the wrong patient bin. A reduction of selecting the wrong patient bin was an anticipated outcome.



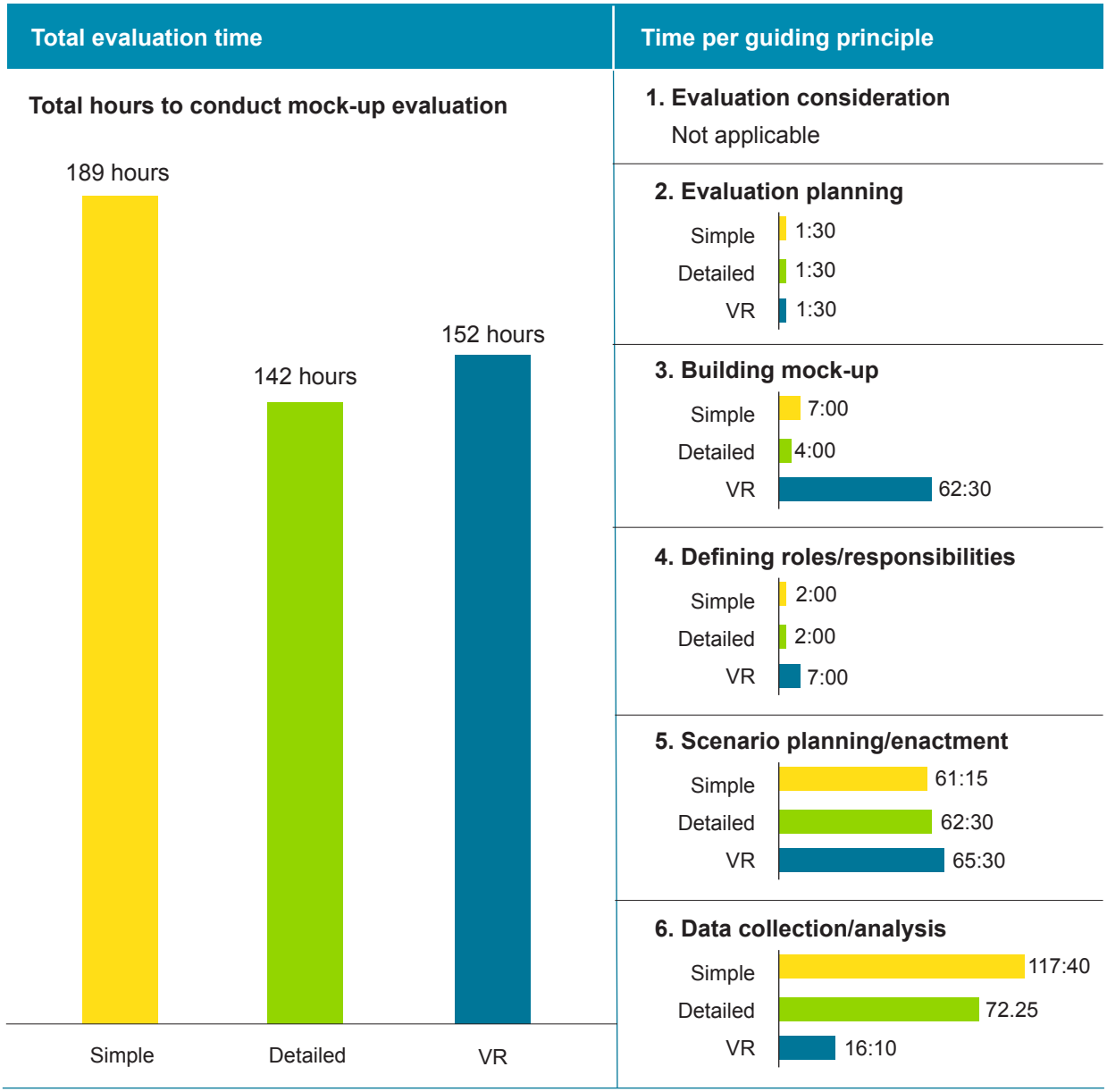
ROI Level 5: Return on Investment

Level 5 of the ROI methodology describes the comparison of the monetary benefits of an intervention versus the costs of that intervention, and may be expressed in various forms. This section will examine data specific to each mock-up type, including hours used to conduct the evaluation, associated costs, and monetary benefits. To highlight how this data varies between mock-up types, as well as between guiding principles, results are reported at an aggregate level and are also broken down to be specific to each of the six guiding principles from the *Simulation-based Mock-up Evaluation Framework*.[1]

Time requirements

The time required to conduct these simulation-based mock-up evaluations is reported in Figure 32. Conducting an evaluation with the simple mock-ups took 189 hours. Comparatively, evaluating with detailed mock-ups took 142 hours (a 35 per cent reduction in hours) and evaluating with VR mock-ups took 152 hours (a 20 per cent reduction in hours). Most of the differences occurred as part of guiding principles 3 and 6. Specifically, the VR mock-ups took more time to 'build' (programming time), which involved working with the VR vendor to embed appropriate interaction capabilities into the mock-ups and also to program capabilities into the software to automate the data collection process (guiding principle 3). Conversely, simple and detailed mock-ups required much more time during data collection/analysis, manually coding behavioural data from all of the videos (guiding principle 6). The difference between the simple and detailed mock-ups was due to ambiguities involved with coding behavioural data in simple mock-ups. For example, because many physical objects are not used in simple mock-ups, it becomes difficult to identify when two objects bump into each other or to identify what objects or supplies the participants were using. Consequently, coding the behavioural data was more time consuming and resulted in a greater number of discrepancies to be resolved.

Figure 32: Total hours to conduct the simulation-based mock-up evaluations (hrs:min).

