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Impact of Smoke Compartment Size on Horizontal Evacuation Time in Healthcare Facilities

A Graduate Independent Study Research Report

Submitted to

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Disclaimer

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Executive Summary

Hospitals provide a wide range of healthcare services to people of all ages and abilities. In addition, they are traditionally seen as safe havens and support mechanisms for people involved in a disaster or other emergency situation. Unfortunately, these institutions are not immune to disruptive events, such as fire or other hazards, (Alvarez and Meacham 2010), (A. Alvarez, B. J. Meacham, et al. 2014), (Scott 2009), and for this reason need to be designed to keep patients safe during such events. This is often accomplished through a combination of building safety features and emergency response plans. Building features may include enhancements for structural resiliency, multiple fire protection systems and security systems. Emergency response plans should include evacuation protocols that address sheltering in place, horizontal, vertical, limited, and total evacuation (Bierster 2010) as appropriate for the building features and event. However, robust evacuation analysis of hospitals and other healthcare facilities can be challenging and complex given the wide range of patient cognitive and mobility conditions, potential connection to life supporting equipment, staff to patient ratios, and evacuation equipment utilized (e.g., see (Sorensen and Dederichs 2012), (Kuligowski, et al. 2012), (Hunt, Galea and Lawrence 2013))).

There may be many reasons to order an evacuation in a healthcare facility; however, the decision needs to be weighed against the safety and reliability of patient care. Reasons for evacuating a facility can be for structural damage, exposure to hazardous materials, armed visitor(s), or credible bomb threats. Each of the different hazards will initiate different evacuation practices in the facility. It is imperative that these evacuations are done in a timely manner that provides that greatest amount of safety possible to patients during transport (AHRQ 2010), (MA DPH 2012).

Given the challenges associated with moving patients vertically in a building, the concept of horizontal evacuation is often used. In brief, this is an approach wherein smoke-rated (and often fire-rated) compartments are used to physically break up a floor area into smaller compartments, with each smoke compartment being designed to hold the occupant load from a horizontally-adjacent compartment as well as its own. In the event of a fire or other emergency, the patients can be moved horizontally from the threatened compartment to an adjacent space, where they will be protected in place while firefighting operations or evacuation to other locations are undertaken.

In the USA, there have been recent proposals to change the 2015 edition of the National Fire Protection Association (NFPA) *Life Safety Code* (NFPA 2015) and the 2015 edition of the *International Building Code* (ICC 2015) to increase the maximum allowable smoke compartment size from 2,090 m^2 (22,500 ft^2) to 3,700 m^2 (40,000 ft^2) in certain healthcare facilities. A natural question that arises from such a change is: what is the difference in time required to move patients out of a 3,700 m^2 (40,000 ft^2) compartment as compared with a 2,090 m^2 (22,500 ft^2) compartment, if all other code requirements and assumptions about patient load, staffing and related factors are kept equal? While this issue was investigated with respect to the NFPA *Life Safety Code* (Alonso 2014), the range of occupant characteristics, staffing ratios, and related issues were somewhat limited, and the implications for *the International Building Code* were not addressed.

To further explore this issue, with particular focus on the IBC requirements, a comparative timed egress analysis was undertaken, using floor plans from actual healthcare facilities, expanded data on patient to

staff ratios, and available data on times for preparation and movement of patients using a variety of transportation mechanisms.

Conducting a comparative timed egress analysis for this type of occupancy required an extensive review of the relevant variables. The variables that were considered are as follows:

- Geometry
- Smoke Compartment Size
- Staff to Patient ratio
- Ambulatory Patient Type
- Patient Characteristic
  - Prep Time
  - Staff Movement Speed
  - Transport Movement Speed
  - Settle Time
  - Patient Width
- Number of Patients per Room
- Total Number of Patients
- Staff Response
  - Origin of Staff
  - Staff Response Time
  - Order of Triage
- Staff Training

Definition and discussion about the variables that were considered, an overview of the research that was conducted to identify a representative range of values for each variable, and suggested values for the variables, for use in timed egress analysis, are detailed in the report.

Key outcomes of the analysis and areas of future study include the following.

- When there is a low staff to patient ratio (1:2) the larger compartment can be evacuated in the same or less time than the smaller smoke compartment.
- When the staff to patient ratio is higher (1:3, 1:5, 1:9) the larger smoke compartment has longer evacuation times than the smaller compartment.
- The importance of staff to patient ratios, and their impact on evacuation, should be studied further.
- Further study of the identified variables, geometry, patient loading, and occupant behavior should be conducted, as those aspects also have an impact on smoke compartment size.
- This study did not consider any design fires or other precipitating event and therefore does not represent a true measure of the level of safety shown by the evacuation times. Future studies should consider the range of initiating events, and specific staff responses to those events, to obtain a more complete picture of the evacuation issues and timing. `

After considering the factors, variables, and analysis for the horizontal evacuation in an I-2 hospital, considered in this study, smoke compartments up to 3,700 m^2 (40,000 ft^2) do not conclusively offer the same level of safety as the smoke compartments less than 2,090 m^2 (22,500 ft^2). This does not necessarily mean that smoke compartment up to 3,700 m^2 (40,000 ft^2) are less safe in an emergency event. However, in terms of the timed evacuation study, the 3,700 m^2 (40,000 ft^2) smoke compartment consistently required a greater time to evacuate than the smoke compartment less than 2,090 m^2 (22,500 ft^2).

1. Research Question

In the United States, there have been recent proposals to change the 2015 edition of the National Fire Protection Association (NFPA) *Life Safety Code* (NFPA 2015) and the 2015 edition of the *International Building Code (IBC)* (ICC 2015) to increase the maximum allowable smoke compartment size from 2,090 m^2 (22,500 ft^2) to 3,700 m^2 (40,000 ft^2) in facilities that provide 24-hour medical care to five or more individuals (ICC 2012). A natural question that arises from such a change is: what is the difference in time required to evacuate patients from a smoke compartment up to 3,700 m^2 (40,000 ft^2) as compared with a smoke compartment less than 2,090 m^2 (22,500 ft^2), with all other code requirements and assumptions about patient load, staffing and related factors being equal? This research project was undertaken to address this question. It should be noted that this effort specifically did not include an initiating event for the evacuation, which is expected to have an impact on any actual evacuation times. It should also be noted that several assumptions and limitations were imposed on the analysis, as described within this report, which should be considered when considering the outcomes of the analysis and any potential application of the findings as part of any specific evacuation assessment.

2. Introduction

Hospitals are unique buildings because of the challenging life safety implications of emergency events. The reduced physical and mental state of patients in healthcare occupancies require the investigation and evaluation of a number of variables that are not present other occupancies. Therefore, the careful consideration must be used to ensure that changes in the building codes do not negatively impact the life safety of patients, hospital staff, first responders and all other occupants. The purpose of this study is to identify and evaluate the impact(s) a change in the code-defined maximum smoke compartment size, of 3,700 m^2 (40,000 ft^2) from 2,090 m^2 (22,500 ft^2) in Group I-2 hospital occupancies, has on evacuation time.

The most relevant previous work was done by Alonso (2014) who conducted a timed egress analysis using models to study the same issue that is considered here. However, there are several areas within Alonso's analysis which raised questions, including the methods that were used to evacuate the patients, the methods of setting up and performing the computational modeling, and the explanation of the results. This study looks to build on that important work and attempts to present a more complete overview of the analysis.

Conducting a comparative timed egress analysis for an IBC I-2 hospital occupancy requires an extensive review of the relevant variables. This report lays out the variables that were considered, the range of values/options considered, the relevant background information and research that was used to determine the range of values, and the recommended areas of interest for further study. The variables that were evaluated are list below:

- Geometry
- Smoke Compartment Size
- Staff to Patient ratio
- Ambulatory Patient Type
- Patient Characteristic
  - Prep Time
  - Staff Movement Speed
  - Transport Movement Speed
  - Settle Time
  - Patient Width
- Number of Patients per Room
- Total Number of Patients
- Staff Response
  - Origin of Staff
  - Staff Response Time
  - Order of Triage
  - Movement Types
  - Staff Training

From review of the published literature, it was found that there was no consensus regarding the values to be used for many of these. As a result, numerous experts were consulted with, and a limited survey was undertaken, in order to obtain values for analysis. To ensure a representative range of values, the selected experts were from different parts of the country, from a range of associated industries, and with varying experience levels. The content of these discussions were distilled into values incorporated into the modeling exercise.

Assumptions and Limitations

A global literature search was conducted to evaluate what is known about the impact of smoke compartment size on egress in hospitals. Previous work on this issue has been done in various capacities, but there is little consensus on the issue. Hospitals are such complex occupancies, and it became evident in the literature review and discussions that there are an infinite number of scenarios, which could occur in a hospital at any given time. Because of this several assumptions and simplifications that were made to focus the analysis and match the scope of work.

The following list denotes the assumptions and limitations of the study.

Comparative Timed Egress Analysis

This study investigates the difference in horizontal evacuation times between smoke compartments with a code-defined maximum size from 2,090 m^2 (22,500 ft^2) to 3,700 m^2 (40,000 ft^2). The purpose of the study is to answer the question of whether or not the small and large compartments provide the same level of safety to occupants. Therefore, the deterministic evacuation times reported from the modeling are not the focus of the study as they may vary depending on the values included in the egress models.

Variables are not "typical"

The variables and associated values used in the egress model are not to be considered "typical" nor may they be applied to every hospital egress analysis. As discussed previously, gaps in data as well as a lack of consensus in the hospital industry required the simplification and bounding of each variable considered in the modeling effort. Variables used in this report are a result of an extensive literature review and numerous discussions with experts in the field. Sensitivity analyses were conducted to determine the significance of choosing different values, and their level of significance in the results.

No Specific Emergency Event

In the evacuation simulations, an emergency event was not specified. It was simply assumed that an event has occurred which required a complete evacuation of a single smoke compartment. Hospitals in the United States must comply with NFPA 101 and the codified procedure in case of a fire is to Remove, Alarm, Contain, Evacuate, "R.A.C.E." as specified in NFPA 101 Section 18.7.2 This procedure was not performed in this study.

Evacuation Contained to Smoke Compartment

This study represents a simplified analysis that considered one, unspecified emergency event. The modeling only considered the evacuation of one smoke compartment at a time. In addition, the actions and procedures that may take place outside the affected smoke compartment were not included in the study. This assumption resulted in the exclusion of additional hospital personnel, other than staff already in the smoke compartment, from assisting with the evacuation.

Inpatient Hospital Department

The areas considered in the study are consistent with inpatient hospital floors that are representative of medical-surgical (med-surg) areas in hospitals. Areas such as intensive care units (ICU), obstetrics, and out-patient areas were considered outside of the scope of this project. The areas used represent a large range of the patients in hospitals and the considerations for the areas selected are also characteristic of areas outside of the scope of the project (i.e. staff-to-patient ratio, type of patients, and number of patients). These other areas offer an example of where additional research should be conducted.

Time of Day

This study assumes that the horizontal evacuation of the smoke compartments took place at night. This allowed the model to only focus on the patients and staff present in any given smoke compartment, without having to include visitors or additional hospital personnel. This also is typically when the staff-to-patient ratio is lowest and therefore represents a conservative approach.

Staff Training

This study assumes that the staff members who are conducting the evacuation know exactly which tasks they must perform as required in NFPA 101 Section 18.7.2.3. However, it is common that inspections, testing and maintenance of fire systems are not always conducted and it depends a great deal on the personnel at the hospital as well as the AHJ. In addition, the amount of training that every person receives cannot be assumed to be uniform. Uncertainty during time-sensitive procedures can cause significant delay and dangerous situations to occur. As a simplification, this study assumed that staff knew the correct procedure.

A summary of the variables used in the analysis is presented in the following pages. A more detailed discussion of the variables and their analysis, including how final values were selected, can be found in the Appendix A: Interim Report - Full Variables Evaluation.

3. Factors Affecting Horizontal Hospital Evacuation

Building Geometries

From the initial research and through communications with key contacts in the healthcare industry, building plans of existing, in-use hospitals were gathered. From these sources, geometries were identified which result in the largest possible difference between the smaller and larger smoke compartment sizes. In this case the smoke compartments were approximately 3,697 m^2 (39,793 ft^2) for the larger compartment and approximately 1,712 m^2 (18,423 ft^2).for the smaller smoke compartment. The use of actual hospital geometries eliminated the uncertainty associated with the applicability of the floor plans used in modeling. There were a number of factors which led to the selection of these geometries, but most important were:

- The total area
- The floor plan layout of the geometry
- The number of patients in the space

The floor plan shown in Figure 1 was chosen for the initial analysis, and the results presented in this paper utilized this particular geometry. To accommodate confidentiality restrictions, any identifying features were removed. Note that this plan below consists of many different medical departments. For the purposes of this study, all smoke compartments were assumed to be med-surg or inpatient departments.

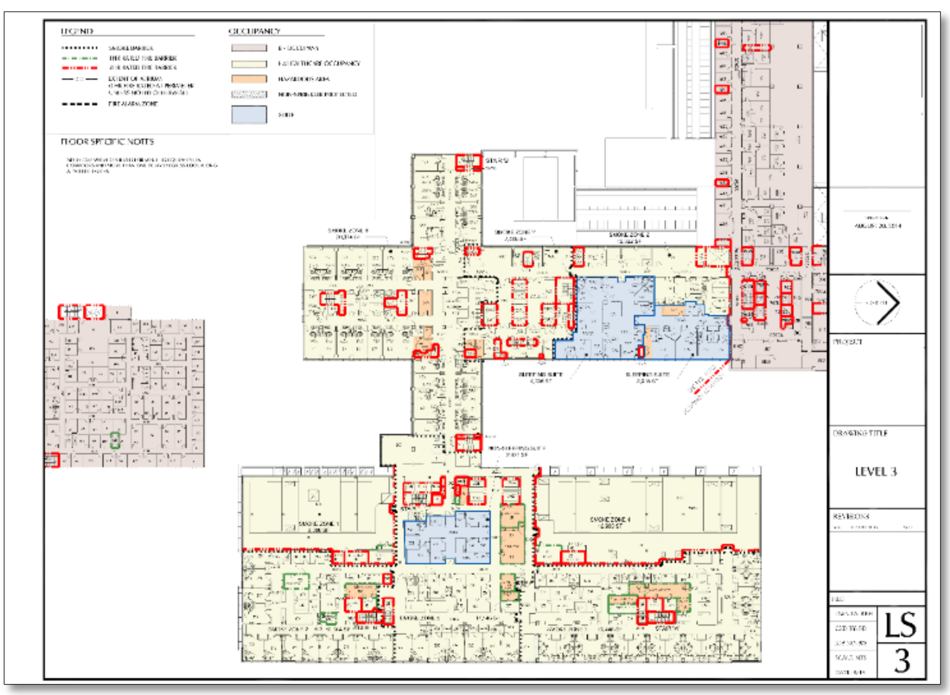


Figure 1: Hospital floor plan utilized in this study.

Smoke Compartment Size

As this is a comparative study to analyze the difference between different code-defined smoke compartment sizes, smoke compartments that are a maximum of 2,090 m^2 (22,500 ft^2) and a maximum of 3,700 m^2 (40,000 ft^2) need to be evaluated. While the range of possible values spans from 0 - 2,090 m^2 (22,500 ft^2) for the small compartments and 2,090 m^2 - 3,700 m^2 (40,000 ft^2) for the large smoke compartments, the goal was to find actual hospital geometries, which had smoke compartments predefined by the building plans that were as close to the maximum limits as possible.

Existing hospitals, which could be interested in taking advantage of the potential code change which allows a larger compartment size, could potentially achieve this by removing existing smoke and fire barriers. This could be seen as advantageous to hospitals because of the reduced costs of the fire rated materials as well as the reduced maintenance costs. Because of this, one of the goals for selecting floor plans for analysis was to find areas that could easily be made larger solely by removing an existing smoke barrier.

The predefined smoke compartments in the building plans which were considered all adhere to 2,090 m^2 (22,500 ft^2) limitation. In order to evaluate a smoke compartment size that may comply with the current version of the 2015 IBC code, which allows a smoke compartment to be no greater than 3,700 m^2 (40,000 ft^2), additional floor space was combined to the original smoke compartment. This method allowed for evacuation to be simulated in such a way that occupant arrangement and egress paths were not additional variables that needed to be considered in evaluation.

The graphic seen below depicts the breakdown of smoke compartments. Figure 2 shows six smoke compartments, all under 2,090 m^2 (22,500 ft^2) as well as two mechanical room (in yellow) smoke compartments. Figure 3 shows the geometry rearranged into three larger smoke compartments, keeping the two mechanical smoke compartments untouched.

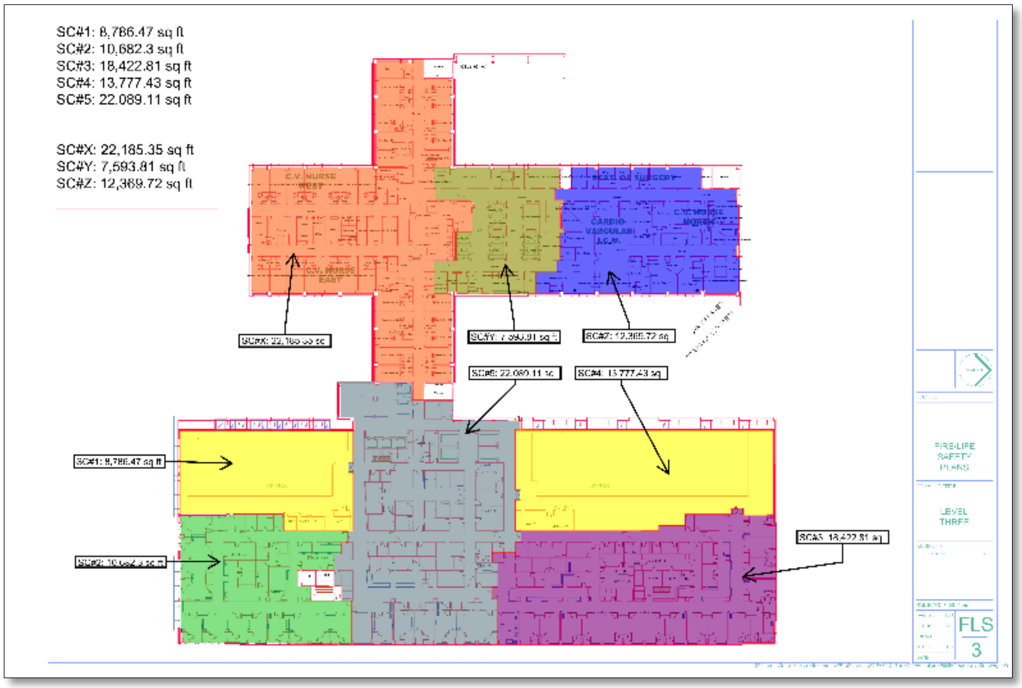


Figure 2: Hospital geometry broken up into small smoke compartments, < 2,090 m^2 (22,500 ft^2).

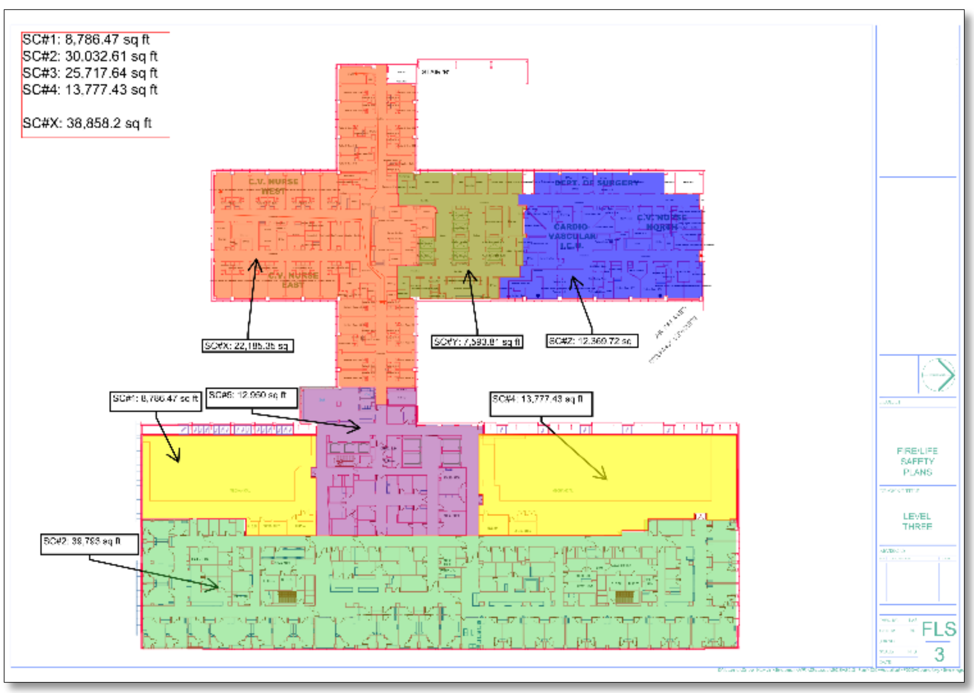


Figure 3: Hospital geometry broken up into large smoke compartments, < 3,700 m^2 (40,000 ft^2).

Travel Distance

Travel distance is defined as the measurement from the most remote point within a smoke compartment, to a smoke barrier door (IBC Section 407.5, 2012). For this study, only I-2 Healthcare facilities are utilized. The travel distances in I-2 occupancies are required to be less than 60.96 meters (200 feet) no matter the size of the smoke compartment.

A major concern when selecting the areas to create a larger smoke compartment was ensuring that the travel distance from each patient room to a smoke compartment door still complied with the 60.96 meters (200 feet) maximum travel distance as required by the IBC Section 407.5. After evaluating the travel distance from every room in the space the longest travel distance in the large smoke compartment was found to be 57.156 meters (187.52 feet). The longest travel distance measured in the smaller smoke compartment was found to be 47.800 meters (156.82 feet). A more detailed analysis of the travel distances are found in Figure 44 and Figure 45 as well as Table 5 and Table 6 located in Appendix B: Measured Travel Distance.

Staff to patient ratio

The ratio of the number of staff to the number of patients is a complex issue that was bounded to a range of ratios. For clarification, the following definitions are applicable to this study:

> **Staff**: Any person employed and trained by the hospital who is within a smoke compartment and when the signal for evacuation is given, and will immediately commence with the evacuation procedure.
>
> **Staff-to-Patient Ratio**: The ratio of staff continually present in the smoke compartment for a given number of patients. A ratio of 1:10 means that for every ten patients in the smoke compartment, there must be at least one staff member present.