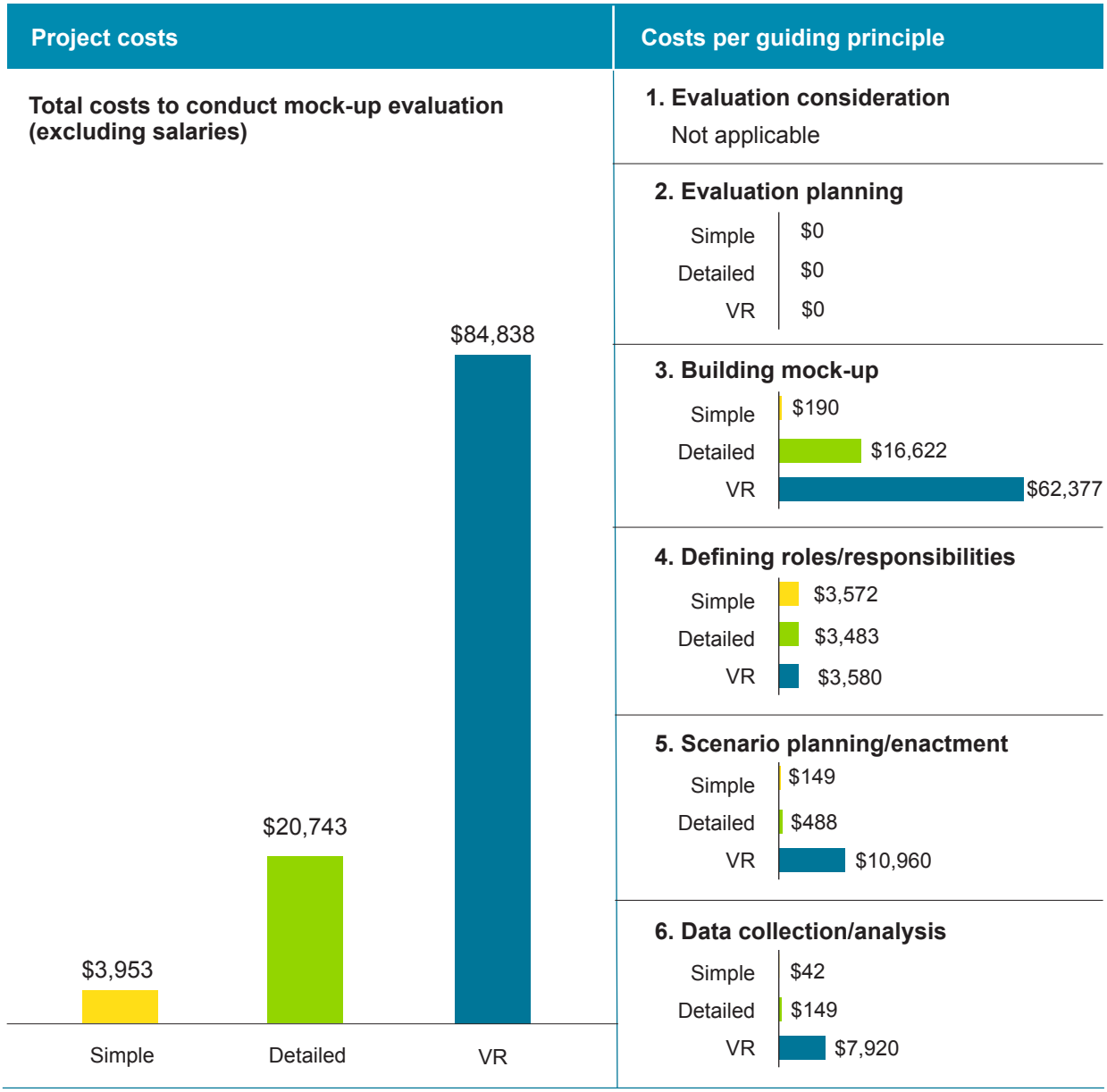


Project costs, excluding salaries

The costs associated with this project included creating the mock-ups (construction of physical mock-ups, programing for the VR mock-ups), travel expenses, honorariums paid to end-user participants, and lunch catering. The space required to house all three mock-ups was provided at no cost. Although many organizations will have access to space to house the mock-up at no cost, rental cost of a facility may be an additional cost for some organizations. Evaluating the VR mock-ups required significantly greater costs ($84,838) than both the detailed mock-ups ($20,743; which is 76 per cent or $64,095 less than the VR mock-ups) and the simple mock-ups ($3,953; which is 95 per cent or $80,885 less than the VR mock-

ups) (Figure 33). Most of the differences were due to the costs of building or programming the mock-ups.

Figure 33: Project costs (excluding salaries) to conduct the simulation-based mock-up evaluations.

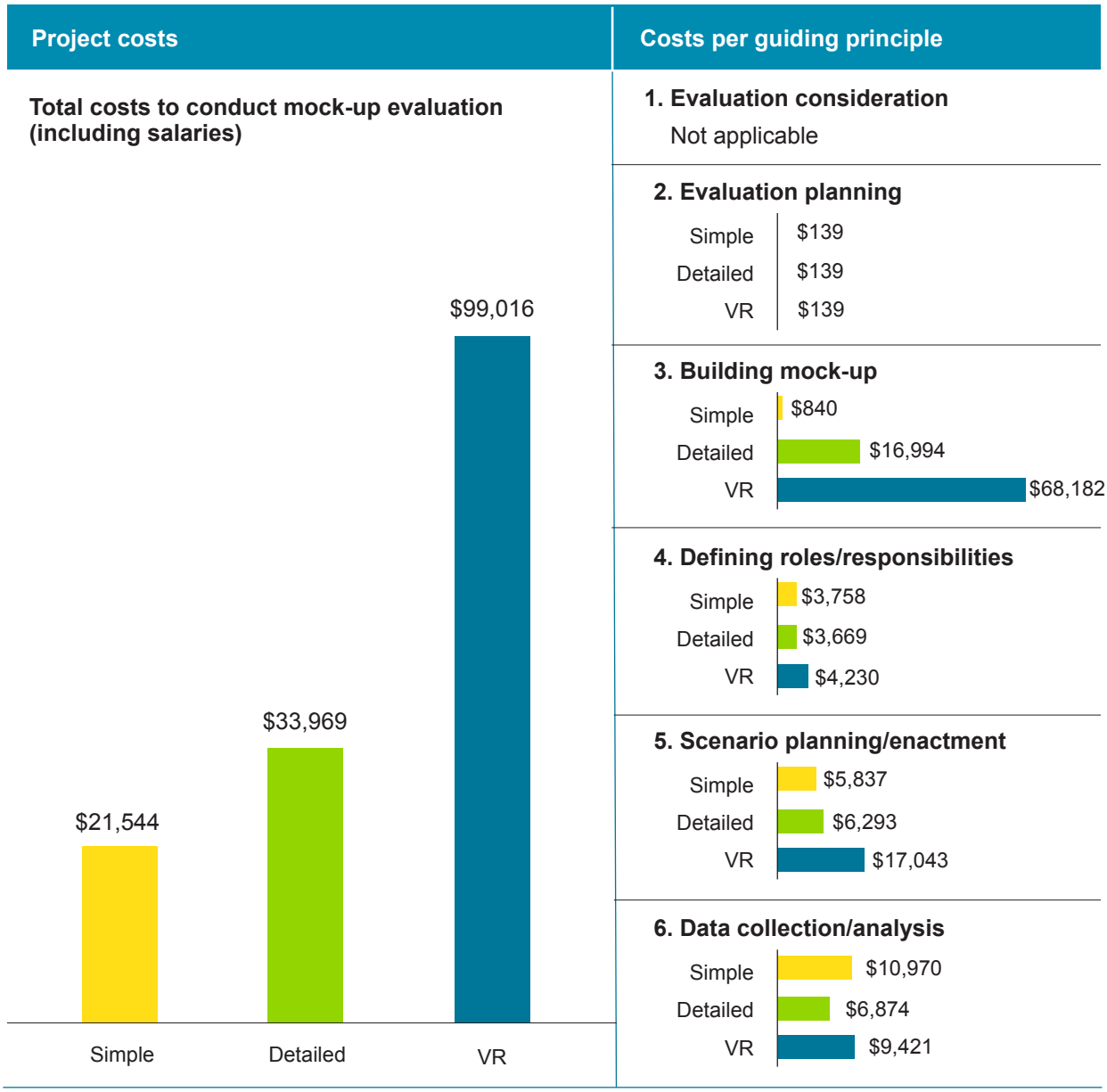


Project costs, including salaries

The soft costs for personnel time of the human factors experts, reported as hours in Figure 32, were added to the hard costs reported in Figure 33. Hourly rates were calculated based on the average payroll (including benefits) for a Human Factors Specialist ($72.87 per hour), plus the general and administrative expenses of the organization ($20 per hour). With salaries included, evaluating the VR

mock-ups still required significantly greater costs ($99,016) than the detailed mock-ups ($33,969; which is 66 per cent or $65,047 less than the VR mock-ups) and the simple mock-ups ($21,544; which is 78 per cent or $77,472 less than the VR mock-ups) (Figure 34).

Figure 34: Project costs (including salaries) to conduct the simulation-based mock-up evaluations.



Net project benefits

Simulation-based mock-up evaluations can enhance quality and patient safety, as is demonstrated below (ROI: Intangible benefits, page 49). By conducting this type of evaluation prior to construction, organizations can prevent costs associated with change order requisitions during the construction process or future renovations after the construction process. The introduction described an adverse

event investigation which recommended that medication rooms be assessed and renovated.[22] The renovations began with a medication room redesign pilot project which involved an allocated $1 million to renovate seven medication rooms. Although not the same medication rooms, the ROI calculation described next is based on the cost avoidance from renovating medication rooms at the hospital where the existing medication room was located. Although these rooms were not actually renovated at the time of this write up, the decision makers indicated that implementing each of the recommendations would be beneficial and that they intend to implement the recommendations (Figure 9).

The capital planning department of the organization with the existing medication room provided average cost ranges to renovate a medication room, and noted two ranges: one for minor medication room renovations ($75,000 - $100,000) and one for typical medication room renovations ($250,000 - $300,000). As per the ROI guiding principles, the most conservative renovation cost was selected to calculate ROI (a minor renovation using the lowest cost estimate: $75,000). This produced the most conservative approach to calculate ROI.

The facility where the POE occurred has eight medication rooms, all of which used the same template for the medication room design. Standardization of medication rooms is important for patient safety. Therefore, the cost to renovate the eight medication rooms at this facility would cost $600,000 based on the most conservative renovation estimate per room (eight rooms x $75,000).

ROI calculation

ROI is a financial metric which is calculated using the project benefits and costs. When presented as a per cent ROI, it is calculated using the following formula:

$$\text{ROI (\%)} = \frac{\text{Net Project Benefits (project benefits-project costs)}}{\text{Project Costs}} \times 100$$

This ROI calculation is based on the notion that discovering the design opportunities during the design process would avoid a renovation after occupancy. The project cost included salaries for the human factors experts.

Simple mock-up ROI: $\frac{\$600{,}000 - \$21{,}544}{\$21{,}544} \times 100 = 2685\%$

Detailed mock-up ROI: $\frac{\$600{,}000 - \$33{,}969}{\$33{,}969} \times 100 = 1666\%$

VR mock-up ROI: $\frac{\$600{,}000 - \$99{,}016}{\$99{,}016} \times 100 = 506\%$

These ROI calculations suggest that depending on the type of mock-up used, an ROI between 506% and 2685% can be anticipated. Stated more specifically, (1) for every dollar invested in simple mock-ups $26.85 can be saved after the investment is recovered, through the avoidance of future renovations, (2) for every dollar invested in detailed mock-ups $16.66 can be saved after the investment is recovered, and (3) for every dollar invested in VR mock-ups $5.06 can be saved after the investment is recovered. Most importantly, all mock-up types have the potential to produce a positive ROI when used to conduct a simulation-based mock-up evaluation. Furthermore, the potential savings reported here are intended to be conservative; larger returns could be expected as technologies advance, or when evaluating larger groups of rooms. Worth noting, these ROI calculations assume the results and opportunities to improve

the design are equal across the three mock-up types. The data reported above highlights that this assumption is not accurate, and thus the decision regarding the most appropriate mock-up should be based on which mock-up type offers the best ROI as well as its ability to answering the questions of interest.

ROI: Intangible benefits

One of the most significant findings is that all three mock-up types were able to generate accurate data regarding interruptions (Figure 22) and thereby test design concepts intended to reduce interruptions. Incorporating the three recommended design changes into the medication room mock-ups reduced the number of interruptions that occurred within the medication room mock-ups. The amount of decrease ranged from 13 – 88 per cent. Research suggests that interruptions occur frequently during medication preparation and are associated with procedural failures and clinical errors.[24]

Prior research examining the introduction of separate medication rooms found that both interruptions and error rates were reduced.[25] Given that interruptions are the leading cause of medication errors, [23] designing medication rooms to further reduce the frequency of interruptions will likely reduce the number of medication errors. Although there is a large range in the estimated costs of a medication error, all estimates suggest that reducing medication errors would produce costs savings.[31] Because the data collected here did not quantify medication error rates, the potential costs savings were not included in the ROI calculations.

Beyond reducing the number of interruptions, the detailed mock-ups were able to identify and evaluate selection errors where individuals selected the wrong patient's medication bin. Selecting the wrong bin could contribute to an adverse event involving the administration of medications to the wrong patient. This highlights a second patient safety implication that was not included in the ROI calculation.

Access to a sharps container while disposing of used needles was an additional design element that was effectively assessed and improved through all mock-up types. Having sharps containers within arms reach of medication preparation areas will likely minimize the likelihood of needle stick injuries.

Additional intangible benefits include improved access to patient bins (as well as less time searching for patient bins), and a reduced time needed to prepare STAT (urgently needed) medications.

DISCUSSION

Multiple factors are considered by design teams when deciding if and what type of a mock-up should be used as part of a healthcare facility design process. Mock-ups can serve many purposes beyond evaluating the design of a space; however, these other purposes are not specifically discussed in this document. When a simulation-based mock-up evaluation is planned with the intent to evaluate a design, organizations should consider cost-effectiveness and accuracy of data collection. Information pertaining to the accuracy of data is reported throughout this document. Figure 1 summarizes which types of data can accurately be assessed within each mock-up type based on predictive validity, subjective and objective measurement consistency, as well as their ability to predict various outcome measures. Figure 1 also summarizes the financial return on investment (ROI).

Figure 1: Types of data which can be accurately assessed with each mock-up type as well as the return on investment realized.

TYPES OF DATA	Simple mock-up	Detailed mock-up	Virtual reality mock-up
Workflow			
Bumps			
Impediments			
Interruptions			
Task completion times			
Searching behaviours			
Selection errors			
Equipment placement			
Amount saved per dollar invested	**$26.85**	**$16.66**	**$5.06**

Legend: Data validity was used to categorize types of data as being:

 Accurate

 Accurate but less sensitive

 Not accurate/ possible

 Not Assessed

Simple Mock-ups

Simple mock-ups are inexpensive to create and produced the largest ROI when used to conduct a simulation-based mock-up evaluation. However, simple mock-ups were perceived by participants and non-participant stakeholders as only able to accurately evaluate room size and compare room layouts. When evaluating simple mock-ups the findings suggest that workflow (link analysis), equipment placement, as well as bumps, impediments, and interruptions can be accurately assessed (Figure 1).