The range of ratios that were considered for this purpose came from documents developed by the NFPA, the US Department of Veterans Affairs, as well as anecdotal evidence provided by experts in the field. NFPA 101A is a document that focuses on applying a risk based approach to a hospital as an alternative means to comply with the *Life Safety Code* (NFPA 101). Included in this risk evaluation is the staff-to-patient ratio, which ranges from 1:1 to 1:10.

Table 1: Range of Staff-to-Patient data found from research

Range of Staff to Patients Ratio	Source	Notes
1:1 – 1:10	NFPA 101A Worksheet 4.7.1 (NFPA 2013)	• Ratio evaluated for worst case ratio (typically during the night shift) • Ratios considered for all health care occupancies, as defined by NFPA 101, not solely hospitals
1:2 – 1:4	VHA Directive 2005-037 (VHA 2005)	• Ratio of 1:2 is required for buildings, with overnight stay, which are not fully sprinklered • Ratio of 1:4 is required for buildings, with overnight stay, which are fully sprinklered • Ratios apply to non-ambulatory patients
1:1-1:5	James Peterkin, Heery International (Perterkin 2015)	• Ratio of 1:1 would be used for ICU or similar • Ratio of 1:5 is a conservative value rarely seen

		in a hospital
1:2 - 1:4	Egress Modeling in Health Care Occupancies Report (Alonso 2014)	• Ratios used in egress modeling exercise, no clear source of values
0.96 – 3.43	Evacuation of the Evacuation Time in an Emergency Situation in Hospitals (Golmohammadi and Shimshak 2011)	• Ratio based upon patient needs in their model • Ratio does not necessarily represent requirements or reality in the real world
1:4	105 CMR 130.311 (Massachusetts 2014)	• Ratio of qualified, registered nurses to patients required for Adult Intensive Care Unit in Massachusetts
1:1 – 1:2	105 CMR 130.750 (Massachusetts 2014)	• Ratio of qualified, registered nurses to patients required for a pediatric intensive care unit (PICU) in Massachusetts
1:2	A Description of Evacuation Drills: Case G: A hospital Ward (Rinne, Tillander and Gronberg 2010)	• Evacuation drill in a hospital ward using a ratio to represent the nighttime staffing levels

There is a wide range of values that are found for the number of staff to the number of patients. From the various studies mentioned above, and in consultation with hospital industry experts, the recommended first approach observed following range of ratios: 1:2, 1:3, 1:5, and 1:9.

It should be noted that based on the type of patients present in the compartment at a given time (i.e. ambulatory, require assistance, non-ambulatory), the staff-to-patient ratios may not be representative of an ideal hospital scenario. From discussions with healthcare experts it seems unlikely that an area of a healthcare occupancy consisting of mainly non-ambulatory patients, would have a staff-to-patient ratio as high as 1:9. This value was still included in the study because while guidelines in the United States advocate for more staff to be present, this may not always be the case. So in an effort to provide a more inclusive comparison on the effects of staff-to-patient ratio as well as smoke compartment size on evacuation time, the range of 1:2 to 1:9 was carried out.

Ambulatory Patient Type

For the purposes of this study, patients that could be present in a med-surg wing of a hospital were divided into three categories related to their mobility capabilities. Categorizing the patients in this manner is a popular choice for analyzing hospital egress (Alonso 2014) (Golmohammadi and Shimshak 2011).

Patient Type 1

The first patient type, *Patient Type 1*, consists of ambulatory patients with reduced mobility. These patients are able to walk out at a reduced speed compared to that of a healthy, able-bodied person. In the event of an emergency, one staff member is required to assist Patient Type 1 occupants in egress travel to the horizontal exit.

Patient Type 2

The second patient type, *Patient Type 2*, comprises of patients that are bound to a wheel-chair. These patients are not able to evacuate themselves, and require assistance by one staff member to push their wheel-chair in the event of an emergency.

Patient Type 3

The third patient type, *Patient Type 3*, consists of patients with the most severe mobility restrictions. These patients need to be moved in a stretcher or bed. Two staff members are required to assist Patient Type 3 occupants from their rooms to the horizontal exit.

Since this was a comparative study, with the focus on smoke compartment size, this study represented the entire patient load with Patient Type 3 characteristics. Continued analysis should be performed that includes different patient types. The distribution of different patient types, as well as the location of the patient types, was too inconsistent for this analysis. On any given day, a hospital could have any number of ambulatory or non-ambulatory patients. There is also no way to predict where a specific patient type may be located in the compartment, as this depends on hospital procedures for placing patients as well as the availability of rooms on a given day.

Utilizing only Patient Type 3 occupants is a conservative approach representing a worst probable scenario for assisted evacuation as these occupants have a longer prep time, slower walking speed, and larger width (discussed below). Additionally, as Type 3 patients require the assistance of two staff members to safely evacuate, the number of patients that staff can assist concurrently is much less, leading to longer evacuation times.

Occupant Characteristics

Movement characteristics of each patient type needed to be defined prior to adding them into the egress models. These characteristics include:

- **Prep Time**
- **Staff Movement Speed**
- **Transport Movement Speed**
- **Settle Time**
- **Representative Width**

Table 2 below contains a range of values suggested for movement characteristic from three different sources. Based on these sources, values for each movement characteristic were chosen to be utilized in the egress models. ((Alonso 2014), (Johnson 2005), (Hunt, Galea and Lawrence 2013)).

Table 2: Summary table of occupant characteristic found from multiple sources

	Virginia Alonso, FPRF	C.W. Johnson	Hunt, Galea, Lawrence
Prep-Time (s)			
Patient Type 1	30 - 90 ($\bar{x}$ = 60)	60 - 180	--
Patient Type 2	100 - 120 ($\bar{x}$ = 110)	180 - 900	29.4 - 35.9
Patient Type 3	180 - 900 ($\bar{x}$ = 360)	180 - 900	67.6 - 87.7
Speed (m/s)			
Staff	0.65 - 2.05 ($\bar{x}$ = 1.35)	0.625 - 1.25	--
Patient Type 1	0.84 – 1.40 ($\bar{x}$ = 1.12)	--	--
Patient Type 2	0.63 (σ=0.04)	0.5 - 0.83	1.39 - 1.55
Patient Type 3	0.40 (σ=0.04)	0.29 - 0.5	0.99 - 1.09
Width (cm)			
Staff	--	--	--
Patient Type 1	--	--	--
Patient Type 2	--	75	48 – 52
Patient Type 3	--	100	111

Prep Time

For the purposes of this study, prep time is the time it takes a staff member to assist the patient in such a way that allows for the patient to safely move to a designated safe area. Based on the sources above, preparation time was found to have a range from a minimum of 30 seconds to a maximum of 900 seconds. The mean was found to be 120 seconds with a standard deviation of 30 seconds. These values were modeled as a log normal distribution to capture the variance in literature.

Feedback from industry concluded that 120 seconds may be far too long of a prep time for med-surg patients despite the literature review. The discrepancy stems from the inclusion of “uncoupling” and “positioning” in the Alonso and Johnson studies. “Uncoupling” is considered to be the time it takes to unhook the patient from any IVs, breathing apparatuses, or similar instrumentation. “Positioning” is either assisting an ambulatory patient out of bed to begin walking, or moving mobility impaired patients to a wheelchair or stretcher. Since the model was fully loaded with Type 3 patients, it was assumed that uncoupling and positioning would not be as significant since the bed-ridden patients would already be in bed, ready to be wheeled out by staff. The values of the Hunt study were then also included in the modeling. A log normal distribution was employed with a maximum of 87.7 seconds, a minimum of 66.7 seconds, and an average of 77.65 seconds.

Sensitivity Analysis of Patient Prep Time

A sensitivity analysis was conducted with IBM’s statistical package for the social sciences (SPSS) to evaluate the effects of choosing different prep times on the evacuation times. There was a significant effect of prep times on the total evacuation time of smoke compartments based upon the commonly utilized $p < 0.05$ rule [F (1, 324) = 69.198; p = 0.000]. This was to be expected as a larger prep time would have a compounding effect on the final evacuation time. However, this study was only concerned with the comparative effects of smoke compartment size on evacuation time. The influence of prep time on the evacuation of the different smoke compartments was then evaluated. The effect size of the smoke compartment size and the prep time independent variables was found to be 0.176. This is assumed to be a weak influence on the comparative evaluation based on widely used statistical guidelines (Cortina and Nouri 2000).

Movement Speed

Staff movement speed is the speed at which a trained staff member travels, unimpeded, to a patient's room. Whereas transport movement speed is the speed at which a staff member and patient combined group travels from the patients' rooms to the horizontal exit.

Of the three sources mentioned in Table 2 the transport speeds, suggested by Hunt (2013), are the most pertinent for the transport speeds in this study. These speeds were gathered during a hospital evacuation study, which looked at horizontal movement speeds, during evacuation in a hallway free of detritus and obstructions. This "free movement" is assumed to result in the faster movement speeds. The Alonso and Johnson papers used data in which occupants were carried and lifted as opposed to being rolled in the wheelchairs and beds, which results in slower transport speeds.

Like many of the variables considered in this study, there are numerous conditions that could be present in an emergency situation that could cause great variances in the movement speed (e.g. crowding and congestion, exhaustion of staff, uncertainty of next step, etc.). Therefore, the chosen speeds used in the egress models should not be considered as the expected speeds, staff movement, and patient transport speeds applicable for every hospital.

For this particular study, a staff movement average speed of 1.25 m/s and a transport average speed of 1.04 m/s were utilized for one set of simulations based on the literature review. Members of the healthcare industry expressed concern with the validity of the aforementioned speeds. Anecdotal data and additional research led to the conclusion that 1.25 m/s may be on the slower side for an emergency situation. The average running speed of an adult has been recorded as 2.2 m/s. Additional models were then run with an average staff movement speed of 2.2 m/s and an average transport speed of 1.09 m/s to evaluate the effects of varying speeds on evacuation. Again, to account for the variances in literature a log normal distribution was employed.

Sensitivity Analysis of Movement Speed

Similar to the prep time, a sensitivity analysis was conducted in order to determine if the results of the comparative study would be impacted if different movement speeds were applied. It was evident that varying transport and movement speeds had a significant effect on the total evacuation times [$F(1, 324) = 172.2$; $p = 0.000$]. However, the varying speeds did not influence the comparison of evacuation times between the smoke compartments [$F(1, 324) = 0.116$; $p = 0.734$]. This was to be expected as the travel distances in the small and large smoke compartments are essentially identical in each simulation. So, as long as the movement and transport speeds were consistent across both compartment sizes, the effect on evacuation speed is moot.

Settle Time

Settle time is the time it takes for a patient to be placed on the non-emergency side of the smoke barrier. This includes transport time on the non-emergency side of the smoke barrier up until the patient is placed as well as searching for any tools or machinery that the patient might need. To incorporate this factor into the modeling exercise, the settle time will be incorporated into the delay of the staff person as they delivered one patient into the safe area and then are delayed when returning.

Settle time was not included in the table as no sources suggest values related to this characteristic. Additional feedback from hospital representatives was requested to fill in this particular information gap. Unfortunately, no consensus was reached on the delay time to be associated with a staff member or staff team to simulate the safe positioning of a patient.

From the literature review and discussions with healthcare industry experts, it is evident that the different hospital protocols greatly influence settle time. In some hospitals, staff members transfer the care of the patient to other hospital personnel who will then relocate the patient in the safe smoke compartment, whereas the procedure in other hospitals requires staff to relocate the patients to an appropriate location themselves. Geometry is also assumed to have a large impact on settle time as some layouts may result in farther travel distances or more congested areas than others.

For this particular study, the model was set up in such a way that settle time was not evaluated. Once the staff and patient group crossed into the adjacent smoke compartment, the model simulated staff members immediately returning to the smoke compartment of origin to retrieve additional patients. The exclusion of settle time reduced the uncertainty associated with the numerous factors that impact the settling of the patients. It is recommended that the role of settle time should be more thoroughly investigated.

Representative Width

Representative width is the largest width associated with a patient relative to the transportation device used. Staff and ambulatory patients were considered to have a representative width associated with an average shoulder width of an adult. Patients requiring assistance to evacuate (Patient Type 2 and 3) will have a representative width of a wheel-chair or hospital bed.

Only the Johnson and Hunt et al. (2013) papers provided information on the wheel-chair and bed widths used in their studies. In each paper there is discussion of how both wheel-chairs and hospital beds vary in size based upon patient use as well as product type. Therefore, average values of 4.548 meters (1.49 feet) for staff and 1.1 meters (3.61 feet) for Patient Type 3 beds were used.

The modeling process used in this study did not allow for a more in depth evaluation of the impact representative width has on horizontal evacuation. It is assumed that the representative widths of different patient types would have the largest impact on the settle time of the patients in the adjacent smoke compartment. In conjunction with the continued investigation of settle time recommended above, it is suggested that representative width be considered as a main variable.

Number of Patients per Room

Based on discussions with healthcare industry experts, it is understood that privacy concerns are playing a large role in hospital protocol. Privacy and comfort has encouraged the healthcare industry to provide single occupancy rooms in hospitals. From the hospital geometries provided as well as the from background research, it is understood that some existing hospitals were designed to accommodate two patients per room, and that today there are some hospitals that utilize the space as such. This study assumed that the trend for increased privacy and comfort will be more prevalent in future hospitals. Therefore, this study modeled a hospital floor in which there was one patient in a room.

Total Number of Patients

From the research that has been conducted it is general practice that the occupant load is determined on a per-room basis rather than by a floor area basis, which is typical of the IBC. The Facility Guidelines Institute publishes a guidance document for hospital occupancies, which suggests that there is typically one patient per room unless an alternative is approved by the authority having jurisdiction (FGI 2014). Since it was determined that this study would only consider one patient per room, the number of patients was therefore equal to the number of rooms.

It should be noted that different hospital protocols may limit the number of patients permitted in a single smoke compartment. However, since there is limited data on the subject and it varies from hospital to hospital, simply using the number of rooms to determine the number of patients in a smoke compartment was utilized to reduce uncertainty.

The increased smoke compartment size was intended to provide additional space in hospital rooms for medical equipment. So, it is assumed by many in the healthcare industry that a smoke compartment of 3,700 m^2 (40,000 ft^2) would hold the same amount of patients as the smaller 2,090 m^2 (22,500 ft^2) compartment. At this time, this is merely a guideline and intended use of the space; there is no restriction that states the larger compartment of almost double the maximum area could not house double the patients.

For this study, the small and large compartments contain 18 and 36 rooms, respectively. The small compartment will then be fully loaded in each simulation and have 18 patients present. The large compartment will be modeled with both 18 and 36 patients.

Staff Response

The staff response is a challenging topic to find data for because of the lack of reliable reports in existence pertaining to staff response in horizontal evacuation events. The variability in hospital protocols makes bounding the variables very difficult. There are three separate parts of the staff response which are important to the study of the problem: the origin of staff, staff response time, and the order of triage.

Origin of Staff

The origin of the staff needed to be considered in order to define the initial setting of the smoke compartment prior to evacuation. There are two things that were considered:

- Where are staff located when they start the evacuation, and
- Whether to include staff from other areas of the building in the model.

Based on available literature and anecdotal guidance from industry experts, there are two main scenarios related to staff origin that may take place in an emergency situation. Either staff will begin evacuation measures from wherever they are located at the time they are notified of an emergency, or staff will meet in a dedicated location to receive instructions and then carry out evacuation procedures. This will either be one central location, or various nursing stations throughout the compartment. The most probable scenario would include a combination of both immediate evacuation and instruction from heads of staff.

In addition to the staff located in the smoke compartment, from which patients need to be evacuated, other hospital personnel may come into the smoke compartment from various locations in the hospital to assist during evacuation. This effort would in essence provide a more ideal staff-to-patient ratio by increasing the number of trained personnel in evacuation procedures for the same number of patients.

For this study, staff members were distributed evenly among the staff workstations seen in the floor layouts. It was also decided to only utilize the staff initially located in the smoke compartment for evacuation procedures. It should be noted that this is highly improbable as healthcare industry members have made it clear that all available hospital personnel will assist in evacuation during and emergency event. This approach reduces the variability of staff locations in a given compartment to begin egress, and eliminates the uncertainty of the number of additional hospital personnel and their respective delay times to the smoke compartment of concern.

Staff Response Time

The staff response time is defined as the time from which the staff is notified of an event until the time they start to move toward their patients. An estimate of the staff response time was not within the scope of this study. This variable would be more significant if staff members from other smoke compartments were considered in the modeling effort. As an effect of conducting a comparative study between the differences in the smoke compartment size, the time for response is not critical to that effort as long as it is consistent between the small and large compartments.

Order of Triage

The order of triage is synonymous with what order the patients will be evacuated. Within a healthcare occupancy, Remove, Alarm, Contain, Evacuate or RACE, is standard practice for a response to a fire situation. There is a consensus in the literature as well with the experts consulted, that the first action that a staff member will take is always to remove those patients in immediate danger who are either intimate with the ignition or are in the room or origin (Marlar 2008) After evacuating the patients in the most danger, there are varying opinions related to the order of patient evacuation related to both to ambulatory abilities of the patients as well as their vicinity to the exit. Since this study does not consider a specific fire event and assumes a smoke compartment that consists of patients with the same mobility capabilities (i.e., Patient Type 3 in beds), the model will be programmed to only include the evacuation.

Without a point of origin or hazardous location, this study chose to evacuate patients based on their proximity to the exit. Patients were evacuated starting with those farthest away from a horizontal exit and moving closer to the exit, or evacuated starting with patients that are closest to the exit and progress further into the compartment of concern. Figure 4 and Figure 5 depicts the two evacuation scenarios from which preliminary evacuation models were conducted to evaluate which was more conservative.

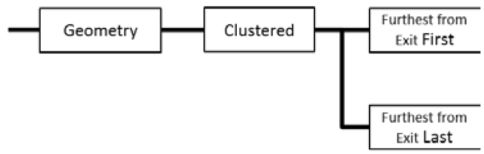


Figure 4: Tree diagram of triage options. The scenarios refer to the figures displayed below.

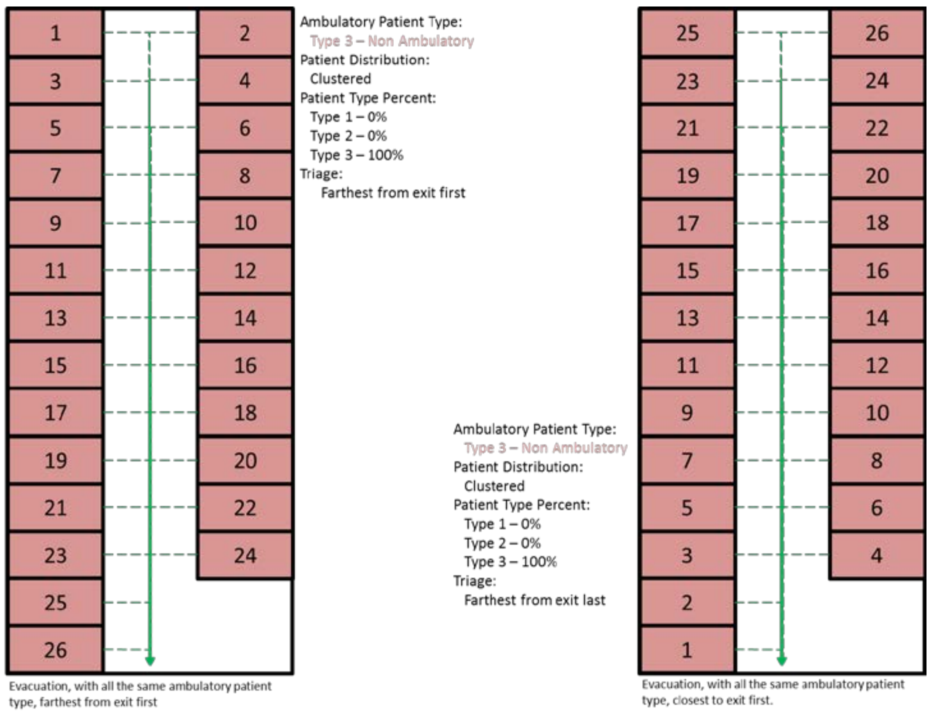


Figure 5: Triage options scenario displayed using simple geometry and all Type 3 Patients. The numbers represent the order in which the patients will be removed from the floor, following the green arrow towards the bottom of the figure.

Utilizing a single, simple geometry resembling that shown in Figure 5, a simple parametric analysis was conducted to investigate the effect of the triage option on evacuation time. Analysis comparing the evacuation times of ten different models using the same number of patients and varying staff-to-patient ratios concluded that the order of evacuation did not have a significant effect on evacuation time. This is likely due to the fact that the total travel distances of the staff members in each scenario were essentially the same.

4. Computational Models

For this study, several timed egress models were built. There were many choices that were made to make the model as close to the physical reality of the space as possible. As such, there were many variables that were programmed into the model software.

All modeling tools contain limitations and sources of uncertainty associated with the program itself, in addition to the inputs provided by the user. The software packages Pathfinder (Thunderhead Engineering 2013) and STEPS (Mott MacDonald 2014) were used for computing the timed egress analysis. This allowed the modelers to take advantage of the features of each, as well as better understand the limitations of each software package. Although both tools were used, after building and running the same geometries in both evacuation tools, it was determined that the features in STEPS allowed the user more control over variable manipulation needed to program the model.

The requirements that we sought in our model was the ability to program the following:

- Assign different speeds to nurse teams depending on if they were moving to, or from the patient rooms
- Assign delay (prep) times for each patient, preferably with the ability to do this categorically or with an automated process
- The ability to automate as much of the model as possible, to the extent where a user did not need to monitor the models to calculate an evacuation time
- The ability to keep the nurse and patient group together as they move to the settle points

Pathfinder

Pathfinder is a software package that is adept at efficiently building and running complex geometries, as well as providing clean visually appealing results. Pathfinder is an agent based, three dimensional computational evacuation model, which uses a navigation mesh for agents to move through the model. The program provides two types of evacuation modes that can be used, SFPE mode and "steering mode." SFPE mode is based on simple hydraulic calculations before computers were extensively used to calculate the egress. The steering mode is a newer computational technique that is meant to provide a truer representation of natural human movement throughout a space. (Thunderhead Engineering 2013)

In general, people movement can be represented by similar physics as the flow of fluid, as long as additional constraints are used to address the individual behavior of the occupants. The individualistic properties can be summarized as behaviors limited to their seeking behavior, avoiding the physical walls, and avoiding other occupants. (Thornton, O'Konski and Hardeman 2007)

To build the model in Pathfinder, there were several steps that were completed to turn the selected hospital floor plans into something that the software package can understand. The first step is to import the floor plans and then identify the floors, walls, and exits on the plans. Next the rooms on the floor are identified and occupied with agents, which in this case consisted of staff and patients. Then the specific occupant characteristics are assigned to the occupants. Next occupant behaviors including the delays, waypoints and pathways, which the occupants will move along, were assigned to the occupants. Then the model is run to determine the timing of the staff movement, which is then incorporated into the patient movement behavior. This is iterated until the movement for all the patients and staff has been completed. Then the results were collected and analyzed.