Detailed Mock-ups

Detailed mock-ups are more costly to construct, but still have a very high ROI. They were perceived to offer the best level of fidelity to evaluate room size, design or design feature comparisons, space

requirements for equipment or processes, and team functioning or performance. The findings suggest that all types of data listed in Figure 1 can be accurately assessed using detailed mock-ups including workflow, bumps, impediments, interruptions, task completion times, searching behaviours, selection errors, and equipment placement.

Virtual Reality (VR) Mock-ups

VR mock-ups were the costliest option; however, they still achieved a positive ROI. They were perceived to be the best fidelity to evaluate supplies and/or equipment, as well as adverse events (depending on how this is measured). The findings suggest that workflow (link analysis), as well as bumps, impediments, interruptions, and task completion times can be accurately assessed using VR mock-ups (Figure 1).

Equipment placement and selection errors were identified post-hoc (after the scenarios were enacted) and were not specified as a requirement in the procurement process, therefore, they were not programmed for automated data collection. This highlights the importance of *a priori* measurement clarity when procuring or programming VR software. The VR software could not be programmed to identify searching behaviours. Because data collection can be automated, VR mock-ups are particularly beneficial for projects where sufficient planning time is allocated but a short turnaround time between the scenario enactments and delivery of recommendations is desired.

VR technologies are quickly evolving and costs are decreasing. The VR mock-up evaluation for this project occurred in 2017. There have already been numerous advances in VR capabilities since that time including wireless VR headsets, decreased hardware costs, and asset development. As an example, much of the programming that occurred to furnish the medication room mock-ups with interactive equipment could be re-used in future evaluations. Similarly, the programming to automate the data collection process would not need to be re-programmed, excluding the introduction of new metrics, and this would reduce the programming time/costs in future evaluations. Given this was one of the first times that VR technologies have been used to conduct a simulation-based mock-up evaluation, advances through future iterations are expected. As such, it is anticipated that VR will become an increasingly cost effective mock-up type. Furthermore, what was not possible at the time when this evaluation occurred, will likely be possible in the near future (if not already). Machine learning has also been advancing rapidly and can be leveraged in the future to substantially improve behavioral coding to include searching and other behaviors.

CONCLUSION

Non-participant stakeholders suggested that conducting simulation-based mock-up evaluations (regardless of the mock-up type) is likely to produce findings that are useful for future projects. Moreover, the process engages front line clinicians in a couple of ways. First, clinicians felt they were able to effectively evaluate the design of the room, and second, they felt their contributions have the potential to improve the room design.

Additionally, all three mock-up types produced a positive return on investment (ROI). However, not all mock-up types are appropriate or effective to assess all evaluation objectives. There were differences between the three mock-up types in the data's ability to predict various outcomes. Given these findings,

organizations considering a simulation-based mock-up evaluation should select the most appropriate mock-up type with consideration of:

- cost-effectiveness; and
- accuracy of data that would permit assessment of evaluation objectives of interest to the design team (Figure 1).

Selecting an appropriate mock-up type based on these considerations is anticipated to further advance the effectiveness for organizations who are considering, planning, or are currently conducting simulation-based mock-up evaluations as part of their design process.

APPENDICES

APPENDIX I

Scenario: RN1

You have just come on shift and are preparing to administer your morning medication pass. You have four patients assigned to you (Patient A, Patient B, Patient C and Patient D). To prepare for your medication pass, you will be taking your Wi-Med cart into the medication room, gathering the blue patient specific bins for your patients, filling the patient specific bins with needed medications and supplies, and then placing the patient specific bins into your Wi-Med cart. Once you have gathered meds and supplies for all of your patients, you exit the medication room through the same doors you entered (door 1).

To open the med room door, touch the card reader (black box beside the doors). Place your hands under the faucet, soap, or hand sanitizer to indicate usage. To view the electronic medication administration record (eMAR) touch any computer screen, except for the screen on the Automated Dispensing Cabinet (ADC). Touch it again to view the next medication ordered. The eMAR will also indicate where medications are stored. To retrieve medications, touch the ADC computer screen which will direct you to an ADC drawer or the fridge. Injectable medications can be prepared by gathering the medications and supplies needed, placing them onto a work surface and holding the progress ball (symbolizes time typically used preparing the IV bag). Supplies are stored on the supply shelf and in the drawer below the med prep areas with the computers. When preparing pantoprazole, assume the vial is premixed and the patient already has a primary line running in their room so you only need the secondary line. You don't need to get the AeroChamber for the inhaler because it is stored in the supply room.

RN1 Tasks

- enter medication room from door 1 with a Wi-Med cart
- use the hand sanitizer
- get patient specific bins for Patients A,B,C,D and place bins onto any work surface
    - NOTE: Blue bins for patient are above both med prep areas. They are labelled "Patient A", etc.

Prepare Medications for Patient A

- use any computer to identify which medications are needed for Patient A
- gather medications for Patient A and put them into the bin for Patient A
    - dalteparin inj 5,000 unit(s) SUBCUTANEOUSLY q24h, start at 08:00 (from ADC)
    - KCl 40 mmol in 0.9% NaCl infusion (Known as: potassium chloride 40 mmol in 0.9% NaCl infusion) 1,000 mL IV <Continuous>, start at 08:00 at 100 mL/hour (from large supply shelves)
    - metoPROLOL tab 50 mg PO bid, start at 08:00 (from ADC)
    - ibuprofen tab 800 mg PO daily, start at 08:00 (from ADC)
- put Patient A's bin into Wi-Med cart

Prepare Medications for Patient B

- use any computer to identify which medications are needed for Patient B
- gather medications for Patient B and put them into the bin for Patient B
    - acetaminophen tab 650 mg PO daily, start at 08:00 (from ADC)
    - thiamine tab 100 mg PO daily, start at 08:00 (from ADC)
    - metoPROLOL tab 50 mg PO bid, start at 08:00 (from ADC)
    - amoxicillin / clavulante tab 875 mg / 125mg PO bid, start at 08:00 (from ADC)
    - pantoprazole inj 40 mg IVPB daily, start at 08:00, requires secondary line only (from ADC, in 100ML 0.9% NaCl)
- gather the following for preparation of Pantoprazole
    - medication added label, orange (from drawer below med prep area)
    - IV line label, white (from drawer below med prep area)
    - alcohol swabs (from drawer below med prep area)
    - blunt fill needle (from large supply shelves OR drawer below med prep area)
    - 20 mL syringe (from large supply shelves)
    - 100 mL 0.9% Sodium Chloride injection USP (from large supply shelves)
    - secondary medication set (from small supply shelves)
- prepare Pantoprazole IV bag
    - hold progress ball at work surface until task is completed
    - throw out garbage
    - put syringe and needle into sharps bin
    - put IV bag and line label into patient bin
    - put secondary medication set onto Wi-Med cart
- put Patient B bin into Wi-Med cart

Prepare Medications for Patient C

- use any computer to identify which medications are needed for Patient C
- gather medications for Patient C on put them into the bin for Patient C
    - diclofenac 2.32% gel Apply TOPICALLY for back pain bid, start at 08:00 (from ADC)
    - salbutamol inhaler 1 puff(s) INHALED daily, start at 08:00 (from ADC)
    - amoxicillin / clavulante tab 875 mg / 125mg PO bid, start at 08:00 (from ADC)
    - thiamine tab 100 mg PO daily, start at 08:00 (from ADC)
- put Patient C's bin into Wi-Med cart

Prepare Medications for Patient D

- use any computer to identify which medications are needed for Patient D
- gather medications for Patient D on put them into the bin for Patient D
    - ampicillin inj 1 g IVPB once, start at 08:00, in 100 mL mini-bag plus (from fridge [entered into ADC first, ADC direct to bin in fridge])
    - salbutamol inhaler 1 puff(s) INHALED daily, start at 08:00, via aerochamber, (from ADC)
    - acetaminophen tab 650 mg PO daily, start at 08:00 (from ADC)
    - piperacillin / tazobactam inj (known as TAZOCIN inj) 4.5 g IVPB once, start at 08:00, in 100ML D5W, (from fridge [entered into ADC first, ADC direct to bin 6 in fridge])
- put Patient D's bin into Wi-Med cart

- use the hand sanitizer
- exit with Wi-Med through door 1

Scenario: RN2

You have just come on shift and are preparing to administer your morning medication pass. You have four patients assigned to you (Patient E, Patient F, Patient G and Patient H). To prepare for your medication pass, you will be taking your Wi-Med cart into the medication room, gathering the blue patient specific bins for your patients, filling the patient specific bins with needed medications and supplies, and then placing the patient specific bins into your Wi-Med cart. Once you have gathered meds and supplies for all of your patients, you exit the medication room through the same doors you entered (door 2).

To open the med room door, touch the card reader (black box beside the doors). Place your hands under the faucet, soap, or hand sanitizer to indicate usage. To view the electronic medication administration record (eMAR) touch any computer screen, except for the screen on the Automated Dispensing Cabinet (ADC). Touch it again to view the next medication ordered. The eMAR will also indicate where medications are stored. To retrieve medications, touch the ADC computer screen which will direct you to an ADC drawer or the fridge. Injectable medications can be prepared by gathering the medications and supplies needed, placing them onto a work surface and holding the progress ball (symbolizes time typically used preparing the IV bag). Supplies are stored on the supply shelf and in the drawer below the med prep areas with the computers. When preparing pantoprazole, assume the vial is premixed and the patient already has a primary line running in their room so you only need the secondary line. You don't need to get the AeroChamber for the inhaler because it is stored in the supply room.

RN2 Tasks

- enter medication room (1 minute after RN1 if applicable) from door 2 with a Wi-Med cart
  - NOTE: RN1 will still be preparing medications
- wash hands at the sink
- get patient specific bins for Patients E,F,G,H and place bins onto any work surface
  - NOTE: Blue bins for patient are above both med prep areas. They are labelled "Patient E", etc.

Prepare Medications for Patient E

- use any computer to identify which medications are needed for Patient E
- gather medications for Patient E and put them into the bin for Patient E
  - dalteparin inj 5,000 unit(s) SUBCUTANEOUSLY q24h, start at 08:00 (from ADC)
  - KCl 40 mmol in 0.9% NaCl infusion (known as: potassium chloride 40 mmol in 0.9% NaCl infusion) 1,000 mL IV <Continuous>, start at 08:00 at 100 mL/hour, (from large supply shelves)
  - metoPROLOL tab 50 mg PO bid, start at 08:00 (from ADC)
  - ibuprofen tab 800 mg PO daily, start at 08:00 (from ADC)
- put Patient E's bin into Wi-Med cart

Prepare Medications for Patient F

- use any computer to identify which medications are needed for Patient F
- gather medications for Patient F and put them into the bin for Patient F
  - acetaminophen tab 650 mg PO daily, start at 08:00 (from ADC)
  - thiamine tab 100 mg PO daily, start at 08:00 (from ADC)
  - metoPROLOL tab 50 mg PO bid, start at 08:00 (from ADC)
  - amoxicillin / clavulante tab 875 mg / 125mg PO bid, start at 08:00 (from ADC)
  - pantoprazole inj 40 mg IVPB daily, start at 08:00, requires secondary line only, (from ADC, in 100ML 0.9% NaCl)
- gather the following for preparation of Pantoprazole
  - medication added label, orange (from drawer below med prep area)
  - IV line label, white (from drawer below med prep area)
  - alcohol swabs (from drawer below med prep area)
  - blunt fill needle (from large supply shelves OR drawer below med prep area)
  - 20 mL syringe (from large supply shelves)
  - 100 mL 0.9% Sodium Chloride injection USP (from large supply shelves)
  - secondary medication set (from small supply shelves)
- prepare Pantoprazole IV bag
  - hold progress ball at work surface until task is completed
  - throw out garbage
  - put syringe and needle into sharps bin
  - put IV bag and line label into patient bin
  - put secondary medication set onto Wi-Med cart
- put Patient F bin into Wi-Med cart

Prepare Medications for Patient G

▪ use any computer to identify which medications are needed for Patient G
▪ gather medications for Patient G on put them into the bin for Patient G
  ○ diclofenac 2.32% gel Apply TOPICALLY for back pain bid, start at 08:00 (from ADC)
  ○ salbutamol inhaler 1 puff(s) INHALED daily, start at 08:00 (from ADC)
  ○ amoxicillin / clavulante tab 875 mg / 125mg PO bid, start at 08:00 (from ADC)
  ○ thiamine tab 100 mg PO daily, start at 08:00 (from ADC)
▪ put Patient G's bin into Wi-Med cart

Prepare Medications for Patient H

▪ use any computer to identify which medications are needed for Patient H
▪ gather medications for Patient H on put them into the bin for Patient H
  ○ ampicillin inj 1 g IVPB once, start at 08:00, in 100 mL mini-bag plus (from fridge [entered into ADC first, ADC direct to bin in fridge])
  ○ salbutamol inhaler 1 puff(s) INHALED daily, start at 08:00, via AeroChamber (from ADC)
  ○ acetaminophen tab 650 mg PO daily, start at 08:00 (from ADC)
  ○ piperacillin / tazobactam inj (known as TAZOCIN inj) 4.5 g IVPB once, start at 08:00, in 100ML D5W (from fridge [entered into ADC first, ADC direct to bin 6 in fridge])
▪ put Patient H's bin into Wi-Med cart

- wash hands at the sink
- exit with Wi-Med through door 2

Scenario: RN3

You have a patient who has is vomiting and plan to administer Ondansetron quickly to avoid potential complications with a fresh post-operative abdominal incision. You enter the medication room, gather the medication and supplies, including new tubing for secondary line, prepare the IV bag, and then exit the medication room through the same doors you entered. If other individuals are working at the Automated Dispensing Cabinet (ADC), please interrupt them to access you medication as quickly as possible. Once you have gathered meds and supplies, you exit the medication room through the same doors you entered (door 1).