When SFPE mode is used, the occupants became very unpredictable and if more than one occupant reached a waypoint at the same time, occupants would either circle around the entire model and come back to the waypoint and finish their egress, or they would get stuck and keep circling around the way point. The model is switched to steering mode and this problem was mostly resolved; however, this mode allows occupants to walk through each other. So, congestion in the hallways or settle points could not be determined if this mode was used. Based on the difficulties using SFPE mode, the effects of congestion were ignored.

Because of the challenges of using the SFPE mode the steering mode was used for the Pathfinder models. Even using the steering mode there were several challenges faced with achieving the requirements listed above.

Requirement 1: Assign different speeds to nurse teams depending on if they were moving to, or from the patient rooms

Assigning different speeds to the nurse teams proved to be one of more difficult challenges to overcome. There were several features that were used to approximate this. Pathfinder includes the ability to add a factor to the corridors, which changes the movement speed of the occupants on that corridor. This feature combined with waypoints allowed the occupants to be guided along the corridors that approximated their correct speed.

From the diagram in Figure 6 we can see that there are three different speeds and types of occupants that needed to be accounted for. To accomplish this, the corridor was split into two and each was assigned a speed factor. In general the staff transport speed is the only one that needed to be changed dynamically throughout the model.

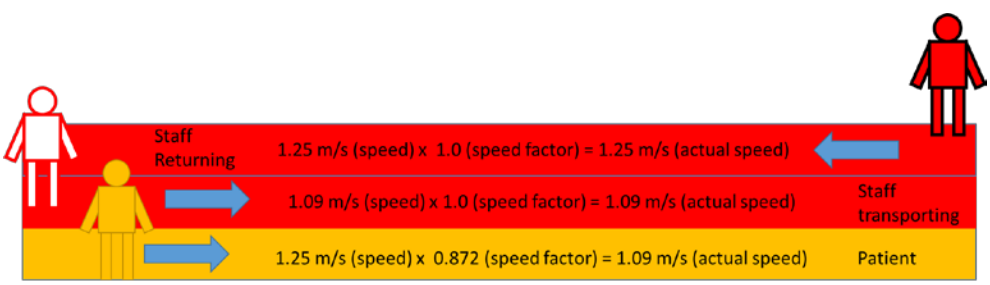


Figure 6: Pathfinder corridor movement model

The hallways in which the staff teams and patients walked were divided into rooms with designated speed factors. Then the occupants were assigned waypoints to ensure they stayed on their "side of the hallway." This was adequate enough when all the same type of patients were being used. If the study is to be continued, it would require the inclusion of a mixture of patients with different movement speeds, so the hallways would have to be further divided unless another method was discovered.

Requirement 2: Assign delay (prep) times for each patient, preferably with the ability to do this categorically or with an automated process

Assigning the delay times was an extremely tedious process as the model had to be run multiple times in order to determine when each nurse team would enter and leave a patient room.

Requirement 3: The ability to automate as much of the model as possible, to the extent where a user did not need to monitor the models to calculate an evacuation time.

There is not a way for occupants to begin movement based on events that occur in the model, such as when a staff member enters a room. To program when patients should begin to evacuate with the staff, individual delay times were assigned to each patient, which corresponded with when the assisting staff would leave their room.

Requirement 4: The ability to keep the nurse and patient group together as they move to the settle points.

Keeping the patient/staff groups together was also difficult with the way the delay times were assigned and the way the hallways were divided. Depending on where/when the occupants crossed over rooms with different speeds, they would become separated.

Suggestions for Software Updates

It would be extremely advantageous if there was a way to assign occupants to groups with a designated leader in Pathfinder. Especially helpful would be a feature that allowed the occupants of the group to have their own speeds, but take on the speed of the group leader. For our modeling this would manifest itself so that the nurse team would go find a patient (leader) while moving at the assigned nurse speed, a delay could be put on the group for prep time, and then the group would move to the settle point at the assigned speed of the patient.

STEPS

Simulation of **T**ransient **E**vacuation and **P**edestrian Movement**s** (STEPS) is a software package for modeling people movement. The model uses an agent-based, 3D approach. The general occupant movement behavior physics is based on the theories of cellular automata, a well-established techniques in the industry. The agent based approach allowed for the ability to assign each agent with specific attributes like walking speed, pre-movement time, relationship and route choice. STEPS provides the option of using evacuation mode or normal mode. Normal mode allows for addition options for how people flow and move in the spaces. (Waterson and Pellissier 2010)

Requirement 1: Assign different speeds to attendee teams depending on if they were moving to, or from the patient rooms

STEPS is a robust program, which allows more manipulation of the occupants in the space. As such one of the advantages is that the attendees can be programmed to travel to the rooms at one speed and travel to the exit at another speed. This is executed by placing a staff occupant in the model with a staff walking speed and instructing them to go to a room. Once they reach the room they leave the model and two identical, except for the slower transport speed, staff people are spurred into action. These staff people then travel from the patient room to the exit with the patient, where other staff occupants are waiting to travel to the other patient rooms. This process is repeated until all the patients are evacuated. This process was able to be programmed so that accurate timing of the evacuation was maintained.

Requirement 2: Assign delay (prep) times for each patient, preferably with the ability to do this categorically or with an automated process

One of the benefits of STEPS is the multiple ways that it can identify different parts of the geometry. STEPS can use either a location and/or a checkpoint to identify a single area. Using this a delay time could be placed on all the patient rooms at once or individually. Additionally the delay time could be changed dynamically using a distribution function. Using STEPS allowed for categorical changes in the delay times for the patient rooms.

Requirement 3: The ability to automate as much of the model as possible, to the extent where a user did not need to monitor the models to calculate an evacuation time.

Using STEPS allowed for low-level programing so that each of the models could be setup and run, with no user interaction. This was also able to be handled as a batch, so that many of these models could be set up on a computer or server with no interaction from the user. It was also possible to capture screenshots using an automated process.

Requirement 4: The ability to keep the nurse and patient group together as they move to the settle points.

STEPS has a tool that is designed to approximate families, which have a leader and stick together. However there is no way to assign the leaders or the specific members of the family. During simplified tests the family sticks together very successfully, but in complex geometries with more people it is almost impossible to get families to work successfully. This function was approximated using staff and patients that started in the same location and left at the same time, and therefore stayed a reasonable distance from each other.

Programming the Model

The complexity of the modeling exercise required that many different variables were required to be identified. Figure 7 shows a schematic of the modeling procedure that was taken. There are many different inputs and considerations that need to be made. The models were built to account for as many of the factors discussed previously in the report. The use of the variables recorded by the STEPS software package as well as the conditional statements programmed allowed the model to be robust enough to operate autonomously from the user, once it was started.

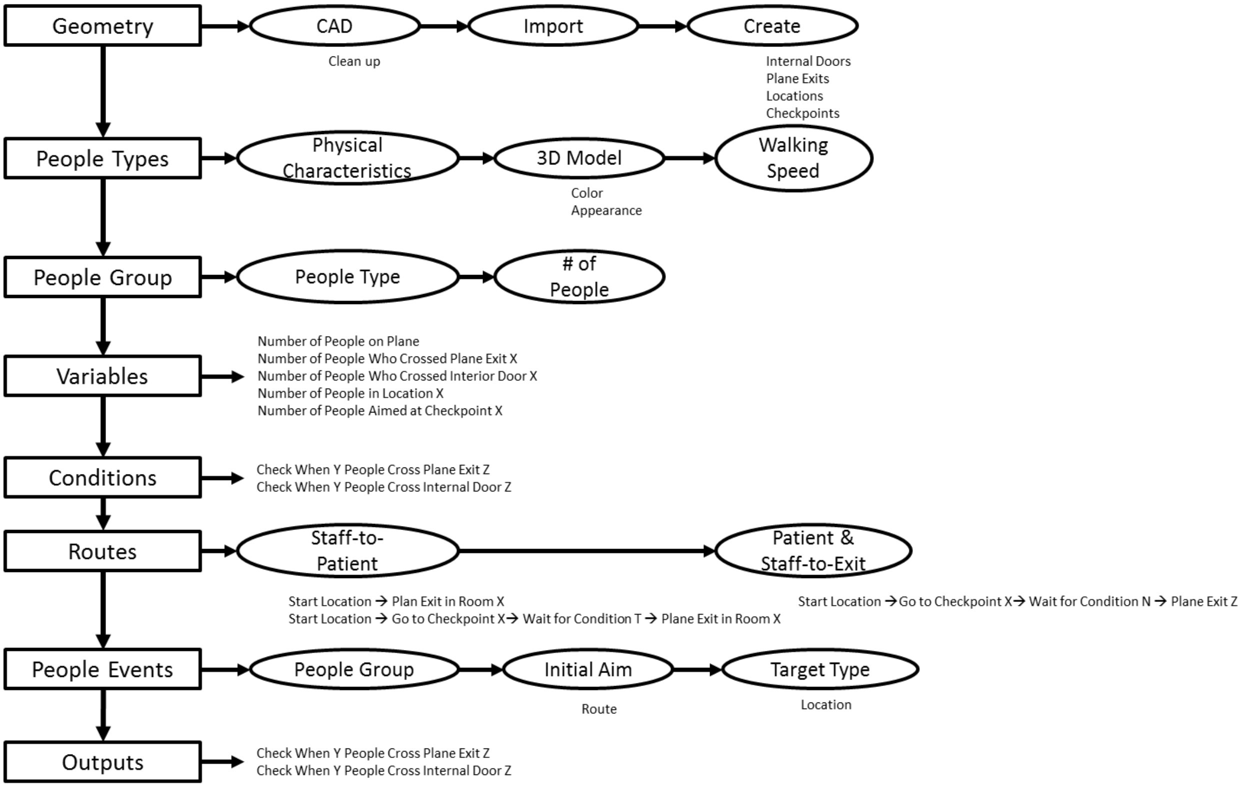


Figure 7: Modeling Procedure for STEPS Model

The STEPS modeling procedure contains a number of processes that are required to take a floor plan and calculate the evacuation time.

Geometry

As can be seen in Figure 8 and Figure 9, the walls and other obstructions are shown in blue. All of the blockages are part of the grid system. For the model the grid size is set at 0.5 meters, which is the default.

Figure 8: The model geometry of the small compartment after it has been imported into STEPS.

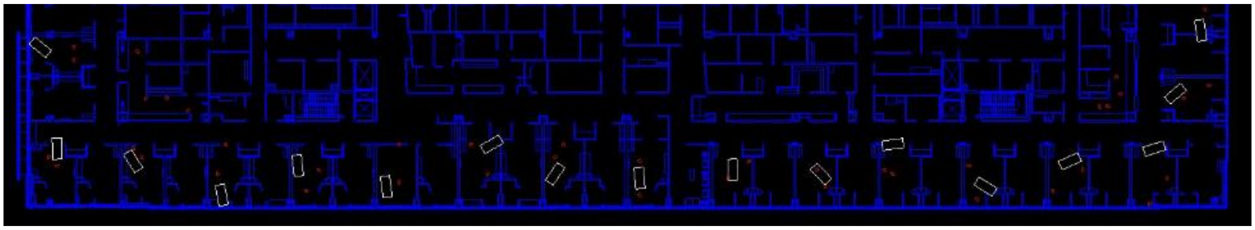


Figure 9: The model geometry of the large compartment after it has been imported into STEPS.

To create the model there were four major model objects that needed to be created: plane exits (Figure 10), internal doors (Figure 11), checkpoints (Figure 12) and locations (Figure 13). Each of these objects has a different purpose, but all were necessary to build into the model.

Early in the modeling process it was decided that the normal conditions mode of STEPS would need to be used so that more control over where and when the occupants move, could be leveraged. Therefore, plane exits were placed, not only at the exits to the smoke compartment, but also in each of the rooms. The reason for this is that staff needs to move from where they begin their journey, to the patient and then staff assist the patient to the nearest exit of the smoke compartment. This issue with this when modeling is that when walking alone staff move at one speed, but when transporting a patient they will walk at a different speed. Therefore when building the model there are staff that make the journey from the nurses station to a room and then “exit” as well as staff that come from outside of the smoke compartment and travel to a patient room and then “exit”. Since the focus is on the timing of the model the extra staff persons present do not have any impact on the results.

Both the Plane Exits and the Internal Doors also function as counters. These objects can then be made into variables so that the number of occupants that go into a room as well as the number of patients who exit the smoke compartment can be counted.

The checkpoints are created for two reasons, the serve as a place to send occupants in a route as well as a way to institute a patient prep time. Routes will be explained further in this document, but checkpoints are different than locations and they can be selected to send occupants in a route. The other reason they were place in each room is to designate the delay time representing the preparation time the staff needs to complete before transporting the patient. In this way the model is programmed to wait until two staff members have crossed the room doorway and then the patient and the two staff members are instructed to move to the checkpoint when the delay timer begins.

The locations are used to place people groups into the model at the start of the simulation. Locations are only used at the beginning of the model. One other advantage that locations have is that they can be tied to a variable to count the number of people located in the location, which can be helpful, but the count function on the door was more useful because of its more binary nature.

All of these items combined are the only elements need to develop the geometry of the space.

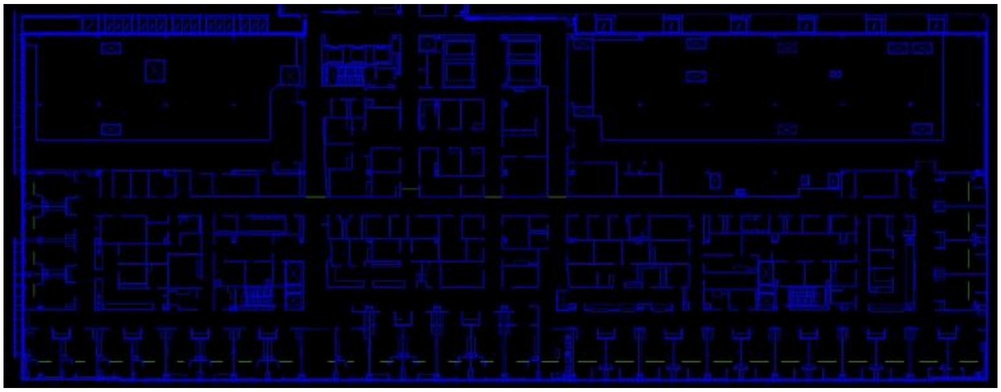


Figure 10: Model Geometry Showing the Plan Exits

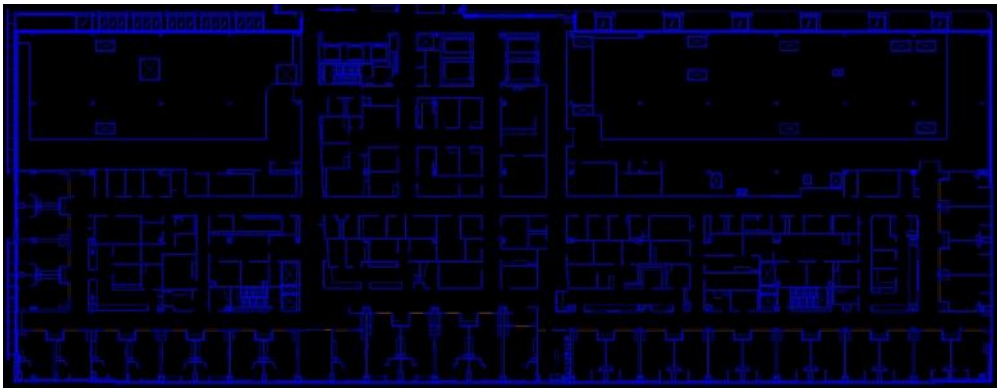


Figure 11: Model Geometry showing the Internal Doors

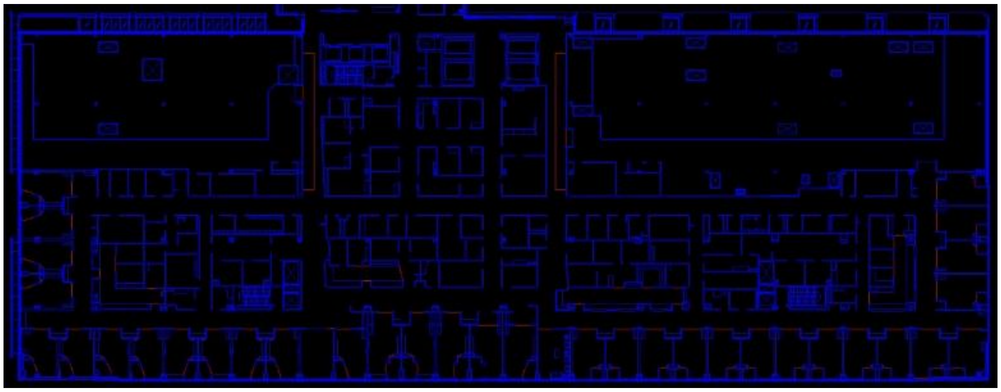


Figure 12: Model Geometry showing the checkpoints

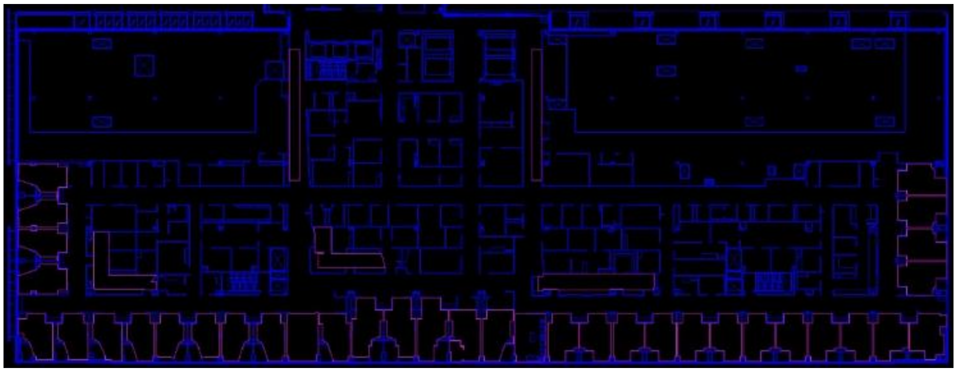


Figure 13: Model Geometry showing the locations

People Types

After the geometry had been drawn into the model the people types are created. These are the characteristics of the people who occupy the model. In this case there are three people types:

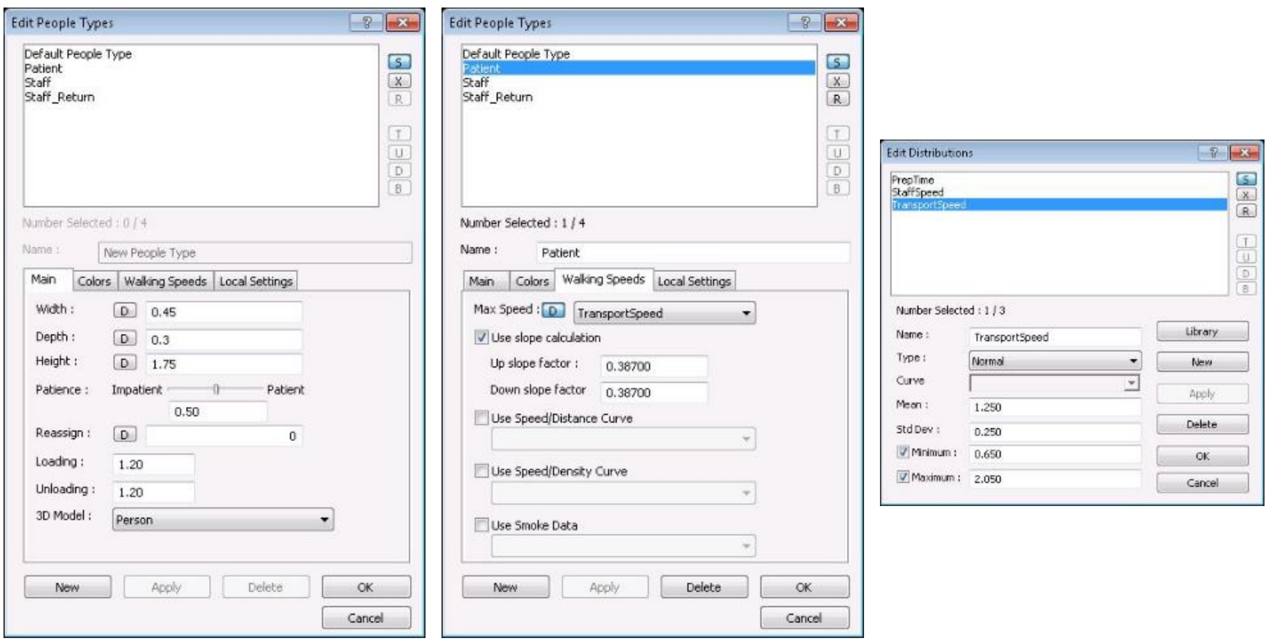


Figure 14: People Types Editing Windows

Staff: Occupants who travel from their start location either at a nurse's station or outside the smoke compartment to a patient room. These occupants travel at a speed that is typical of an unimpeded human. In this model the speed is modeled as a distribution to account for any errors in the data that was collected during the research phase of the project. Staff people types are represented by red circles in the model.

Staff_Return: Occupants who start in a patient room and wait for two "staff" to cross the door to take action and prep the patient. These staff members transport the patient to the exit. These occupants will travel at a speed less than the staff to represent the impeded walking speed of traveling with a patient bed. In this model the speed is modeled as a distribution to account for any errors in the data that was collected during the research phase of the project. Staff_Return people types are also represented by red circles in the model.

Patient: The patient is similar to the "Staff_Return" in that they start in a patient room and wait for two "Staff" to walk through the door before preparing to move. The Patients use the same distribution as "Staff_Return." Patient people types are represented by white shapes in the model.

People Groups

The People Group is a simple input box where number of people in the group is selected and the fraction of which people types make up the people group. In this model the patient exit is made up of one Patient. The Staff_Exit group is made up of two staff return people types and the Staff_Patient (staff to patient) group is made up of one staff.