To open the med room door, touch the card reader (black box beside the doors). Place your hands under the faucet, soap, or hand sanitizer to indicate usage. To retrieve the medication, touch the ADC computer screen which will open an ADC drawer. Injectable medications can be prepared by gathering the medications and supplies needed, placing them onto a work surface and holding the progress ball (symbolizes time typically used preparing the IV bag). Supplies are stored on the supply shelf and in the drawer below the med prep areas with the computers. When preparing ondansetron, assume the patient already has a primary line running in their room so you only need the secondary line.

RN3 Tasks

- enter medication room from door 1 without a Wi-Med cart
- wash hands at the sink

Prepare Medication for Patient I

▪ interrupt person using ADC to urgently access medication from the ADC for Patient I
  ○ ondansetron inj 4 mg IVPB once, start at 08:00, requires secondary line only, (from ADC, in 50ML 0.9% NaCl)
▪ gather the following for the preparation of Ondansetron
  ○ medication added label, orange (from drawer below med prep area)
  ○ IV line label, white (from drawer below med prep area)
  ○ alcohol swabs (from drawer below med prep area)
  ○ blunt fill needle (from large supply shelves or drawer below med prep area)
  ○ 5 mL syringe (from large supply shelves)
  ○ 50 mL 0.9% Sodium Chloride injection USP (from large supply shelves)
  ○ secondary medication set (from small supply shelves)
▪ prepare IV bag
  ○ hold progress ball at work surface until task is completed
  ○ throw out garbage
  ○ put syringe and needle into sharps bin
  ○ put IV bag and line label into patient bin
▪ put secondary medication set onto Wi-Med cart

- wash hands at the sink
- exit door 1

Scenario: Rx

You are about to stock the med room with medications. To do this you will be taking your pharmacy cart into the medication room and placing medications from within the top drawer of your cart into its appropriate storage location. Once you have emptied the top drawer of your pharmacy cart, you exit the medication room through the same entrance (door 2) you entered.

To open the med room door, touch the card reader (black box beside the doors). Place your hands under the faucet, soap, or hand sanitizer to indicate usage. Once you open the top drawer of the pharmacy cart, you will see a label with the medication name and appropriate storage location. Pick up the medication, touch the Automated Dispensing Cabinet (ADC) to indicate that you are stocking the medication and then place the medication in the appropriate storage location. Re-open the top drawer until there are no remaining medications.

Rx Tasks

- enter the medication room (1 minute after RN2) from door 2 with an Rx cart
- use the hand sanitizer

Stock Medications
▪ stock medications from the Rx cart into the ADC, fridge and supply cabinet ○ acetaminophen tab 352 mg (into ADC [NOTE: involves picking up med, entering {touching} into ADC computer, drawer and bin lid auto opens, put into bin]) ○ thiamine tab 100 mg (into ADC) ○ amoxicillin/clavulante tab 875 mg / 125mg (into ADC) ○ Ibuprofen tab 800 mg (into ADC) ○ metoPROLOL tab 50 mg (into ADC) ○ pantoprazole 40 mg (into ADC) ○ piperacillin / tazobactam inj 4.5 g IVPB, in 100ML D5W (enter in ADC, then directed to bin in fridge) ○ ampicillin 1 g, in 0.9% NaCl 100 mL Minibag Plus (enter in ADC, then directed to bin in fridge) ○ KCl 40 mmol in 0.9% NaCl infusion 1,000 mL IV (into large supply shelves) ○ salbutamol inhaler (into ADC) ○ diclofenac 2.32% gel (into ADC) ○ dalteparin inj 5,000 unit (into ADC)

- exit the room through door 2 with Rx cart

APPENDIX II

Post-scenario Enactment Survey

Scenario (circle one):	1	2	3	4	5	6	7	8
Role (circle one):	RN1		RN2		RN3		Rx	
Layout (circle one):	1	2						
Preferred layout (circle one)	1	2	N/A					

Based on this scenario enactment, please rate your level of agreement with the following statements:	Strongly Disagree				Strongly Agree	
1. I was able to effectively evaluate the design of this room.	1	2	3	4	5	N/A
2. I liked the design of this room	1	2	3	4	5	N/A
3. The room felt congested	1	2	3	4	5	N/A
4. I could easily access medications and supplies	1	2	3	4	5	N/A
5. I could easily access the sharps container	1	2	3	4	5	N/A
6. I could easily access the electronic medication administration record	1	2	3	4	5	N/A
7. This scenario was realistic	1	2	3	4	5	N/A
8. The enactment of this scenario represented realistic workflow.	1	2	3	4	5	N/A
9. The medication room mock-up was realistic	1	2	3	4	5	N/A
10. I am able to identify opportunities to improve the design	1	2	3	4	5	N/A

End of Day Survey

Role (circle one): RN Rx

Preferred layout (circle one) 1 2 N/A

Rate your level of agreement with the following:	Strongly Disagree				Strongly Agree	
My contributions have the potential to improve the design of this medication room……	1	2	3	4	5	N/A
This evaluation method would allow me to provide accurate feedback regarding:						
Unit configuration ……	1	2	3	4	5	N/A
Room size……..…	1	2	3	4	5	N/A
Design or design feature comparisons (e.g., compare room layouts) ……	1	2	3	4	5	N/A
Space requirements for equipment or processes	1	2	3	4	5	N/A
Access to the patient and/or equipment……..	1	2	3	4	5	N/A
Patient/family spaces and experiences……	1	2	3	4	5	N/A
Patient transport routes to and from the room…	1	2	3	4	5	N/A
Room configuration……	1	2	3	4	5	N/A
Furniture, fixtures, and equipment placement…	1	2	3	4	5	N/A
Furniture, fixtures, and equipment usability……	1	2	3	4	5	N/A
Visibility of patient, monitors, supplies, and/or equipment…….	1	2	3	4	5	N/A
Supply placement……	1	2	3	4	5	N/A
Adverse events……	1	2	3	4	5	N/A
Work flows and processes……	1	2	3	4	5	N/A
Team functioning/performance……	1	2	3	4	5	N/A

Non-participant Stakeholder Survey

Name (optional): _____

On a scale from 1 to 5, where “1” means “strongly disagree” and “5” means “strongly agree”, please rate your level of agreement with the following statements (please rate each mock-up method individually):

Note: Simple = tape on the floor
Detailed = built space from cardboard/plywood
VR = virtual reality

	Simple	Detailed	VR
The mock-up environment was/typically is realistic……	___	___	___
The information gathered from this evaluation method will be useful for future projects…….....	___	___	___
This evaluation method would allow me to provide accurate feedback regarding:			
Unit configuration ……	___	___	___
Room size……..	___	___	___
Design or design feature comparisons (e.g., compare room layouts) ……	___	___	___
Space requirements for equipment or processes….	___	___	___
Access to the patient and/or equipment……	___	___	___
Patient/family spaces and experiences……..	___	___	___
Patient transport routes to and from the room……	___	___	___
Room configuration…….	___	___	___
Furniture, fixtures, and equipment placement……	___	___	___
Furniture, fixtures, and equipment usability……...	___	___	___
Visibility of patient, monitors, supplies, and/or equipment……	___	___	___
Supply placement……	___	___	___
Adverse events……	___	___	___
Work flows and processes……..	___	___	___
Team functioning/performance……..	___	___	___