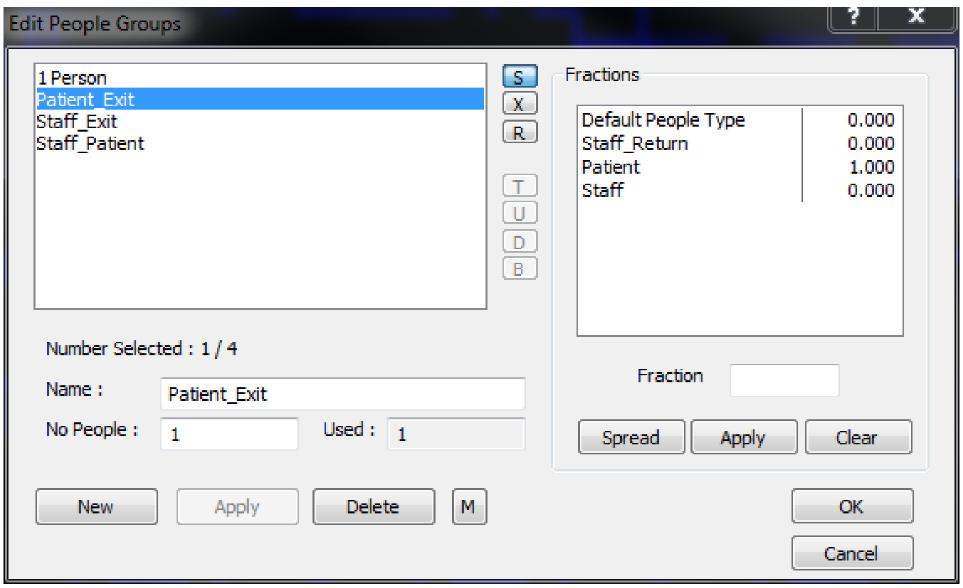


Figure 15: Edit People Groups Dialog Box

Variables

Variables are another straightforward tool in the model creation process. For the purpose of this model there are many variables that are focused on measuring the number of people in each patient room. This is done with checking the status of the checkpoint, checking the value of the location and counting how many occupants go through the doors.

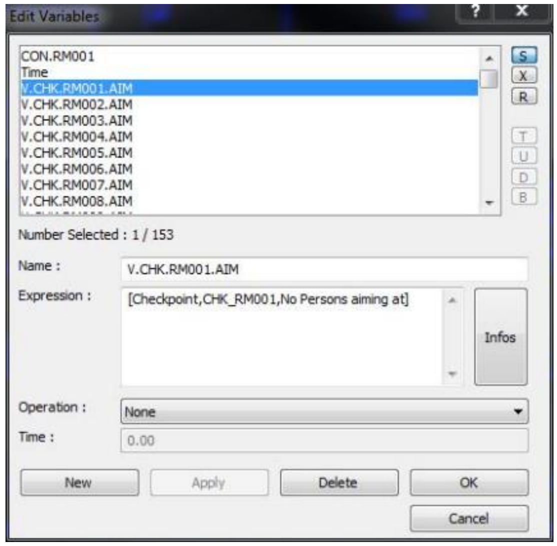


Figure 16: Edit Variables dialog box

Conditions

The conditions are one of the more tricky parts of the model to get correctly as they are very finicky. As mentioned previously it is necessary to have a check to see when staff members from the nurse's station arrive at the room so that the prep time can start. Therefore, a check to see when the variable looking at the door going to that room is equal to 2. These were created for all 36 rooms

```
[Variable,V.PE.RM001.USE,Value]==2.00
```

The other condition that is necessary is to check when the patients have arrived at the exit. Therefore, a condition was also created to check how many people have exited out of the smoke compartment and send staff back in to the compartment to attend to the remainder of the patients. These were created to count from 3 up to 51 for each exit.

```
[Variable,V.PE.H.USE,Value]==3.00
```

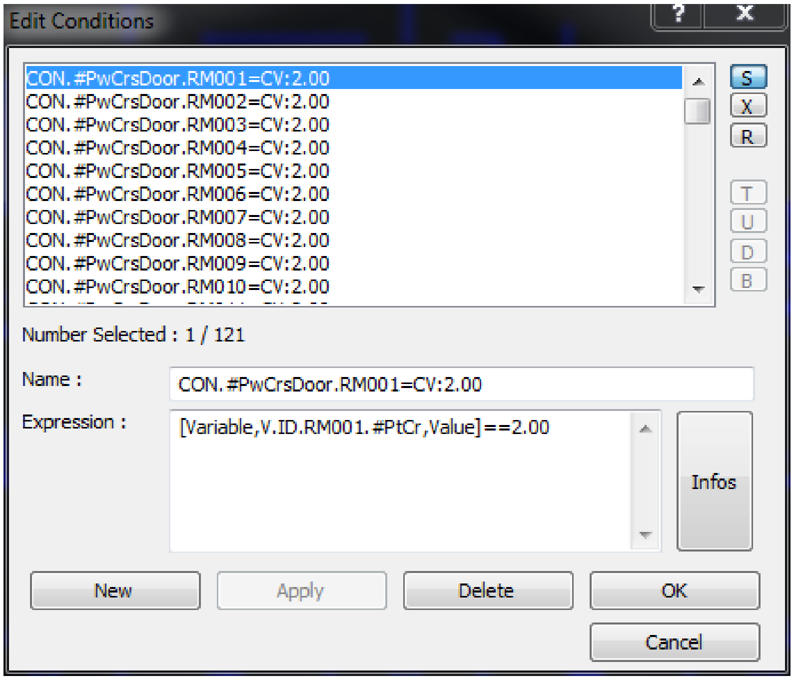


Figure 17: Edit Conditions Dialog Box

Routes

The routes are the more complicated piece of the modeling process, but allow for a tremendous amount of control and automation in the model. It also would have been perfect if the speeds of the people types could have been changed with a route, however this was not the case. The goal is to maintain the timing of the staff traveling to the patients, the timing of the prep time, and the timeing of the patients traveling to a save location.

In this model each patient and two staff were located in a patient room. They waited there for the two staff members to arrive from the nurse's station or from outside the smoke compartment. Once two staff members would make the condition true (two staff members cross the doorway) then the patient and the two staff ("Staff_Return") then go to the check point within the room and the prep time begins. When the prep time is over, the patient and staff travel to the plane exit. This logic can be seen in as Figure 18 below.

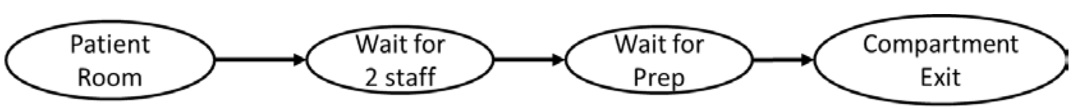
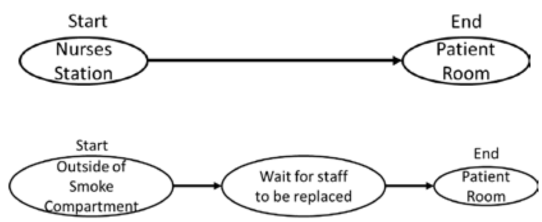


Figure 18: Sequence Logic

The other piece of the model is the staff. The number of staff is limited through the use of the Staff-to-Patient ratio, so that only a select few staff start at the nurse's stations. The rest are located outside of the smoke compartment. First the staff located at the nurse's station go to the patient rooms, thus releasing the patients, and then they exit the model.



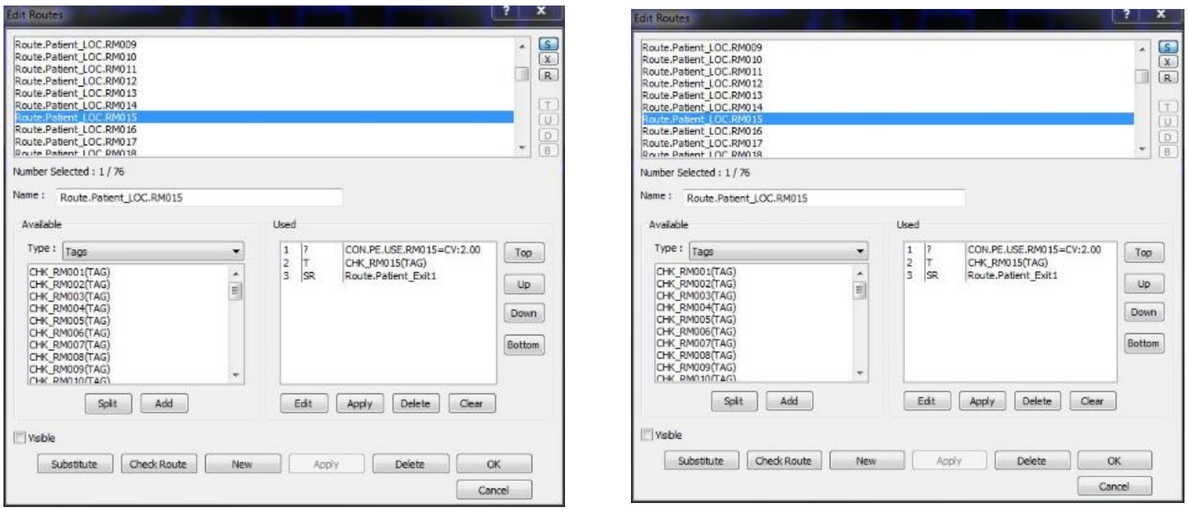
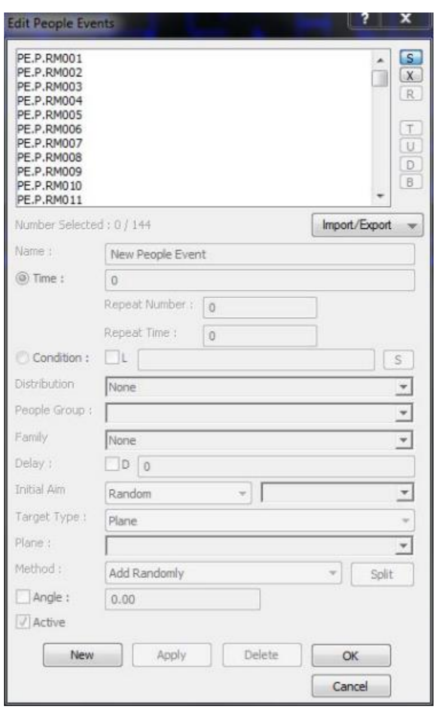


Figure 19: Edit Routes Dialog Box

People Events

The people events is the part of the model that assigns the starting places of the people groups as well as tells them which routes to follow. Fortunately, STEPS has included some features that allow these to be exported to a csv file for easier manipulation.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Name	Time	Spread	Repeat Ti	Repeat N	People Gi	Number c	Family	Delay	Aim Type	Aim	Target Ty	Target	Method	Spli
2	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
3	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
4	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
5	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
6	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
7	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
8	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
9	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
10	PE.P.RM0C	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0(	Add Rand	N
11	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
12	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
13	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
14	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
15	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
16	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
17	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
18	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
19	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
20	PE.P.RM01	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N
21	PE.P.RM02	0		0	0	Patient_E	1		0	Route	Route.Pat	Location	LOC_RM0:	Add Rand	N

Figure 20: People Events Edit box and .csv file used to import people events.

For the larger models with 36 people there were approximately 144 people events and about 72 people events for the smaller model. For these the location and route for the people groups needed to be assigned.

Outputs

The outputs are the data from the model that actually gets output. STEPS is a very nice program in that it allows for almost unlimited outputs. For this analysis, to simplify the amount of data that needed to be analyzed the evacuation time was outputted as well as the timeline of the number of people going through the plane exits.

Suggestions for Software:

STEPS is a very versatile software package, however there are a few things that could be improved for a better user experience and clearer results. The windowing of all of the different tools prevents any maximization or minimization of the windows, which can make it very difficult to access and edit different fields. Allowing the windows to change size would be a great improvement on the user experience.

Families are a point in the model that seems like more development could be added to add a lot more functionality. There are numerous scenarios where a “family” consisting of a leader and “children” would be useful. Whether this is for an actual family or for the patient-staff group from this study or for studying issues of leadership during evacuation in general.

The ability to batch several different simulations is very useful, but greater attention should be placed in connecting those runs. This study focused on a comparative analysis and it would have been useful to compile all of the outputs into one csv file. Alternatively it would be extremely useful to use one model as a base and then change different features of the model, re-run the simulation, and compile the results. An example might be having a simulation with no blocked exits and then blocking one or more exit. It is still the same model, but if there are things, other than time, which need to be compared, it can be challenging.

5. Results

The results were determined using the STEPS software package, using the method shown above. The STEPS model was used as it was able to be programmed to be completely autonomous as well as run in batches, so that created an easier process for the modelers.

The average time it takes for all the patients to exit the smoke compartment by crossing the horizontal exit is contained in Table 3, below. It should be noted that each of the 12 model scenarios listed below were run three times in order to account for the variances in transport/movement speeds and prep times. For each simulation, each of the 12 models was run 10 times to account for the stochastic nature of the models that employed log distributions.

Table 3: Table of the Results showing the Evacuation Time

Smoke Compartment Size	Staff-to-patient Ratio	# of Staff	# of Patients	Time
Large	1:9	4	36	3548
Large	1:5	8	36	1852
Large	1:3	12	36	1214
Large	1:2	18	36	728
Large	1:9	2	18	3360
Large	1:5	4	18	1753
Large	1:3	6	18	1641
Large	1:2	8	18	838
Small	1:9	2	18	3092
Small	1:5	4	18	1668
Small	1:3	6	18	1088
Small	1:2	8	18	988

When there is a high staff-to-patient ratio the large compartment with the most patients takes the longest to evacuate, followed by the large smoke compartment with least amount of patients, followed by the small smoke compartment. When the staff-to-patient ratio is high, then the small compartment has the fastest egress time.

Looking at the lower staff to patient ratios, it is less clear whether the smoke compartment size is the dominant factor. Consider Figure 21, for a ratio of 1:2 the large smoke compartment with a high number of patients is the fastest to evacuate. This is likely due to the fact that there are more overall staff members in the compartment which allows for greater efficiencies and negates the effects of longer travel distances. Another determining factor is that the compartment is almost uniform in terms of the patient rooms and the exits, so it does not present significantly longer travel distances, compared to the travel distances in the small smoke compartment.

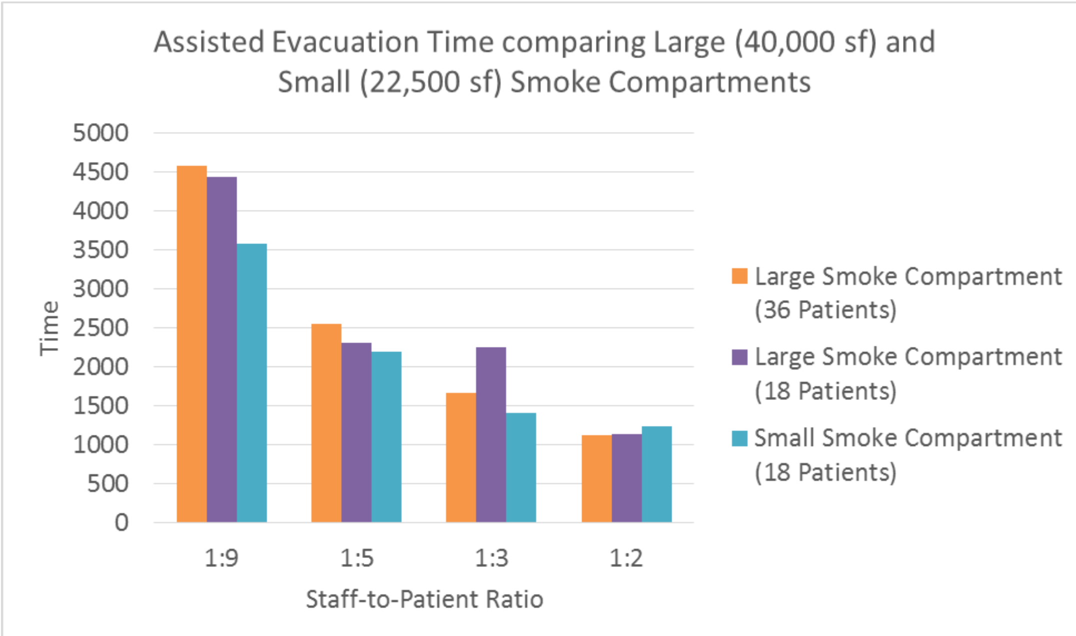


Figure 20: Graph of the Results showing the average evacuation time

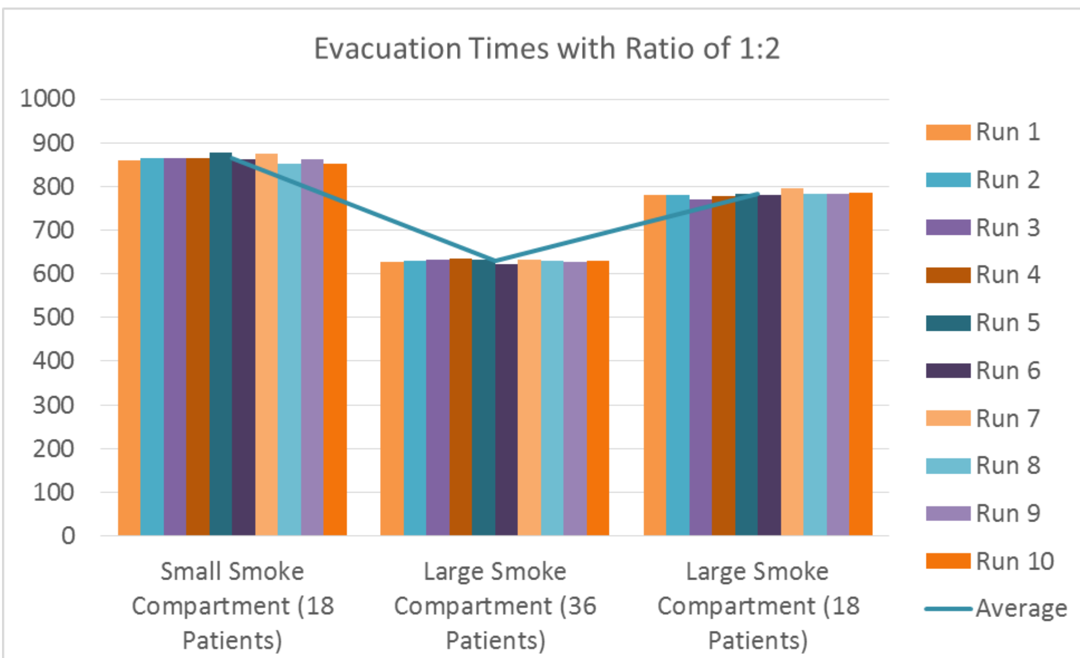


Figure 21: Alternative display of the results showing all runs with a staff-to-patient ratio of 1:2. The results show that the large smoke compartment, with 36 patients, clearly has the fastest evacuation times. In addition, the results show that the small smoke compartment has on average the longest evacuation times.

When the large and small smoke compartments have the same number of occupants, and therefore the same number of staff, the small smoke compartment generally evacuates before the larger smoke compartment as seen in Figure 22, Figure 23, and Figure 24. In this case, the distances that a staff member has to travel are most likely the dominant factor despite both compartments complying with the 60.96 meters (200 feet) travel distance.

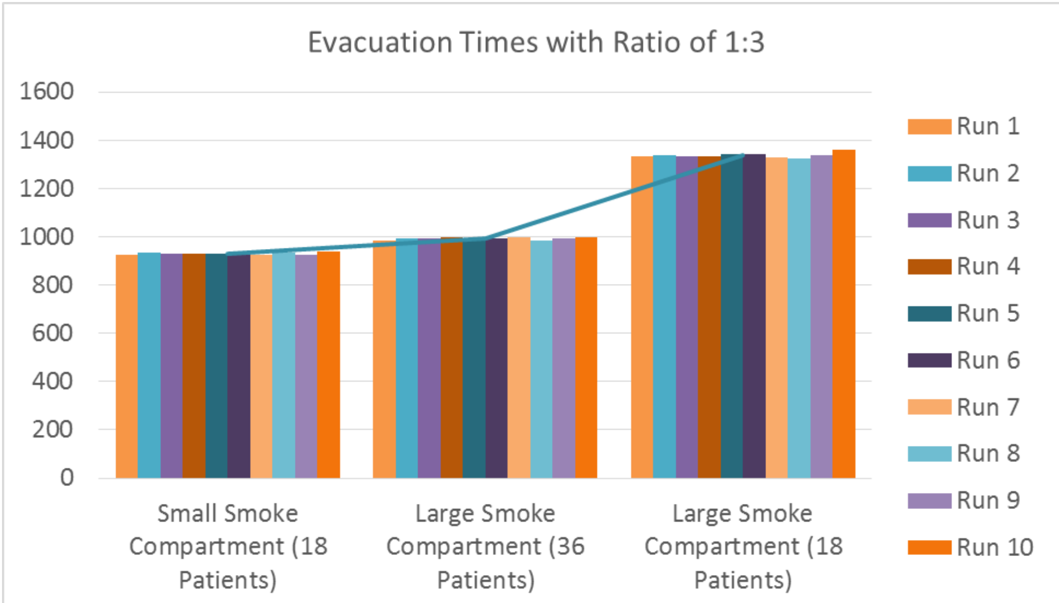


Figure 22: Alternative display of the results showing all runs with a staff-to-patient ratio of 1:3. The results show that the small smoke compartment has the fastest evacuation times, in most cases. In addition, the results show that the large smoke compartment with 18 patients has on average the longest evacuation times.

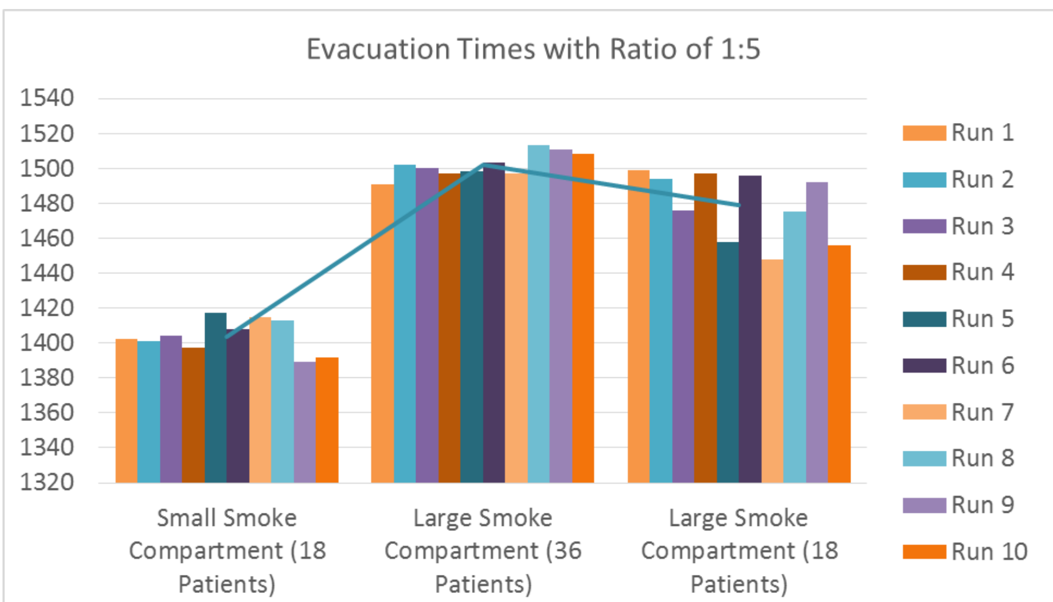


Figure 23: Alternative display of the results showing all runs with a staff-to-patient ratio of 1:5. The results show that the small smoke compartment has the fastest evacuation times. In addition, the results show that the large smoke compartment with 36 patients has on average the longest evacuation times.