Decision Maker Survey

Rate your level of agreement with the following:	Strongly Disagree				Strongly Agree	
Recommendation 1: Switch the locations of the supplies with the ADC / med prep area.						
Implementing this recommendation would:	1	2	3	4	5	N/A
reduce the number of interruptions	1	2	3	4	5	N/A
reduce congestion	1	2	3	4	5	N/A
reduce the time required to prepare medication	1	2	3	4	5	N/A
provide better space to store carts	1	2	3	4	5	N/A
provide better access to the fridge	1	2	3	4	5	N/A
Implementing this recommendation would be beneficial	1	2	3	4	5	N/A
I intend to implement this recommendation	1	2	3	4	5	N/A
Recommendation 2: Include a sharps container within arm's reach of both med prep areas.						
Implementing this recommendation would:	1	2	3	4	5	N/A
reduce congestion when accessing the sharps	1	2	3	4	5	N/A
improve access to the sharps container	1	2	3	4	5	N/A
Implementing this recommendation would be beneficial	1	2	3	4	5	N/A
I intend to implement this recommendation	1	2	3	4	5	N/A
Recommendation 3: Store all patient bins together.						
Implementing this recommendation would:	1	2	3	4	5	N/A
make it easier to find patient bins	1	2	3	4	5	N/A
reduce congestion when accessing patient bins	1	2	3	4	5	N/A
reduce the likelihood of selecting the wrong bin	1	2	3	4	5	N/A
Implementing this recommendation would be beneficial	1	2	3	4	5	N/A
I intend to implement this recommendation	1	2	3	4	5	N/A
General questions						
The recommendations delivered from this project are relevant to medication room design	1	2	3	4	5	N/A

Preferred layout (circle one)	Existing layout	Proposed layout	Not sure

APPENDIX III

ROI Guiding Principles (Phillips & Phillips, 2005)

1. When a higher-level evaluation is conducted, data must be collected at lower levels.
2. When an evaluation is planned for a higher level, the previous level of evaluation does not need to be comprehensive.
3. When collecting and analyzing data, use only the most credible sources.
4. When analyzing data, choose the most conservative alternatives for calculations.
5. At least one method must be used to isolate the effects of the solution.
6. If no improvement data are available for a population or from a specific source, it is assumed that no improvement has occurred.
7. Estimates of improvements should be adjusted for the potential error of the estimate.
8. Extreme data items and unsupported claims should not be used in ROI calculations.
9. Only the first year of benefits (annual) should be used in the ROI analysis of short-term solutions.
10. Costs of the solution should be fully-loaded for ROI
11. Intangible measures are defined as measures that are purposely not converted to monetary
12. The results from the ROI Methodology must be communicated to all key stakeholders.

APPENDIX IV: LIST OF FIGURES

Figure 1: Types of data which can be accurately assessed with each mock-up type as well as the return on investment realized.

Figure 2: Existing medication room design.

Figure 3: Photos of the simple mock-up, mobile ultrasound machines used as Wi-Med carts, and crash cart used as a pharmacy cart.

Figure 4: Exterior and interior photos of the detailed mock-up along with the Wi-Med carts and pharmacy cart.

Figure 5: VR room mock-up. Head-mounted displays worn by participants allowed immersion and interaction within the VR environment.

Figure 6: Ten steps in the in the Phillips ROI Methodology.

Figure 7: The existing medication room layout replicated the design of the medication room evaluated in the POE. The proposed medication room layout incorporated recommendations from the POE.

Figure 8: Average ratings regarding the relevance of the POE recommendations from decision makers.

Figure 9: Average ratings from decision makers regarding the degree to which it would be beneficial to implement recommendations and their intention to implement recommendations.

Figure 10: Average ratings regarding the perceived realism of the mock-ups and scenarios enacted within each mock-up type.

Figure 11: Average ratings from non-participant stakeholders regarding the degree to which information gathered would be useful for future projects.

Figure 12: Average ratings from decision makers regarding the anticipated outcomes resulting from switching the location of medication supplies with the automated medication dispensing cabinet (ADC) and medication preparation area.

Figure 13: Average ratings from decision makers regarding the anticipated outcomes resulting from having the sharps container located within arm's reach of medication preparation areas.

Figure 14: Average ratings from decision makers regarding the anticipated outcomes resulting from having all patient bins stored together.

Figure 15: Average ratings from scenario enactment participants regarding their contributions to improve the design of the medication room.

Figure 16: Average ratings regarding perceived accuracy to evaluate various design considerations.

Figure 17: Sample link analyses illustrating workflow from mock-up evaluation scenarios which involved four people using the medication room simultaneously (simple, detailed, virtual reality) as well as from the POE of the existing medication room. The red line indicates the area with the highest volume of traffic.

Figure 18: Average task completion times comparing mock-up evaluation data to POE data of the existing medication room.

Figure 19: Interruption data aggregated across scenarios comparing mock-up evaluation data to POE data of the existing medication room.

Figure 20: Subjective and objective measures regarding access to the sharps container.

Figure 21: Subjective and objective measures regarding room congestion.

Figure 22: Total occurrences of interruptions across scenario enactments. A reduction of interruptions was an anticipated outcome.

Figure 23: Typical cart placement during medication preparation. A less obstructive cart storage location was an anticipated outcome.

Figure 24: Cart placement across all applicable scenario enactments. A less obstructive cart storage location was an anticipated outcome.

Figure 25: Total occurrences of bumps and impediments. A reduction of bumps and impediments were anticipated outcomes.

Figure 26: Total occurrences of people or equipment bumping into the fridge. Total occurrences of impediments while accessing the fridge. A reduction of bumps and impediments while accessing the fridge were anticipated outcomes.

Figure 27: Average time to prepare a single medication (min:sec). A reduction in time for medication preparation was an anticipated outcome.

Figure 28: Total occurrences of impediments while placing a used needle in the sharps container. A reduction of impediments while accessing the sharps container was an anticipated outcome.

Figure 29: Total occurrences searching for a patient bin (left). Total time spent searching for patient bins (min:sec; right). A reduction in occurrences and time searching for patient bins were anticipated outcomes.

Figure 30: Total occurrences of impediments while accessing patient bins. A reduction of impediments while accessing patient bins was an anticipated outcome.

Figure 31: Total occurrences of selecting the wrong patient bin. A reduction of selecting the wrong patient bin was an anticipated outcome.

Figure 32: Total hours to conduct the simulation-based mock-up evaluations (hrs:min).

Figure 33: Project costs (excluding salaries) to conduct the simulation-based mock-up evaluations.

Figure 34: Project costs (including salaries) to conduct the simulation-based mock-up evaluations.

APPENDIX V: LIST OF TABLES

Table 1: Guiding principles from the HQCA's *Simulation-based Mock-up Evaluation Framework*.

Table 2: Five levels of data, plus intangible benefits, collected as per the Phillips ROI Methodology.

Table 3: Recommended design changes and anticipated outcomes.

Table 4: Methodology overview for the evaluations conducted.