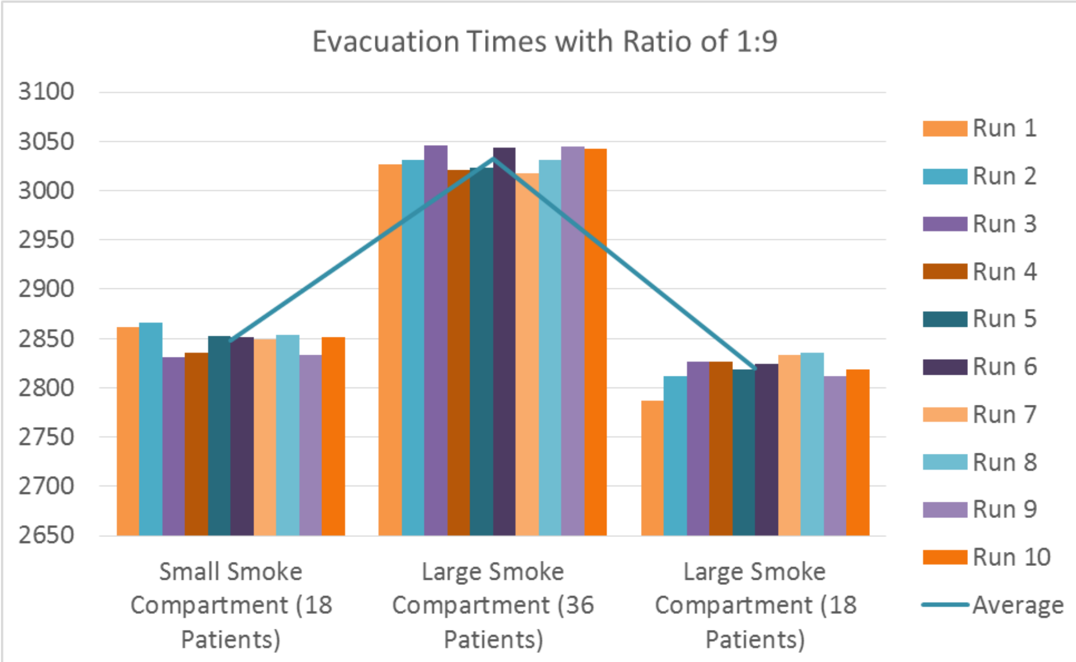


Figure 24: Alternative display of the results showing all runs with a staff-to-patient ratio of 1:9. The results show that the small smoke compartment clearly has the fastest evacuation times. In addition, the results show that the large smoke compartment with 36 patients has on average the longest evacuation times

An analysis of variance or ANOVA, a method of estimating statistical significance, was applied to the 360 runs to determine the significance of the evacuation parameters on evacuation time. It was determined that smoke compartment size did significantly affect evacuation time [F (1, 324)=285.14; p = 0.000]. The effect size measurement of smoke compartment size was found to be 0.468 which is considered a moderate influence.

Even more significant was the impact of staff to patient ratio on evacuation time [F (1, 324)=7646; p = 0.000] with an effect size of 0.986. In terms of the smoke compartment size, the staff to patient ratio still played an influential role [F(1, 324) = 93.5; p = 0.000] with an effect size of 0.464.

6. Conclusions

In the USA, there have been recent proposals to change the 2015 edition of the NFPA *Life Safety Code* (NFPA 2015) and the 2015 edition of the *International Building Code* (ICC 2015) to increase the maximum allowable smoke compartment size from 2,090 m^2 (22,500 ft^2) to 3,700 m^2 (40,000 ft^2) in certain healthcare facilities.

A natural question that arises from such a change is: *what is the difference in time required to move patients out of a 3,700 m^2 (40,000 ft^2) compartment as compared with a 2,090 m^2 (22,500 ft^2) compartment, if all other code requirements and assumptions about patient load, staffing and related factors are kept equal?*

To further explore this issue, with particular focus on the IBC requirements, a comparative timed egress analysis was undertaken, using floor plans from actual healthcare facilities, expanded data on patient to staff ratios, and available data on times for preparation and movement of patients using a variety of transportation mechanisms.

Conducting a comparative timed egress analysis for this type of occupancy required an extensive review of the relevant variables. The variables that were considered are as follows:

- Geometry
- Smoke Compartment Size
- Staff to Patient ratio
- Ambulatory Patient Type
- Patient Characteristic
  - Prep Time
  - Staff Movement Speed
  - Transport Movement Speed
  - Settle Time
  - Patient Width
- Number of Patients per Room
- Total Number of Patients
- Staff Response
  - Origin of Staff
  - Staff Response Time
  - Order of Triage
- Staff Training

Key outcomes of the analysis and areas of future study include the following.

- When there is a low staff to patient ratio (1:2) the larger compartment can be evacuated in the same or less time than the smaller smoke compartment.
- When the staff to patient ratio is higher (1:3, 1:5, 1:9) the larger smoke compartment has longer evacuation times than the smaller compartment.
- The importance of staff to patient ratios, and their impact on evacuation, should be studied further.
- Further study of the identified variables, geometry, patient loading, and occupant behavior should be conducted, as those aspects also have an impact on smoke compartment size.
- This study did not consider any design fires or other precipitating event and therefore does not represent a true measure of the level of safety shown by the evacuation times. Future studies should consider the range of initiating events, and specific staff responses to those events, to obtain a more complete picture of the evacuation issues and timing.

Given the variables and analysis considered in this study, it is concluded that larger compartment sizes do not conclusively offer the same level of safety as the smaller compartments. This does not necessarily mean that the larger smoke compartments are less safe in an emergency event. However, in terms of the timed evacuation study, the 3,700 m^2 (40,000 ft^2) smoke compartment consistently required a greater time to evacuate than the small compartment.

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Appendices

Appendix A: Interim Report - Full Variables Evaluation

Hospital Evacuation Variable Choices

Submitted to

Fire Safe North America (FSNA)

Submitted by

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February 25, 2015

DRAFT

Introduction

The purpose of this study is to develop timed egress evacuation models in order to identify and evaluate the issues associated with having a code-defined maximum smoke compartment size of 40,000 sf as compared to 22,500 sf in Group I-2 hospital occupancy. Conducting a comparative timed egress analysis in this occupancy type requires an extensive review of the relevant variables that are to be considered. This report lays out the variables that were considered, the range of values/options we considered, the relevant background information and research that were used to determine the range of values, and what we recommend as areas of interest to move forward in the study. The variables that we evaluated are as follows:

- Geometry
- Smoke Compartment Size
- Attendee to staff ratio
- Ambulatory Patient Type
- Patient Characteristic
    - Prep Time
    - Staff Movement Speed
    - Transport Movement Speed
    - Patient Width
    - Settle Time
- # Patients per Room
- Staff Response
    - Staff Time for Response
    - Origin of Staff
    - Order of Triage
    - Movement Type
- Patient types
    - Percent Distribution of Patient types
    - Location of Patient types
- Time of day
- Number of Patients
- Risk

Group I-2 occupancy requires the study of more variables than other occupancies due to the reduced physical and mental state of the patients.

Questions & Recommendations:

Throughout this working document there were be items that are highlighted. The items that are highlighted in yellow are questions or information gaps that are still present despite the background research. Items highlighted in green are the recommended values or ranges that will be utilized in the models. For a quick review of the variables, please see the supplemental document.

Yellow = Question Green = Recommendation

Building Geometries

From our initial research and through communication with our contacts in the healthcare industry, we have identified three geometries which will most convincingly result in a significant difference between the smaller and large smoke compartment sizes. There were a number of factors which led us to select these three geometries, but most important were:

- The total square footage
- The floor plan layout of the geometry
- The number of patients in the space.

Recommendation

Use the three geometries represented in the timed egress evacuation models, shown below. Note that the hospital floors shown below consist of many different medical departments. For the purposes of this study, all smoke compartments will be assumed to be used for "in-patient" or "med-surg" care.

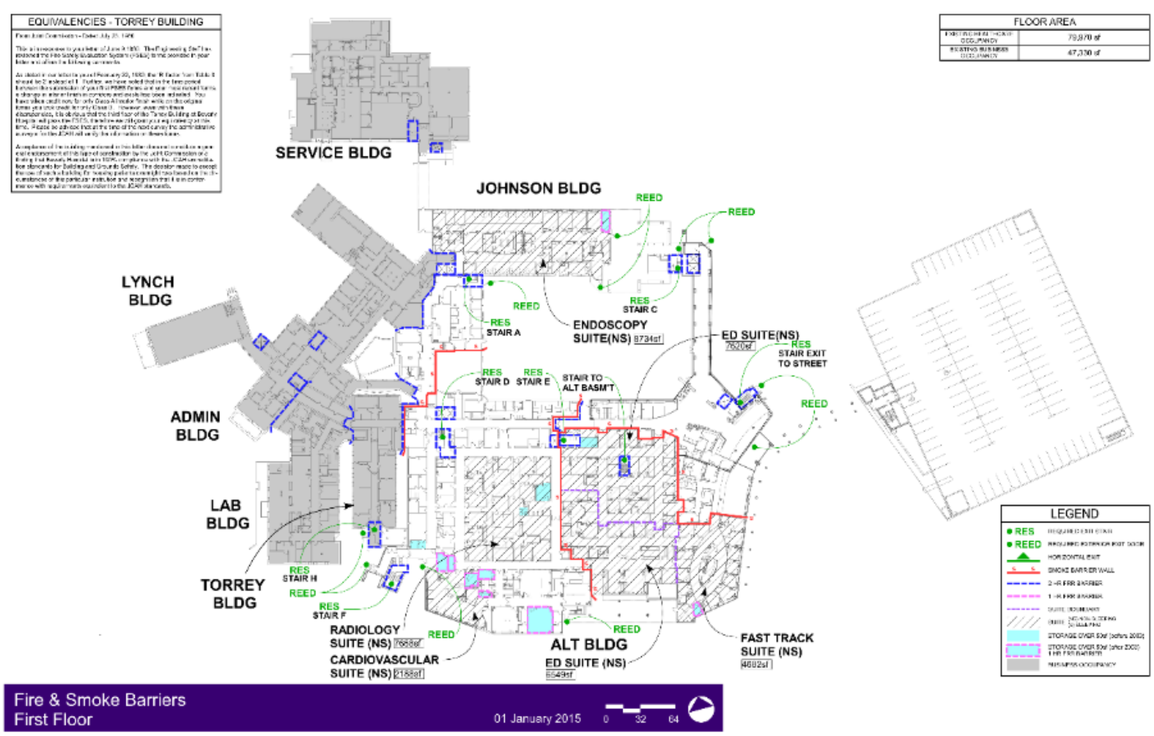


Figure 25: Building with large floor plate surrounded by non-hospital occupancies

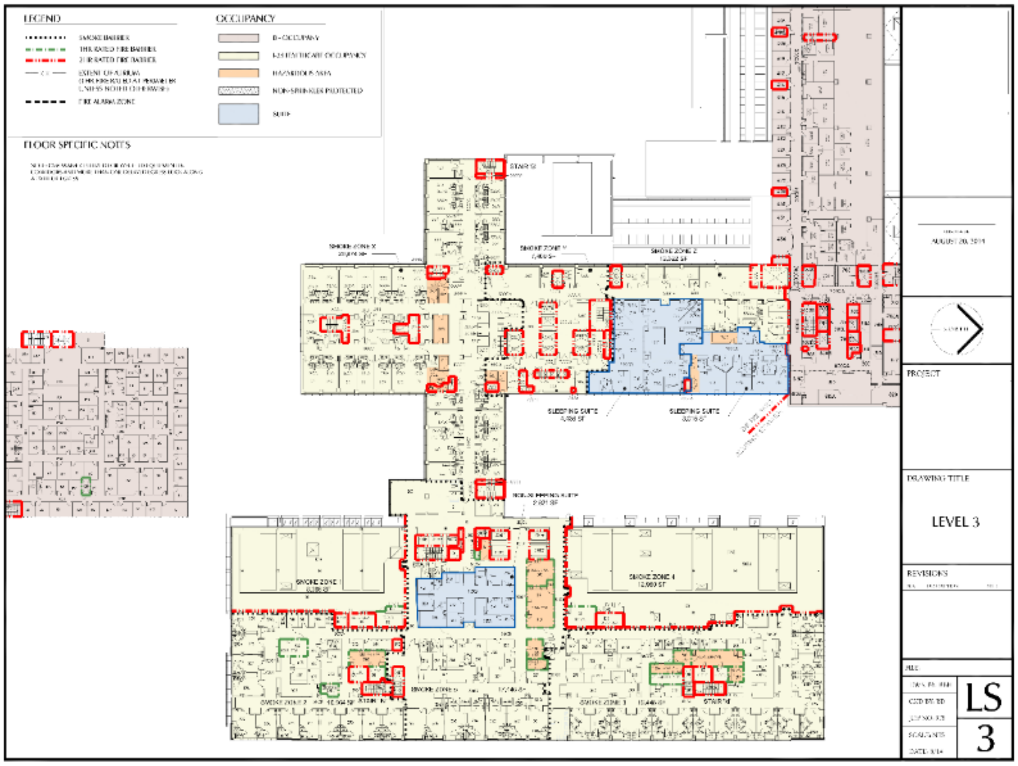


Figure 26: Geometry number 2 with an interesting cross geometry possibly resulting in bottleneck conditions.

Figure 27: Geometry #3 with a large floor plate and interesting curved walls.

Smoke compartment Size

This is a comparative study to analyze the difference between smoke compartments that are a maximum of 22,500 sf and a maximum of 40,000 sf. To do this we are taking the geometries that we have and running a model with the currently identified smoke compartment as well creating our own smoke compartments that are over 22,500 square feet.

The maximum smoke compartment size as defined in IBC Section 407.5 and Section 422.3 (ICC 2012) is 22,500 square feet in 2012 International Building Code. The relative performance of the smoke compartment size during this egress study will be reviewed for a possible code change in the 2018 IBC.

While the range of possible values spans from 0-22,500 sf for the small compartments and 22,500-40,000 sf, the concentration of the study is to find actual hospital geometries and use the smoke compartments defined by the building plans. The smoke compartment geometry will then be altered to contain all smoke compartments that approach 40,000 sf in size. This method will allow for evacuation to be evaluated over several different geometries and other factors to ensure that we identify which of the variables are most significant.

The spaces that we see below are an example of how we can break up the buildings into different sized smoke compartments. Figure 2 is shows that we have 6 smoke compartments, all under 22,500 sf as well as 2 mechanical room smoke compartments. Figure 3 shows the geometry broken up into 3 larger smoke compartments, keeping the 2 mechanical smoke compartments untouched.

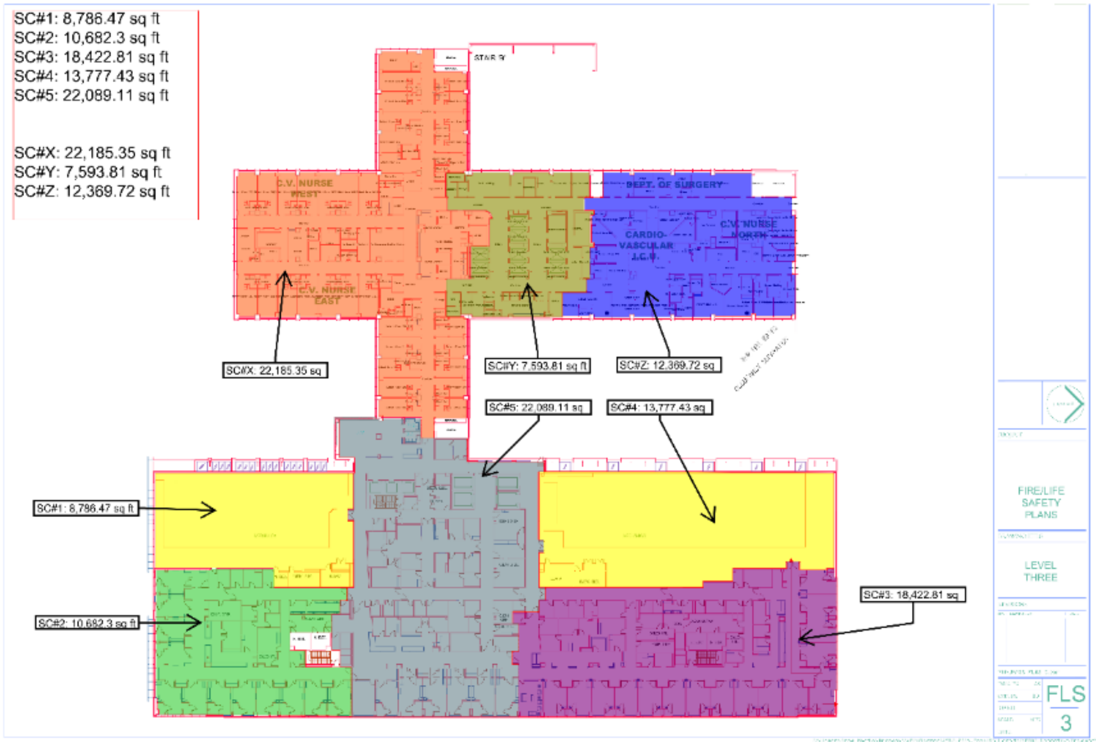


Figure 28: Geometry #2 with small smoke compartments, all under 22,500 sf

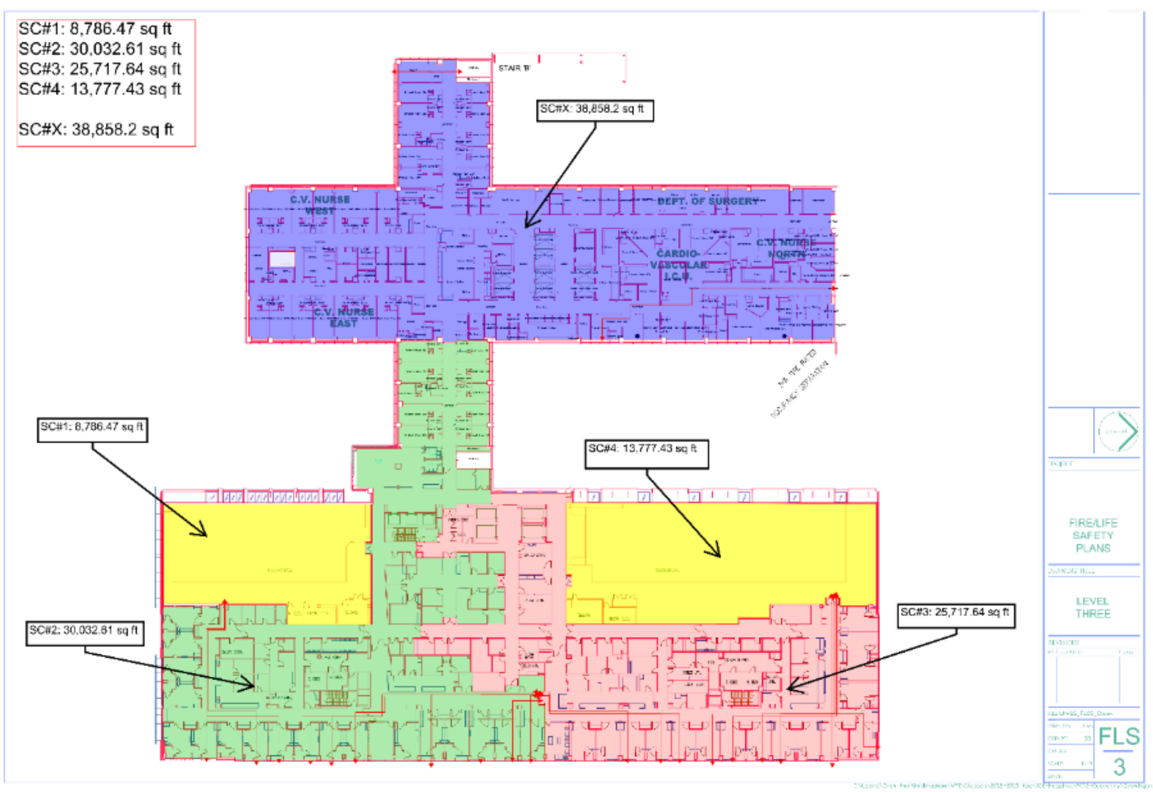


Figure 29: Geometry #2 with large smoke compartments, all over 22,500 sf

Attendee to patients ratio

The ratio of the number of attendees to the number of patients is a complex issue that we have simplified into a range of ratios that are considered during this study. Also for clarification we have developed several definitions:

> **Attendee**: Any person employed and trained by the hospital who is within a smoke compartment and when the signal for evacuation is given, will immediately commence with the evacuation procedure.
>
> **Staff**: Any person employed and trained by the hospital who is not in the smoke compartment being evacuated, and will respond to aid in the evacuation of patients in another smoke compartment.
>
> **Nurses**: Any person employed and trained by the hospital who has the capacity to provide patient care. This term will not be used for describing a required number of people to evacuate a smoke compartment.
>
> **Patient**: Any person who is under the care and supervision of the hospital and for whom the hospital is responsible for providing support for evacuation from an unsafe condition.

These definitions are solely to be used within the confines of this study and for the purpose of clearly identifying which hospital employees are evacuating patients as well as where those employees start their evacuation of the patients.

The range of ratios that we are considering for this purpose come from documents developed by the NFPA, the Veterans Administration, as well as anecdotal evidence provided by experts in the field. NFPA 101A is a document that focus on applying a risk based approach to a hospital as an alternative means to comply with the life safety code (NFPA 101). Included in this risk evaluation is the Attendee to patient ratio, which ranges from 1:1 to 1:10.

Table 4: Range of Attendee to Patient data found from research

Range Ratios of Attendees to patients	Source	Notes
1:1 – 1:10	NFPA 101A Worksheet 4.7.1 (NFPA 2013)	• Ratio evaluated for worst case ratio (typically during the night shift) • Ratios considered for all health care occupancies, as defined by NFPA 101, not solely hospitals
1:2 – 1:4	VHA Directive 2005-037 (VHA 2005)	• The ratio of 1:2 is required for buildings, with overnight stay, which are not fully sprinklered • Ration of 1:4 is required for buildings, with overnight stay, which are fully sprinklered • Ratio applies to non-ambulatory patients

1:1-1:5	James Peterkin, Heery International	• 1:1 would be used for ICU or similar • 1:5 is a conservative value rarely seen in a hospital
1:2 - 1:4	Egress Modeling in Health Care Occupancies Report (Alonso 2014)	• Ratios used in egress modeling exercise, no clear source of values
0.96 – 3.43	Evacuation of the Evacuation Time in an Emergency Situation in Hospitals (Golmohammadi and Shimshak 2011)	• Ratio based upon patient needs in their model • Ratio does not necessarily represent requirements or reality in the real world
1:4	105 CMR 130.311 (Massachusetts 2014)	• Ratio of qualified, registered nurses to patients required for Adult Intensive Care Unit in Massachusetts
1:1 – 1:2	105 CMR 130.750 (Massachusetts 2014)	• Ratio of qualified, registered nurses to patients required for a pediatric intensive care unit (PICU) in Massachusetts
1:2	A Description of Evacuation Drills: Case G: A hospital Ward (Rinne, Tillander and Gronberg 2010)	• Evacuation drill in a hospital ward using a ratio to represent the nighttime staffing levels

Recommendation

As we can see in the above tables there is a wide range of values that can be found for the number of attendees to the number of patients. From the various studies mentioned above and in consultation with hospital experts the recommended first approach will look at a conservative ratio of 1 attendee to 5 patients. Subsequently once the ratio of 1:5 has been completed we can cover a wider range of values to better understand the effect of the staffing ratio on evacuation.

Ambulatory Patient Type

For the purposes of this study, the patients present in the hospital are divided into three categories related to their mobility capabilities. Categorizing the patients in this manner is a popular choice for analyzing hospital egress (Alonso 2014) (Golmohammadi and Shimshak 2011).

Patient Type 1

The first patient type, *Patient Type 1*, consists of ambulatory patients with reduced mobility. These patients are able to walk out at a reduced speed compared to that of a healthy, able-bodied person. In the event of an emergency, one staff member is required to assist Patient Type 1 occupants in egress travel to the horizontal exit.

Patient Type 2

The second patient type, *Patient Type 2*, comprises of patients that are bound to a wheel-chair. These patients are not able to evacuate themselves, and require assistance by one staff member to push their wheel-chair in the event of an emergency.

Patient Type 3

The third patient type, *Patient Type 3*, consists of patients with the most severe mobility restrictions. These patients need to be moved in a stretcher or bed. Two staff members are required to assist Patient Type 3 occupants from their rooms to the horizontal exit.

Recommendation

Since this is a comparative study, with the focus on smoke compartment size, this study will represent the entire patient load with Patient Type 3 characteristics. Utilizing only Patient Type 3 occupants is a conservative approach representing a worst probable scenario for assisted evacuation as these occupants have a longer prep time, slower walking speed, and larger width (discussed below). This approach will likely result in a significant difference in large versus small smoke compartment evacuation times.

Occupant Characteristics

Movement characteristics of each patient type need to be defined prior to adding them into the egress models. These characteristics include:

- **Prep Time**
- **Nurse Movement Speed**
- **Transport Movement Speed**
- **Representative Width**
- **Settle Time**

The table below contains a range of values suggested for movement characteristic from three different sources. Based on these sources values for each movement characteristic have been chosen to be utilized in the egress models.

	Virginia Alonso, FPRF	**C.W. Johnson**	**Hunt, Galea, Lawrence**
Prep-Time (s)			
Patient Type 1	30 - 90 ($\bar{x}$ = 60)	60 - 180	--
Patient Type 2	100 - 120 ($\bar{x}$ = 110)	180 - 900	29.4 - 35.9
Patient Type 3	180 - 900 ($\bar{x}$ = 360)	180 - 900	67.6 - 87.7
Speed (m/s)			
Nurse	0.65 - 2.05 ($\bar{x}$ = 1.35)	0.625 - 1.25	--
Patient Type 1	0.84 – 1.40 ($\bar{x}$ = 1.12)	--	--
Patient Type 2	0.63 (σ=0.04)	0.5 - 0.83	1.39 - 1.55
Patient Type 3	0.40 (σ=0.04)	0.29 - 0.5	0.99 - 1.09
Width (cm)			
Nurse	--	--	--
Patient Type 1	--	--	--
Patient Type 2	--	75	48 – 52
Patient Type 3	--	100	111

Prep Time

For the purposes of this study, prep time is the time it takes the nurses to uncouple and position the patient in a way that promotes evacuation. "Uncoupling" is defined at the time it takes to unhook the patient from any IVs, breathing apparatuses, or similar instrumentation. "Positioning" would be either assisting an ambulatory patient out of bed to begin walking, or moving mobility impaired patient to a wheelchair or stretcher.

Of the three sources mentioned in the table, we believe that the values suggested by the C. W. Johnson paper are the most applicable to our study. Unlike the values suggested by Alonso and Hunt et al, these values represent the time it takes for nurses to both uncouple a patient and move them from their bed. The Alonso paper uses the prep time values to represent moving a patient from a bed (not including coupling) as well as the delay time of a nurse to start moving toward a patient. Additionally, the Alonso paper cites that these "prep times" are derived from a paper that evaluates human behavior on passenger trains, not the healthcare industry. The Hunt et al paper only suggest times for moving a patient from a bed and does not include uncoupling.

Recommendation

The ranges provided by the Johnson paper are quite large since they represent the maximum and minimum recorded prep times. For this particular study, the following values are suggested for each patient type:

- Patient Type 1: 120 seconds
- Patient Type 2: 360 seconds
- Patient Type 3: 540 seconds

Movement Speed

Nurse movement speed is the speed at which a trained member of the hospital travels unimpeded to a patient's rooms. Whereas transport movement speed is the speed at which a nurse and patient combined group travels from the patients' rooms to the horizontal exit.

Again, of the three sources mentioned in the table, we believe that the speeds suggested by the C. W. Johnson paper are the most valuable. The speeds suggested by the Hunt et al paper were discarded due to the fact that they were collected from an independent study. During the recording of these speeds, the hallway in which the horizontal movement was measured was clear. This "free movement" is assumed to result in the significantly faster movement speeds. The paper itself states that the horizontal transport speed of Patient Type 2 group is "slightly better than the free walking speed… of 1.4 m/s." Therefore, this value seems to fast and not conservative enough for our study.

The Alonso paper cited the Johnson paper as the source of horizontal speed. It is unknown where the discrepancies were developed with their values, or how Alonso calculated averages from the ranges provided by Johnson.

Recommended Values

For this particular study, the following values are suggested for the staff and each patient type:

- Nurse alone: 1.25 m/s
- Patient Type 1: 1.12 m/s
- Patient Type 2: 0.63 m/s
- Patient Type 3: 0.4 m/s

Representative Width

Representative width is the largest width associated with a patient relative to the transportation device used. Nurses and ambulatory patients (Patient Type 1) will have a representative width associated with an average shoulder width of an adult. Patients requiring assistance to evacuate (Patient Type 2 and 3) will have a representative width associated with the assumed width of a wheel-chair or hospital bed.

Only the Johnson and Hunt et al papers provided information on the wheel-chair and bed widths used in their studies. In each paper there is discussion of how both wheel-chairs and hospital beds vary in size based upon patient use as well as product type. Therefore, additional feedback from those in the hospital industry is requested in order to provide an acceptable range of values that will adequately represent the transportation devices found in hospitals.

Settle Time

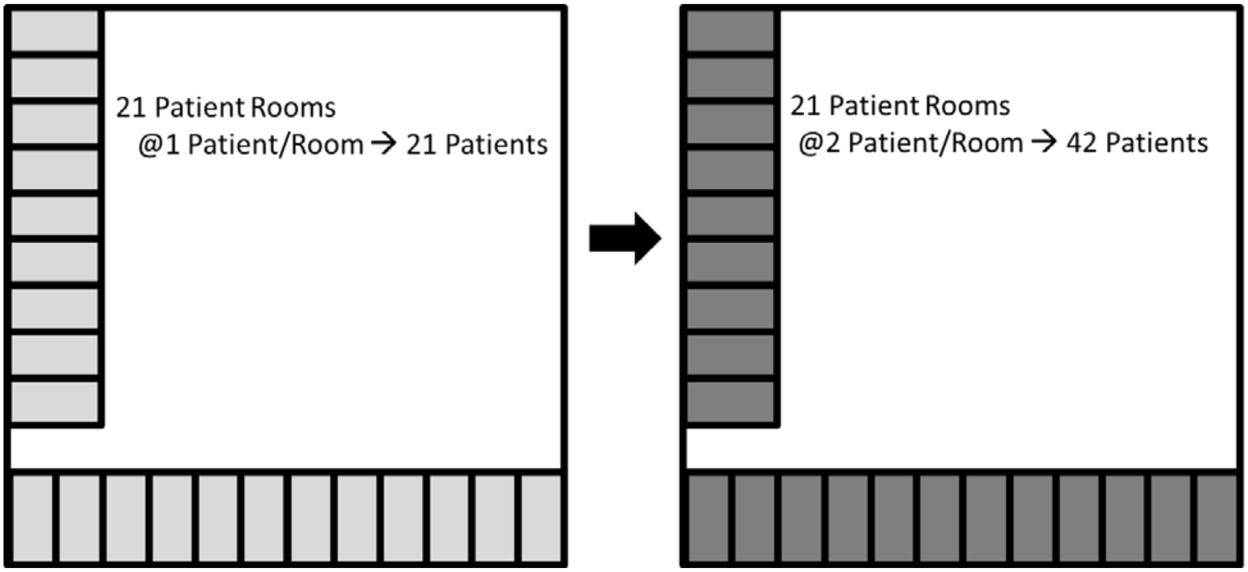
Settle time is the time it takes for a patient to be placed on the non-fire side of the smoke barrier. This will include transport time on the non-fire side of the smoke barrier up until the patient is placed. For modeling, “Settle Time” will be associated with the delay time of a nurse from when he/she crosses the horizontal exit until he/she can go retrieve another patient.

Settle time was not included in the table as no sources suggest values related to this characteristic. Additional feedback from hospital representatives will be required to fill in this particular information gap.

Number of Patients per Room

The current trend seen in in-patient hospital floors is to keep the number of patients per room held constant at one patient per room. Privacy and comfort have increased the desire by the patients to want private rooms as well as the hospital.

It is understood that some existing hospitals were designed to accommodate two patients per room, and that today there are still some hospitals that utilize the space as such. However, based on discussions with persons in the hospital industry, it is understood that privacy concerns are playing a large role in hospital protocol. Therefore, this study is assumed to be reflective of the effects privacy and comfort concerns for patients has led to more hospitals assigning only one patient per room.



Recommendation

This study will model a hospital floor, in which there will only be one patient in any given room. However, this assumption is based on limited evidence other than anecdotal remarks related to this change in the number of patients per room. Additional feedback from the hospital representatives is encouraged in order to justify this recommendation.

Patient Distribution and Location

As discussed previously, this comparative study will represent the entire patient load with Patient Type 3 occupants. It should be noted, however, that this approach may not be representative of all scenarios expected in a hospital evacuation. In many "in-patient" or "med-surg" areas it is more likely that all three patient types will be present. Based on background research and talking to experts in the hospital industry, it is evident that each hospital has adopted its own protocol for housing patients. So when evaluating the models presented in this study, it is important to consider what factors related to patient type may be applicable to a given hospital and those that may not.

Two factors assumed to most significantly affect egress in terms of patient type would be the distribution and location of patients. For instance, if there are different types of ambulatory patients in a smoke compartment what percent of each patient type would normally occupy the area? It is assumed that the more bedridden occupants (Patient Type 3) in a smoke compartment will have an adverse effect on evacuation time as opposed to a smoke compartment with more mobile patients (Patient Type 1).

Another consideration would be where these patients are located within the smoke compartment. If there are different types of ambulatory patients, are they located in one central region? Or are they dispersed about the smoke compartment? Based on the triage or patient prioritization methods of a hospital, the locations and distribution of patient types may affect evacuation time.

Staff Response

The staff response is a challenging topic to find data for because of the lack of reliable reports that are in existence. There are three separate parts of the staff response, which are important to the study of the problem. First is the staff time for response, then where the staff originate and then what the order of triage is.

Staff Time for Response

The time for staff response is defined as the time from which the staff is notified of an event until the time they start to move toward their patients. For the models in this study we will not attempt to characterize this value as we are doing a comparison study between the differences in the smoke compartment size and the time for response is not critical to that effort.

To determine a value for this variable there were several studies that were completed that include a timeline of effects helpful in determining the response time. The first is based upon an evacuation drill completed in a hospital ward in Norway. For this drill, cold smoke was used to trigger the alarm. From the time the alarm bell sounded until the nurses react to the fire was 7 seconds. In addition this research shows that nurses from another ward arrived after 1 minute and 10 seconds (Rinne, Tillander and Gronberg 2010). Origin of Staff

The origin of the staff is another variable that needs to be considered as we go through this analysis. Within this variable there are two things that need to be considered:

1. Where the model will assume the staff will be when they start the evacuation and
2. Whether we choose to include staff from other areas of the building in the mode.

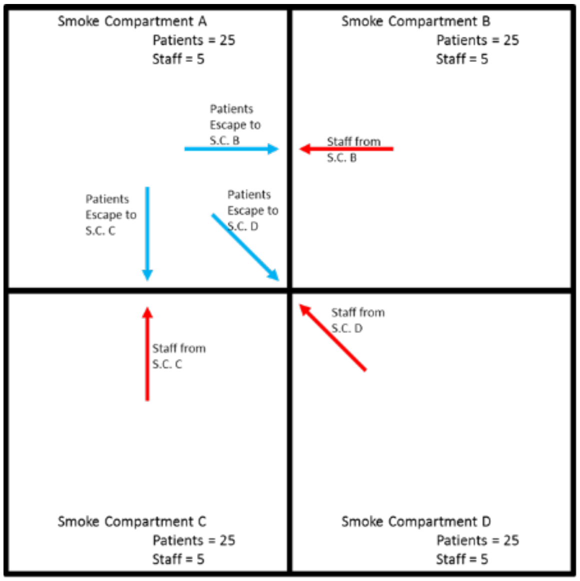
To represent the first situation, Figure 30 shows the two options. The figure on the left represents the staff starting location as dispersed at the different staff and nursing locations around the floor. The figure on the right represents where the staff would gather to get instructions.

Figure 30: Hospital floor with staff locations identified in red. The figure on the left represents the staff starting location as dispersed at the different staff and nursing locations around the floor. The figure on the right represents where the staff would gather to get instructions. These are two options for how we can model staff in the model

The second decision is whether to include staff members from other smoke compartments in the evacuation process. Figure 31 shows an example of a scenario comparing a floor with four smoke compartments and a floor with 2 smoke compartments. The scenario which includes four smoke compartments has 25 patients and 5 staff members in each smoke compartment. In this scenario when one smoke compartment needs to be evacuated, there are the 5 staff that will be in the compartment as well as a portion of the staff from the adjacent smoke compartments. Overall this will allow more staff to help evacuate fewer patients. If we assume that 40% of the staff from each adjacent smoke compartment can assist the evacuating smoke compartment then:

$$Small = \frac{25\,Patients}{5\,Staff\ (SC\ A) + 2\,staff\ (sc\ B) + 2\,staff\ (sc\ C) + 2\,staff\ (sc\ D)} = \frac{25\,Patients}{11\,Staff}$$

$$Large = \frac{50\,Patients}{10\,Staff\ (SC\ A) + 4\,staff\ (sc\ B)} = \frac{50\,Patients}{14\,Staff}$$



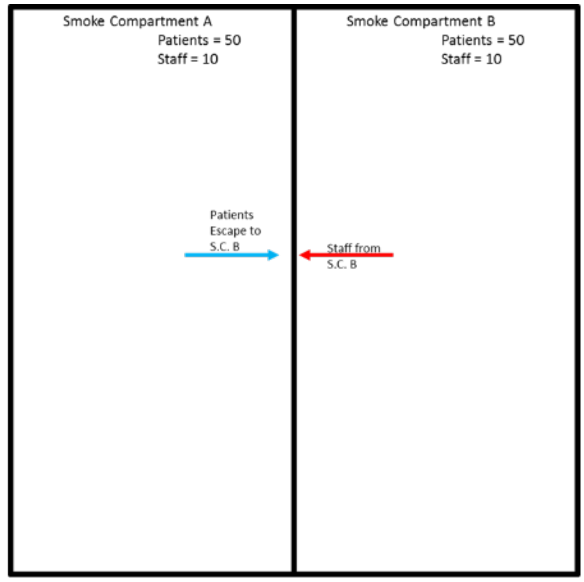


Figure 31: The different options for the origin of staff in comparison to the number of smoke compartments on a floor.

- How many staff from other areas of the building will respond?
- How long would it take people from other areas of the hospital to respond?
- Do the staff and attendees start at a centralized location or are they dispersed?

Recommendation

The recommendation going forward is to analyze the floor plans and populate the smoke compartment with the amount of attendees and staff commensurate with the patient level in that compartment, using the attendee-to-patient ratio. Then the models will send a certain portion of the attendees from the other compartment to the compartment being evacuated.

Order of Triage

The order of triage is synonymous with what order the patients will be evacuated. There is conflicting evidence regarding what a majority of hospitals recommend; however, there are two basic options. Always the first action that an attendee will take is to remove those patients in immediate danger who are either intimate with the ignition or are in the room or origin (Marlar 2008).

In the Hospital Emergency Evacuation Toolkit developed by Florida's Department of Health a triage order of most ambulatory to least ambulatory is advised (FDOH 2011). The Alonso study chose to order the evacuation of patients going from most ambulatory to least ambulatory (Alonso 2014). The Alonso evacuation scheme follows scenario (b) as displayed in Figure 35 and Figure 37. A survey study was performed in Oregon to investigate the patient prioritization utilized in hospital evacuation and from the responses that were gathered, 40%, of the responses, would move ambulatory patients first (Marlar 2008).

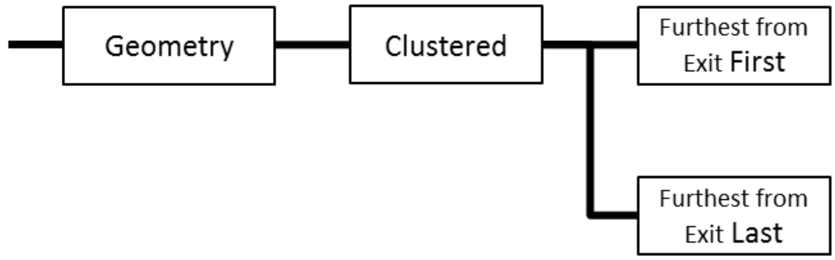
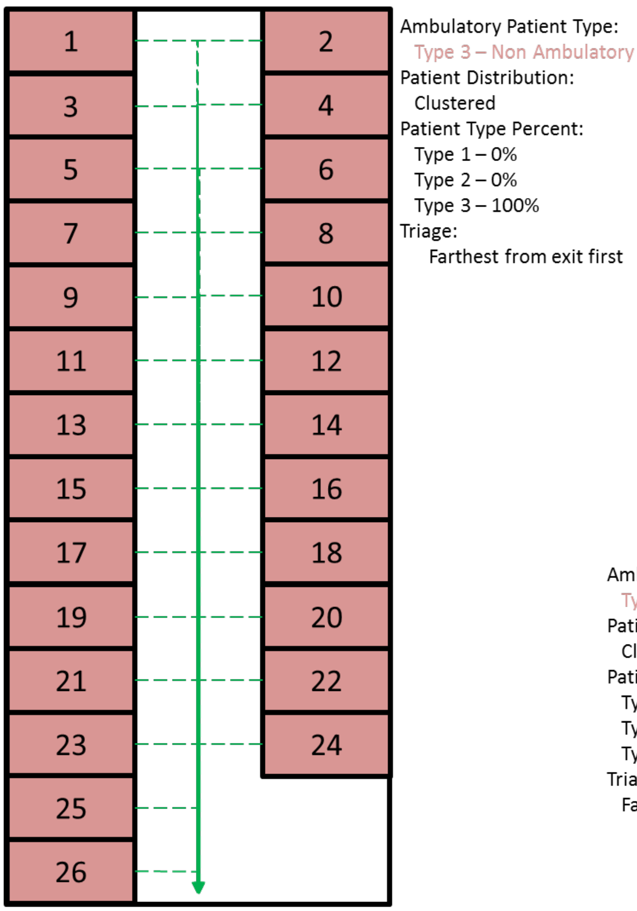
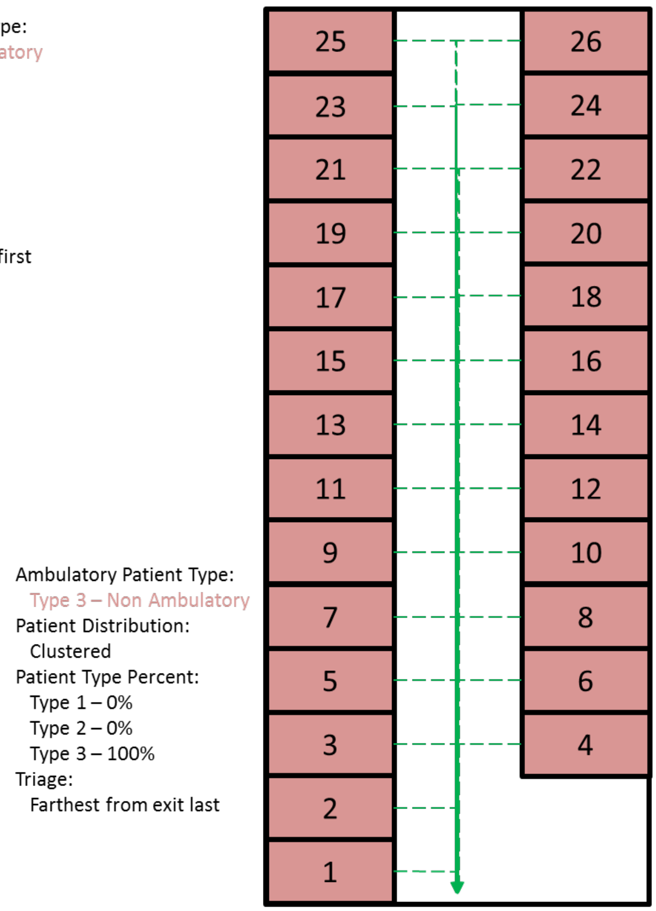


Figure 32: Tree diagram of triage options. The scenarios refer to the figures displayed below.