REFERENCES

[1] Health Quality Council of Alberta Simulation-based mock-up evaluation framework [Internet]. Calgary, Alberta, Canada: Health Quality Council of Alberta; 2016. [cited 2020 Jan 13]. Available from: https://hqca.ca/health-care-provider-resources/frameworks/simulation-based-mock-up-evaluation-framework/

[2] Phillips P, Phillips J. Return on investment (ROI) basics. Alexandria: ASTD Press; 2005.

[3] The Center for Health Design. Knowledge repository [Database]. The Center for Health Design; 2019 [Cited 2019 Mar 24]. Available from: https://www.healthdesign.org/knowledge-repository

[4] 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. HERD. 2019;OnlineFirst:1-13. Available from: https://doi.org/10.1177/1937586719855777

[5] Colman N, Doughty C, Arnold J, Stone K, Reid J, Dalpiaz A, Hebbar KB. Simulation-based clinical systems testing for healthcare spaces: From intake through implementation. Adv Simul. 2019;4(1):19. Available from: https://doi.org/10.1186/s41077-019-0108-7

[6] Colman N, Stone K, Arnold J, Doughty C, Reid J, Younker S, Hebbar KB. Prevent safety threats in new construction through integration of simulation and FMEA. Pediatr Qual Saf. 2019;4(4);e189. Available from: https://doi.org/10.1097/pq9.0000000000000189

[7] Durham J, & Kenyon A. Mock-ups: Using experiential simulation models in the healthcare design process. HERD. 2019;12(2):11–20. Available from: https://doi.org/10.1177/1937586719848860

[8] Kaba A, Barnes S. Commissioning simulations to test new healthcare facilities: A proactive and innovative approach to healthcare system safety. Adv Simul. 2019;4(1):1–9. Available from: https://doi.org/10.1186/s41077-019-0107-8

[9] Torres-Landa S, Neylan C, Quinlan K, Klock C, Jefferson C, Williams NN, Caskey RC, Greulich S, Kolb G, Morgan C, Mahoney K, Dumon KR. Interprofessional simulations to inform perioperative facility planning and design. J Surg Educ. 2019;76(1):223–233. Available from: https://doi.org/10.1016/j.jsurg.2018.06.016

[10] Canadian Standards Association. Z8000-18: Canadian health care facilities. Ottawa, Canada: Standards Council of Canada; 2018.

[11] Alberta Infrastructure. Health facilities capital program manual. [Internet]. Alberta, Canada: Alberta Infrastructure; 2018 [cited 2018 Jun 28]. Available from: http://www.infrastructure.alberta.ca/3782.htm

[12] Facilities Guidelines Institute. Simulation-based tool for evaluating health care designs [Internet]. 2018 [cited 2020 Jan 13]. Available from: https://fgiguidelines.org/resource/simulation-based-tool-evaluating-health-care-designs/

[13] Joshi R, Joseph A, Wingler D, Allison D. Realizing improved patient care through human-centered design in the operating room [Internet]. 2017-2019;3-4. [cited 2019 Sep 30]. Available from: https://issuu.com/clemsonchfdt/docs/ripchd.or_vol._3

[14] Bayramzadeh S, Joseph A, Allison D, Shultz J, Abernathy J. Using an integrative mock-up simulation approach for evidence-based evaluation of operating room design prototypes. Appl Ergon. 2018;70:288-299.

[15] Wingler D, Joseph A, Bayramzadeh S, Robb A. Using virtual reality to compare design alternatives using subjective and objective evaluation methods. HERD. 2019;OnlineFirst:1-16.

[16] Kohn LT, Corrigan J, Donaldson MS, Institute of Medicine. To err is human: Building a safer health system. Washington, DC: The National Academies Press; 2000. Available from: https://doi.org/10.17226/9728

[17] Cowley E. Assessing and preventing medication errors in home care. Home Health Care Consultant. 2000;7(3):33–40.

[18] Wu AW, Pronovost P, Morlock L. ICU incident reporting systems. J Crit Care. 2006;17(2):86–94.

[19] Frith KH, Anderson EF, Tseng F, Fong EA. Nurse staffing is an important strategy to prevent medication errors in community hospitals. Nurs Econ. 2012;30(5):288-294. Available from CINAHL.

[20] Leape LL, Bates DW, Cullen DJ, Cooper J, Demonaco HJ, Gallivan T, Hallisey, Ives RJ, Laird N, Laffel G, Nemeskal R, Petersen LA, Porter K, Servi D, Shea BF, Small SD, Sweitzer BJ, Thompson T, Vliet, MV. Systems analysis of adverse drug events. JAMA. 1995;274(1):35–43.

[21] Winterstein AG, Johns TE, Rosenberg EI, Hatton RC, Gonzalez-Rothi R, Kanjanarat P. Nature and causes of clinically significant medication errors in a tertiary care hospital. Am J Health Syst Pharm. 2004;61:1908-1916. Available from: Academic Search Elite.
[22] Robson R, Salsman R, McMenemy J. External patient safety review. Calgary, Canada: Calgary Health Region; 2004.
[23] Hayes C, Jackson D, Davidson PM, Power T. Medication errors in hospitals: A literature review of disruptions to nursing practice during medication administration. J Clin Nurs. 2015;24:21-22.
[24] Johnson M, Sanchez P, Langdon R, Manias E, Levett-Jones T, Weidemann G, Aguilar V, Everett B. The impact of interruptions on medication errors in hospitals: An observational study of nurses. J Nurs Manag. 2017;25:498-507.
[25] Huckels-Baumgart S, Baumgart A, Buschmann U, Schüpfer G, Manser T. Separate medication preparation rooms reduce interruptions and medication errors in the hospital setting: A prospective observational study. J Patient Saf. 2016 [ePub ahead of print]. Available from: https://www.ncbi.nlm.nih.gov/pubmed/28009601
[26] The Center for Health Design. Safety risk assessment toolkit: A process to mitigate risk [Internet]. The Center for Health Design; 2017. Available from: https://www.healthdesign.org/sra
[27] Taylor E, Quan X, Zborowsky T. Safety risk assessment: The Center for Health Design toolkit – risk component. The Center for Health Design; 2015 [Cited 2019 Jun 26]. Available from: https://www.healthdesign.org/system/files/res_files/Executive%20Summary_SRA_All_2017_0.pdf
[28] Wingler D, Machry H, Bayramzadeh S, Joseph A, Allison D. Comparing the effectiveness of four different design media in communicating desired performance outcomes with clinical end users. HERD. 2018;12(2),87–99. Available from: https://doi.org/10.1177/1937586718796626
[29] ROI Institute. Show me the money: The ROI methodology in 10 easy steps. ROI Institute Canada; 2013.
[30] Kirkpatrick DL. Evaluating training programs. Alexandria, VA: American Society for Training and Development; 1975:1-17.
[31] Walsh EK, Hansen CR, Sahm LJ, Kearney PM, Doherty E, Bradley CP. Economic impact of medication error: A systematic review. Pharmacoepidem Dr S. 2017;26(5):481–497. doi:10.1002/pds.4188.

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