Evacuation, with all the same ambulatory patient type, farthest from exit first



Evacuation, with all the same ambulatory patient type, closest to exit first.

Figure 33: Triage options scenario displayed using simple geometry and all patient type 3. The numbers represent the order in which the patients will be removed from the floor, following the green arrow towards the bottom of the figure.

For this study we developed a series of hypothetical scenarios in which we thought that staff could choose to evacuate patients. These are only developed to show the general principle of the different triage options.

Using the assumption that all types of ambulatory patient are in a hospital ward the tree diagram in Figure 4 shows the 2 scenarios from which we will do preliminary evacuation modeling to compare the results.

The tree diagram in Figure 35 displays a more representative set of triage options, which are shown visually in Figure 36 through Figure 43 as scenarios (a) through (h). In these figures the colors of the "rooms" represent the different types of patients; Green in Type 1, Blue is Type 2, and Red is Type 3. The numbers in the rooms represent the order of evacuation with 1 being the first to evacuate and 26 being the last to evacuate.

Recommendation

From these results the most common triage order is to remove the patients intimate with ignition and then evacuate patients going from most able-bodied to least able-bodied. We will move forward to conduct preliminary egress modeling using the two scenarios represented by Figure 5. It is not clear whether we should choose to evacuate those furthest away from the exit or those patients closest to the exit first. Input from the panel would be helpful.

Time of day

To maintain conservatism in the model as well as to agree with the data found in the literature we are using the assumption that the event will occur during the night shift (Alonso 2014) (Rinne, Tillander and Gronberg 2010) (Johnson 2005) (AHRQ 2010). There is much evidence to suggest that during the night time hours there are less staff available then at any other time. This assumption also will reduce the number of visitors that would be in the space.

Recommendation

The developing models will be set-up to simulate an evacuation scenario at night. This is based on the assumption that the nighttime will be the most conservative estimate of the evacuation time because it is when the lowest attendee-to-staff ratio is as well as the patients will be drowsy and more difficult to move.

Number of Patients

The number of patients on a floor could be determined by the occupancy load calculation, or, more likely, by some other healthcare specific guideline. This number of patients on a floor is related to the number of patients per room. For example, Figure 34 shows that if a floor had 21 patient rooms then the floor could have between 21 patients and 42 patients depending on whether the hospital allowed one or two patients per room.

- How is the number of patients per floor determined?

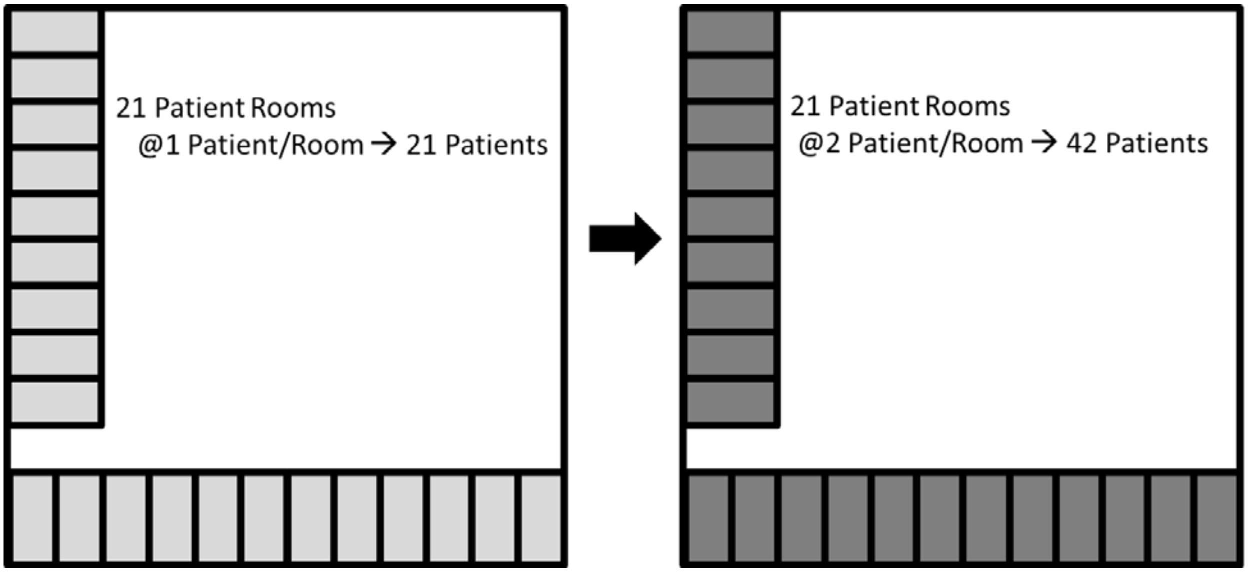


Figure 34: With the same amount of patient rooms the number of patients on a floor will vary greatly based on whether there is one patient per room or two patients per room.

Recommendation

Initially in the study assume that there will be only one patient per room.

Risk

From the discussions thus far with the project panel it is important that we identify what factors we should focus on that will increase the chances of success during the code meetings. From the panel with would be helpful to know:

- What Variables do we think will result in the most controversy during the ICC hearings?
- We should focus on these variables to keep arguments scientific and data driven.

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Appendix A-1: Further Analysis on Order of Triage

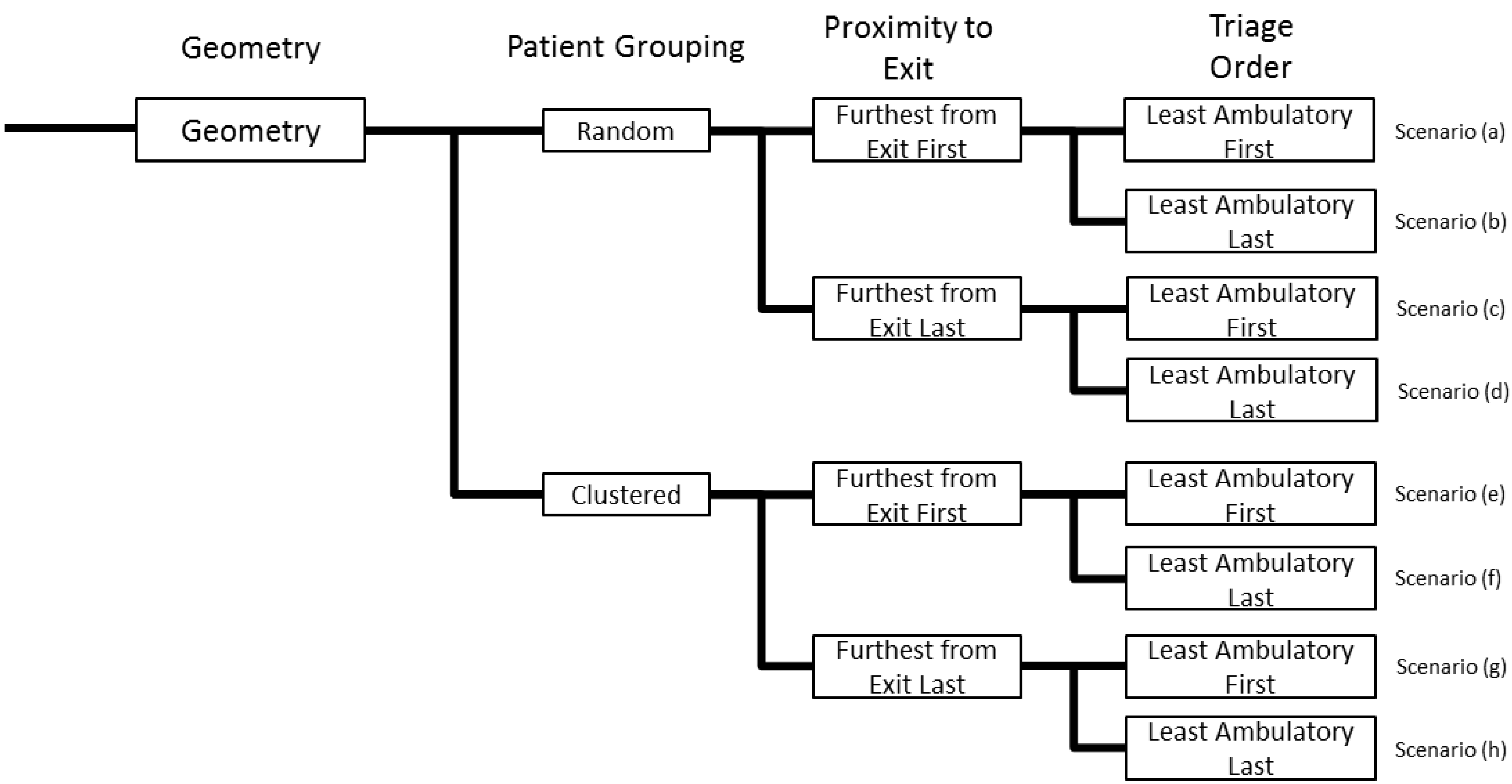


Figure 35: Tree diagram of the entirety of triage options which use the variables shown. The scenarios refer to the figures displayed below.

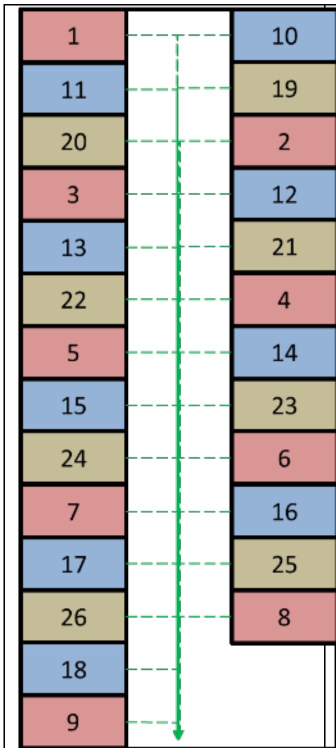


Figure 36: Scenario (a): Random. Least Ambulatory First. Farthest from Exit First

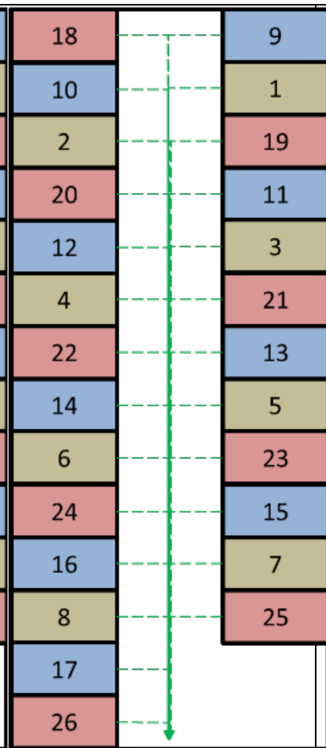


Figure 37: Scenario (b): Random. Least Ambulatory Last. Farthest from Exit First

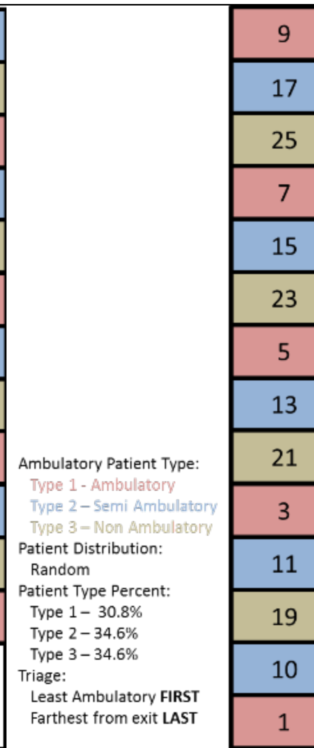


Figure 38: Scenario (c): Clustered. Least Ambulatory First. Farthest from Exit Last

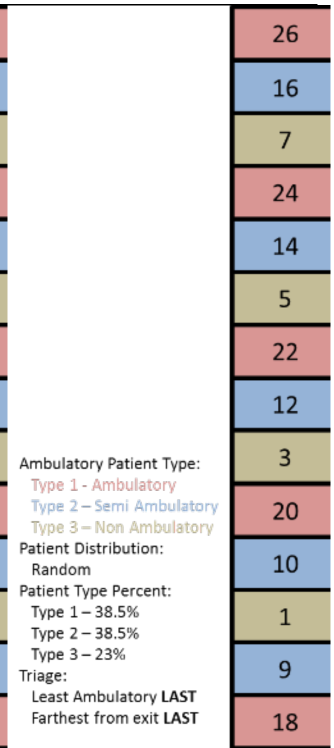


Figure 39: Scenario (d): Clustered. Least Ambulatory First. Farthest from Exit First

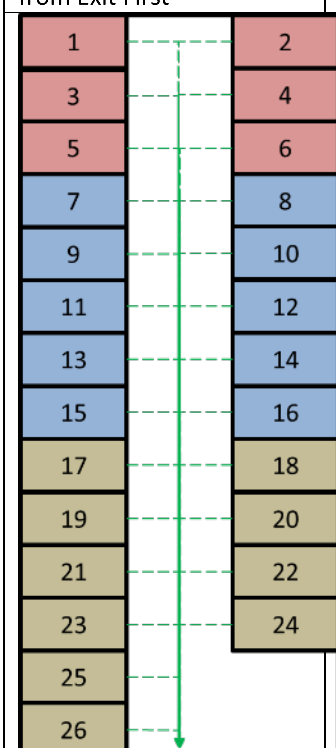


Figure 40: Scenario (e): Clustered. Least

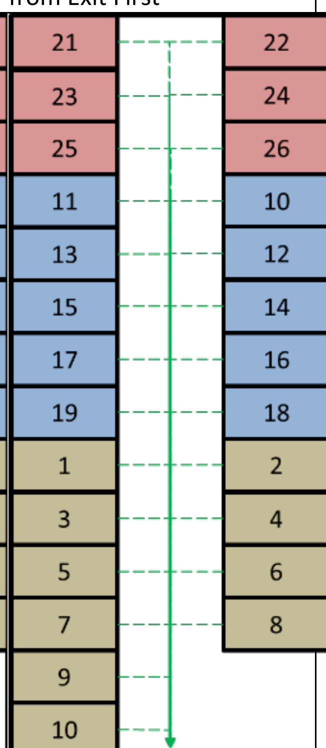


Figure 41: Scenario (f): Clustered. Least

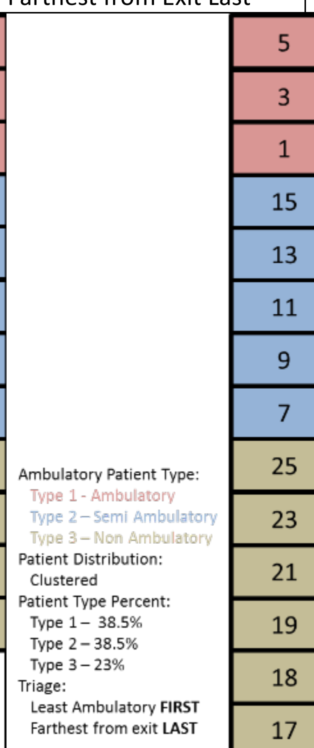


Figure 42: Scenario (g): Clustered. Least

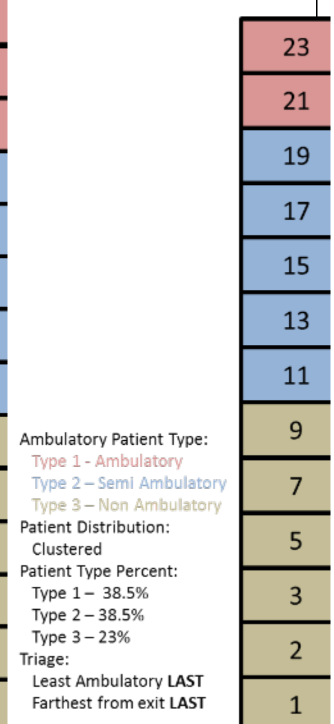


Figure 43: Scenario (h): Clustered. Least

Ambulatory First. Farthest from Exit First	Ambulatory Last. Farthest from Exit First	Ambulatory First. Farthest from Exit Last	Ambulatory Last. Farthest from Exit Last

Appendix B: Measured Travel Distance

The following list comprises of travel distance requirements for Group I-2 Healthcare facilities taken straight from the IBC:

- 407.4.2 Travel distance: The travel distance between any point in a Group I-2 occupancy sleeping room and an exit access door in that room shall be not greater than 50 feet (15 240 mm). (IBC Section 407.4.2, 2012)
- 407.4.3.5.3 Travel distance: The travel distance between any point in a care suite containing sleeping rooms and an exit access door from that care suite shall be not greater than 100 feet (30,480 mm). (IBC Section 407.4.3.5.3, 2012)
- 407.5 Smoke barriers: Smoke barriers shall be provided to subdivide every story used by persons receiving care, treatment or sleeping and to divide other stories with an occupant load of 50 or more persons, into no fewer than two smoke compartments. Such stories shall be divided into smoke compartments with an area of not more than 3,700 m^2 (40,000 ft^2) and the travel distance from any point in a smoke compartment to a smoke barrier door shall be not greater than 200 feet (60 960 mm). The smoke barrier shall be in accordance with Section 709. (IBC Section 407.5, 2015)
- 1016.3 Measurement. Exit access travel distance shall be measured from the most remote point within a story along the natural and unobstructed path of horizontal and vertical egress travel to the entrance to an exit. (IBC Section 1016.3, 2012)

To evaluate the travel distance a program called PDF xChange (Tracker Software 2015) was used to view a PDF of the plans. This software package has tools that allow measurement of a linear distance, a string of distances, and area. Figure 45 and Figure 44 show the measured travel distances from each patient room in the large and small smoke compartments, respectively. Table 5 and Table 6 outline the associated travel distances, with the maximum large compartment travel distance highlighted in yellow.

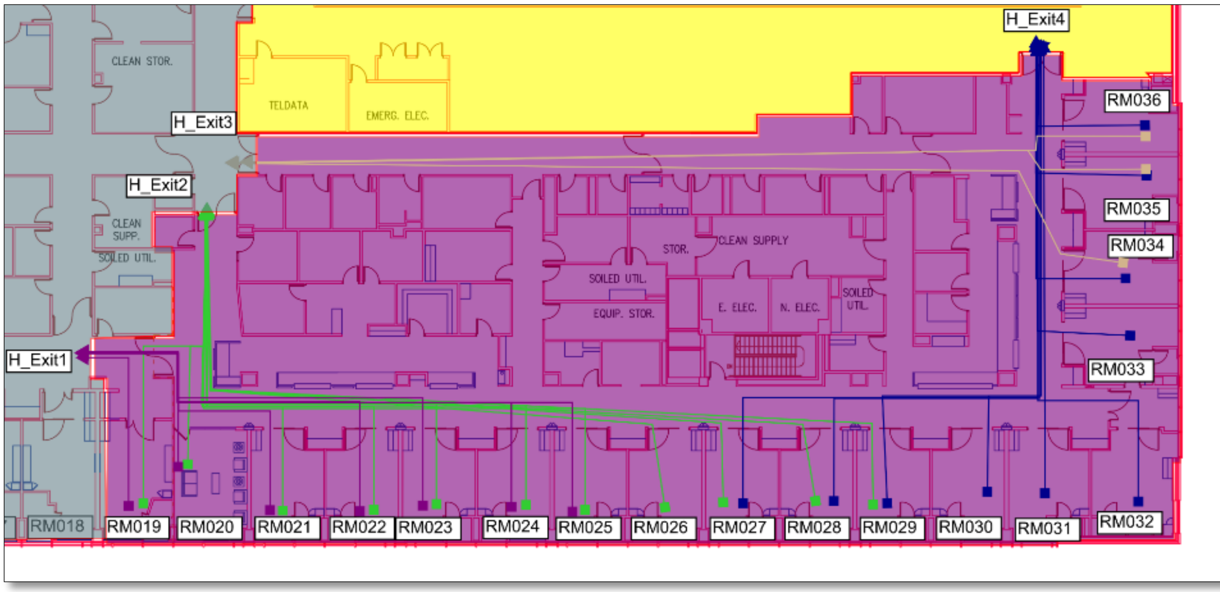


Figure 44: The measured travel distance in the smaller smoke compartment. Each door was assigned a colored line.

Figure 45: The measured travel distance in the larger smoke compartment. Each door was assigned a colored line.

Table 5 and Table 6 outline the associated travel distances, with the maximum large compartment travel distance highlighted in yellow.

Table 5: Measurements from the patient rooms in the smaller compartment. The rooms and the exits can be seen in Figure 2.

Room Number	Room Name	Max	H_Exit1	H_Exit2	H_Exit3	H_Exit4
RM019	Patient Room	41.53	41.53	74.28		
RM020	Lounge	44.98	44.98	56.59		
RM021	Patient Room	72.72	72.72	79.89		
RM022	Patient Room	91.73	91.73	98.05		
RM023	Patient Room	103.57	103.57	110.94		

Room Number	Room Name	Max	H_Exit1	H_Exit2	H_Exit3	H_Exit4
RM024	Patient Room	121.99	121.99	128.72		
RM025	Patient Room	136.03	136.03	142.97		
RM026	Patient Room	147.8		147.8		
RM027	Patient Room	156.82		160.53		156.82
RM028	Patient Room	138.36		177.37		138.36
RM029	Patient Room	127.71		192.03		127.71
RM030	Patient Room	104.65				104.65
RM031	Patient Room	93.88				93.88
RM032	Patient Room	115.77				115.77
RM033	Patient Room	80.09				80.09
RM034	Patient Room	68.94			196.71	68.94
RM035	Patient Room	50.54			193.28	50.54
RM036	Patient Room	39.58			190.58	39.58

Table 6: Measurements from the patient rooms in the larger compartment. The rooms and the exits can be seen in Figure 3.

Room Number	Room Name	Max	H_Exit1	H_Exit2	H_Exit3	H_Exit4	H_Exit5	H_Exit6
RM001	Patient Room	60.11	141.8				60.11	
RM002	Patient Room	54.98	137.23				54.98	
RM003	Patient Room	76.91	158.57				76.91	
RM004	Patient Room	88.75	170.75				88.75	
RM005	Patient Room	119.18	197.92				119.18	
RM006	Patient Room	187.52	187.52					
RM007	Patient Room	168.75	168.75					
RM008	Patient Room	153.49	153.49					
RM009	Patient Room	140.16	140.16					
RM010	Patient Room	122.26	122.26					
RM011	Patient Room	108.59	108.59					
RM012	Patient Room	90.52	90.52					
RM013	Lounge	89.13	89.13					
RM014	Patient Room	98.59	98.59					
RM015	Patient Room	112.8	112.8					
RM016	Patient Room	112.62	129.98		112.62			
RM017	Patient Room	97.88			97.88			
RM018	Patient Room	81.57			81.57			
RM019	Patient Room	90.04			90.04	91.75		
RM020	Lounge	75.79			93.71	75.79		
RM021	Patient Room	96.9				96.9		
RM022	Patient Room	115.25				115.25		
RM023	Patient Room	127.17				127.17		
RM024	Patient Room	146.3				146.3		

Room Number	Room Name	Max	H_Exit1	H_Exit2	H_Exit3	H_Exit4	H_Exit5	H_Exit6
RM025	Patient Room	160.94				160.94		
RM026	Patient Room	165.99				165.99		
RM027	Patient Room	156.82				178.29		156.82
RM028	Patient Room	138.36				195.28		138.36
RM029	Patient Room	127.71						127.71
RM030	Patient Room	104.65						104.65
RM031	Patient Room	93.88						93.88
RM032	Patient Room	115.77						115.77
RM033	Patient Room	80						80
RM034	Patient Room	68.94				199.94		68.94
RM035	Patient Room	53.63				199.62		53.63
RM036	Patient Room	39.58				199.85		39.58

Appendix C Hospital Floor Plans

Hospital Geometry Selection

(For Internal Use ONLY)

Introduction

At the moment we have a wide variety of options for the different geometries that we could select for creating and running timed egress analysis over. There are several different geometries that could be selected, which Fire Safe North America (FSNA) coordinated for us. In addition, Eugene Cable, has provided scaled PDF documents for 4 hospitals in the area. Internally we have two geometries. In total we have 27 floor plans in our possession.

Looking back at the scope of the project, our goal is to conduct a timed egress analysis that compares the evacuation time difference between a smoke compartment size of 22,500 sf (2,090 m^2) and 40,000 sf (3,716 m^2). Because we are looking at compartments of different sizes it makes sense to choose geometries larger than 40,000 sf (3,716 m^2) so they can be divided up into smaller and larger smoke compartments for a comparative study. From the list of 27 floors there are only 11 floor plans that are greater than 40,000 sf (3,716 m^2).

Table 7: Table of Building Geometries in our Possession (Note: Confidential Information Removed from table)

Source	Hospital	Location	Building	Floor	Area (SF)
FSNA			East Building	4	35993
FSNA			South Building	4	18233
FSNA			West Building	4	10623
FSNA			East Building	3	54674
FSNA			South Building	3	18383
FSNA			West Building	3	11408
HDR			Main Building	1	50243
HDR				0	17013
HDR				1	94201
HDR				2	76567
HDR				3	
HDR				4	
HDR				5	
HDR				6	
Eugene Cable				G	68830
Eugene Cable				1	50980
Eugene Cable				2	26200

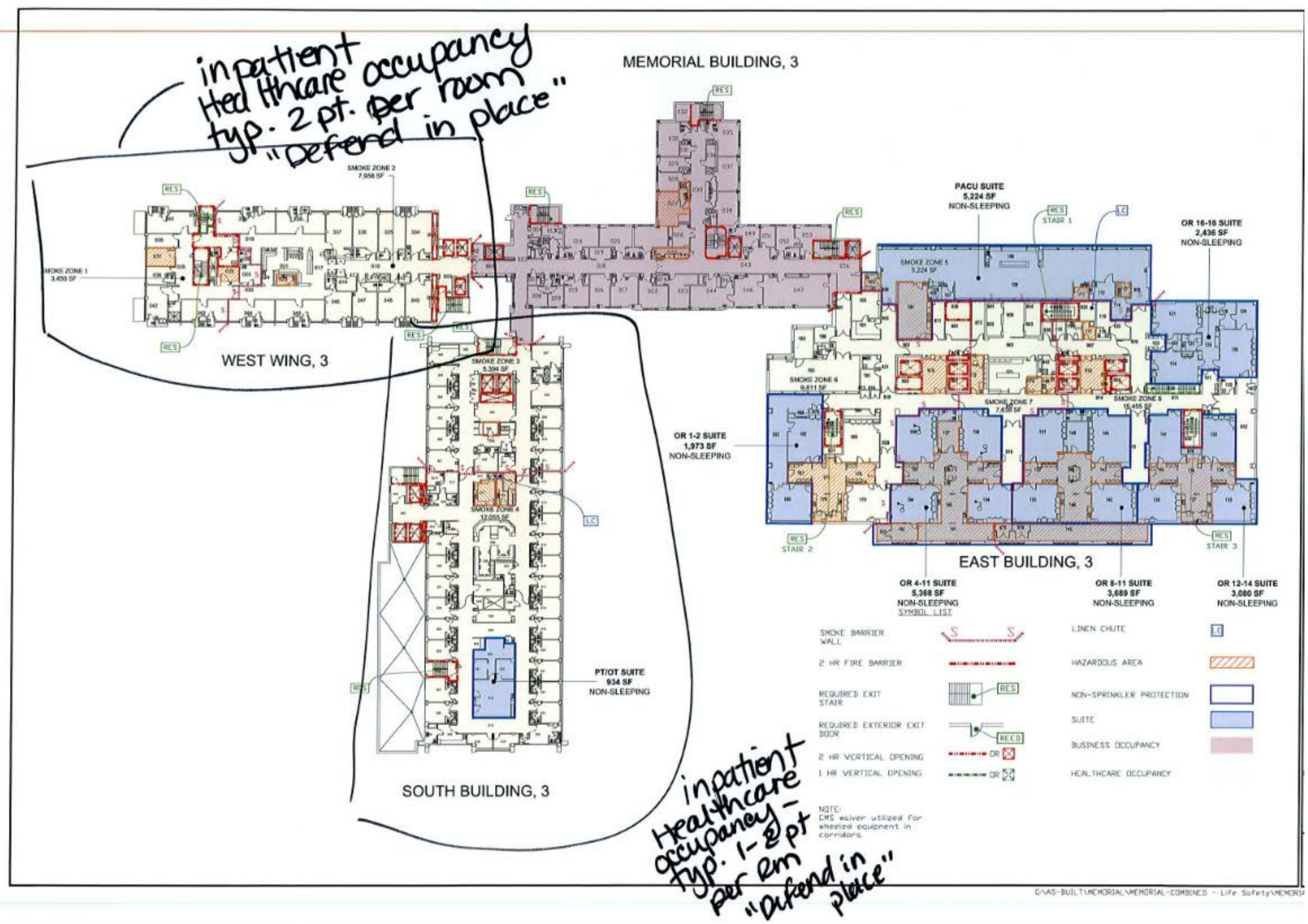
Source	Hospital	Location	Building	Floor	Area (SF)
Eugene Cable				3	18640
Eugene Cable				4	12980
Eugene Cable				1	45280
Eugene Cable				2	36400
Eugene Cable				3	14560
Eugene Cable				G	8990
Eugene Cable				1	11190
Eugene Cable				2	11220
Eugene Cable				1	127300
Eugene Cable				2	107580
Eugene Cable				3	68210
Eugene Cable				4	44780
Eugene Cable				5	17470
Eugene Cable				6	18250

Table 8: Table of building floors with an area of over 40,000 sf (Note; Confidential items removed from table)

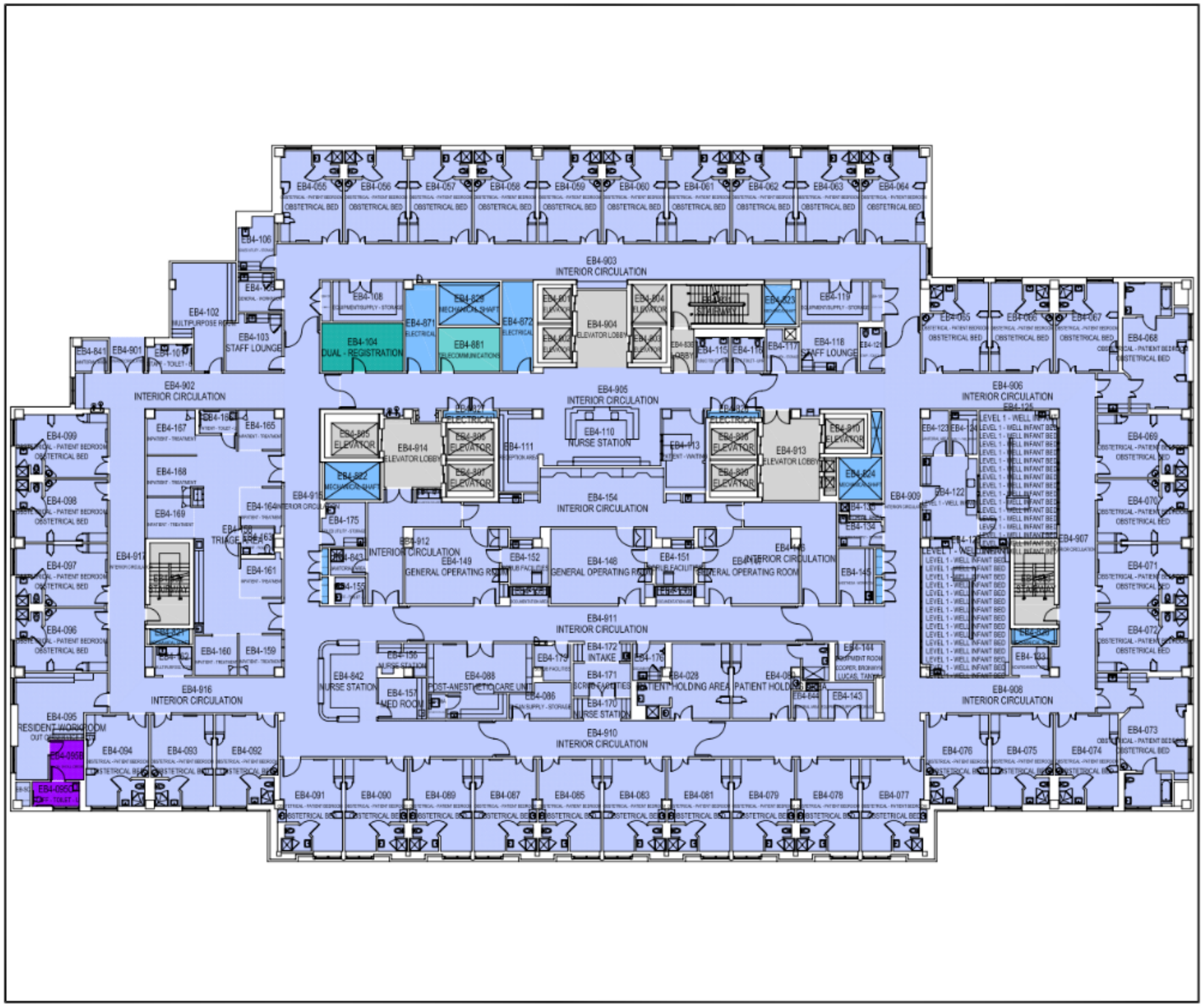
Source	Hospital	Location	Building	Floor	Area (SF)
FSNA			East Building	3	54674
HDR				1	50243
HDR				1	94201
HDR				2	76567
Eugene Cable				G	68830
Eugene Cable				1	50980
Eugene Cable				1	45280
Eugene Cable				1	127300
Eugene Cable				2	107580
Eugene Cable				3	68210
Eugene Cable				4	44780

Appendix C-1: Building Plans From FSNA

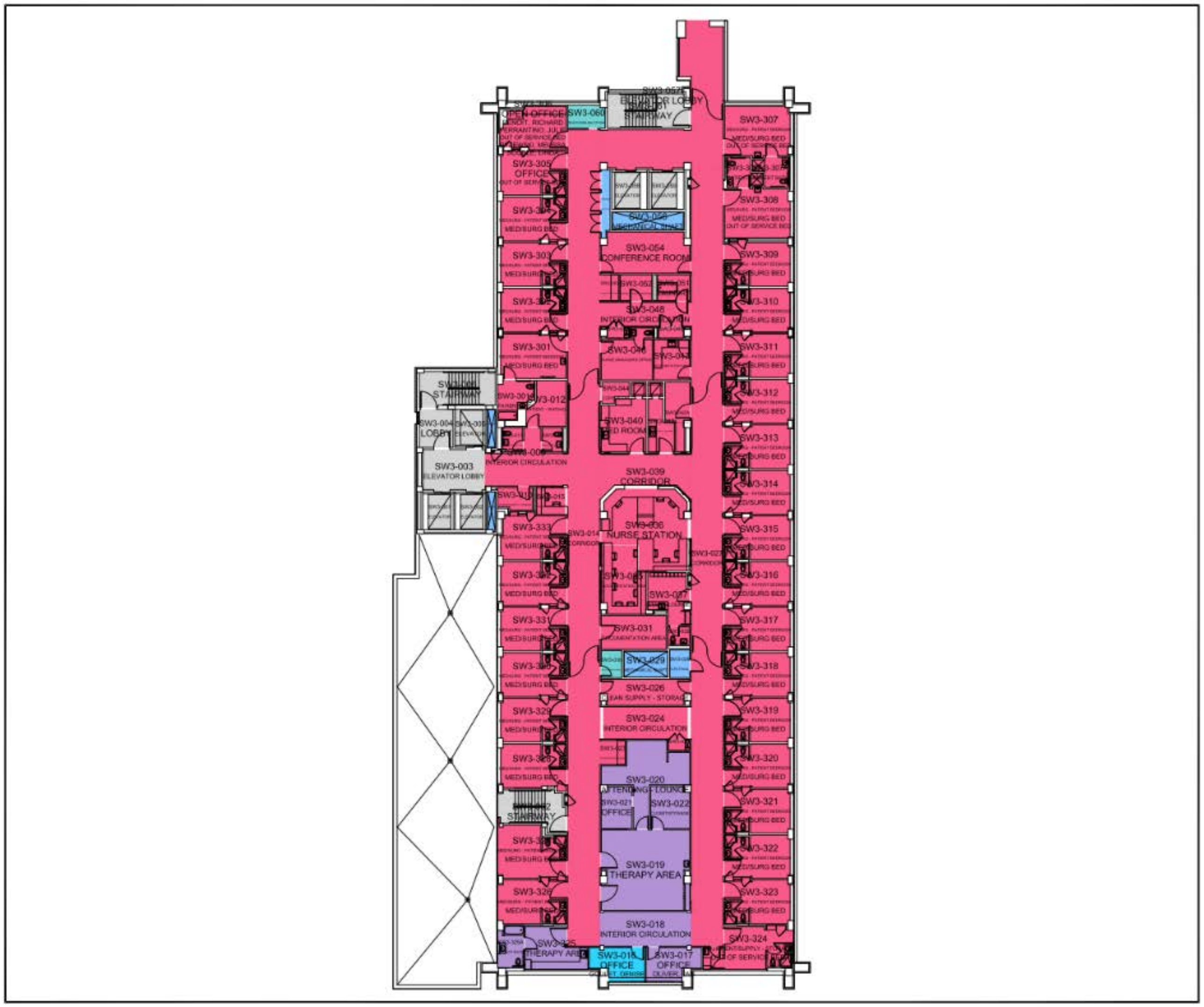
M-3: Hospital Campus Overview



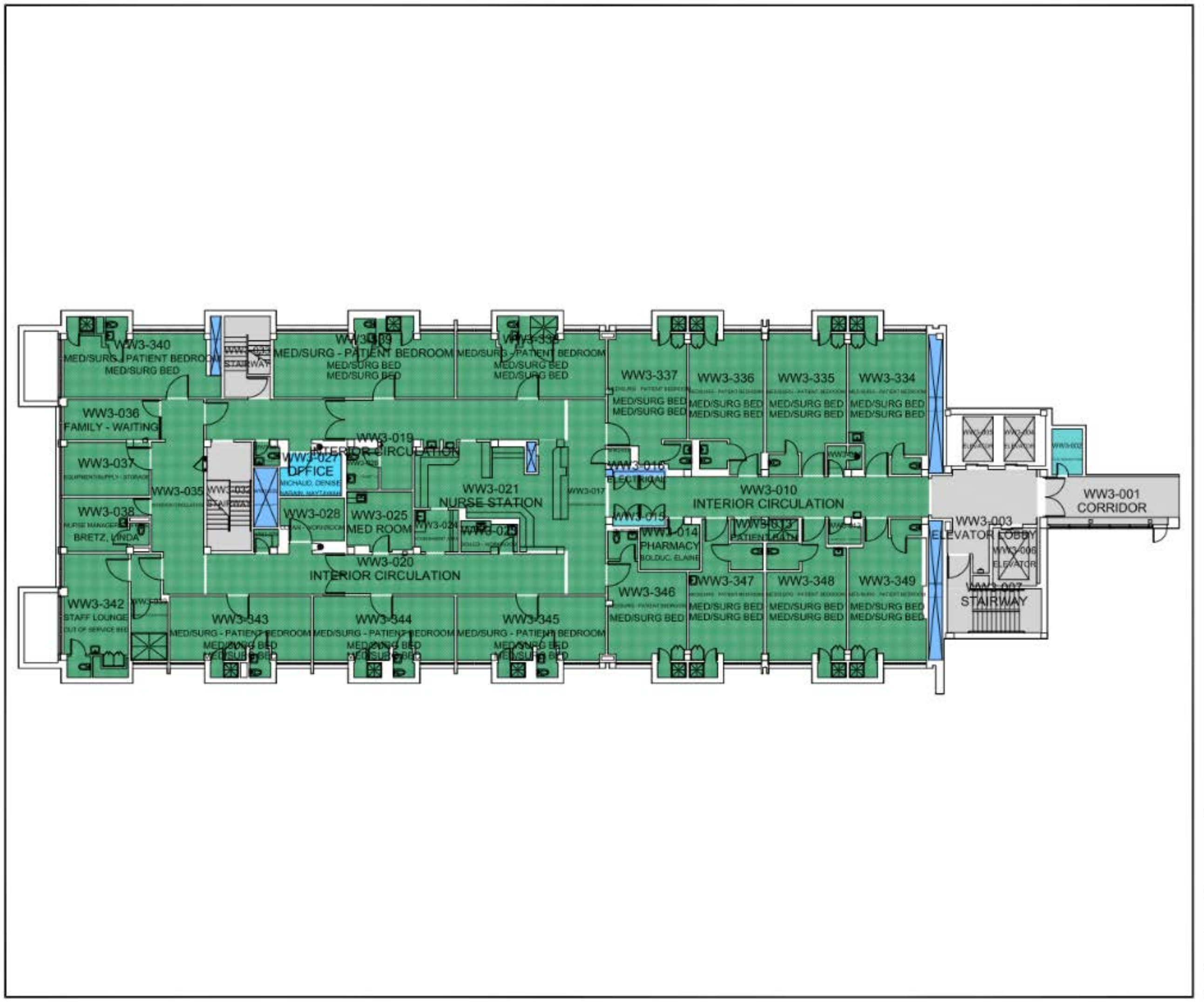
EB-4: East Wing, Floor 4



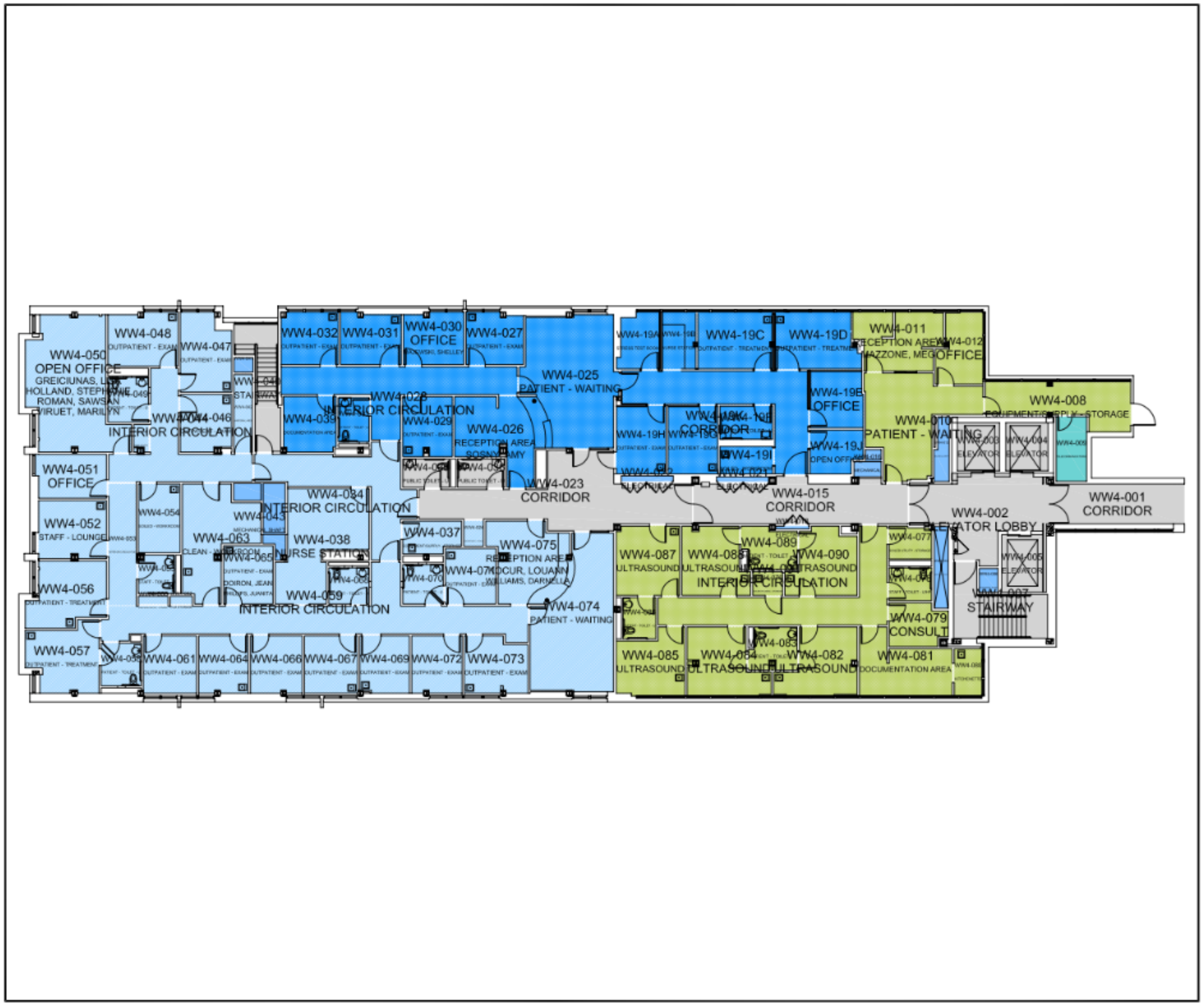
SW-3: South Wing, Floor 3



WW-3: West Wing, Floor 3

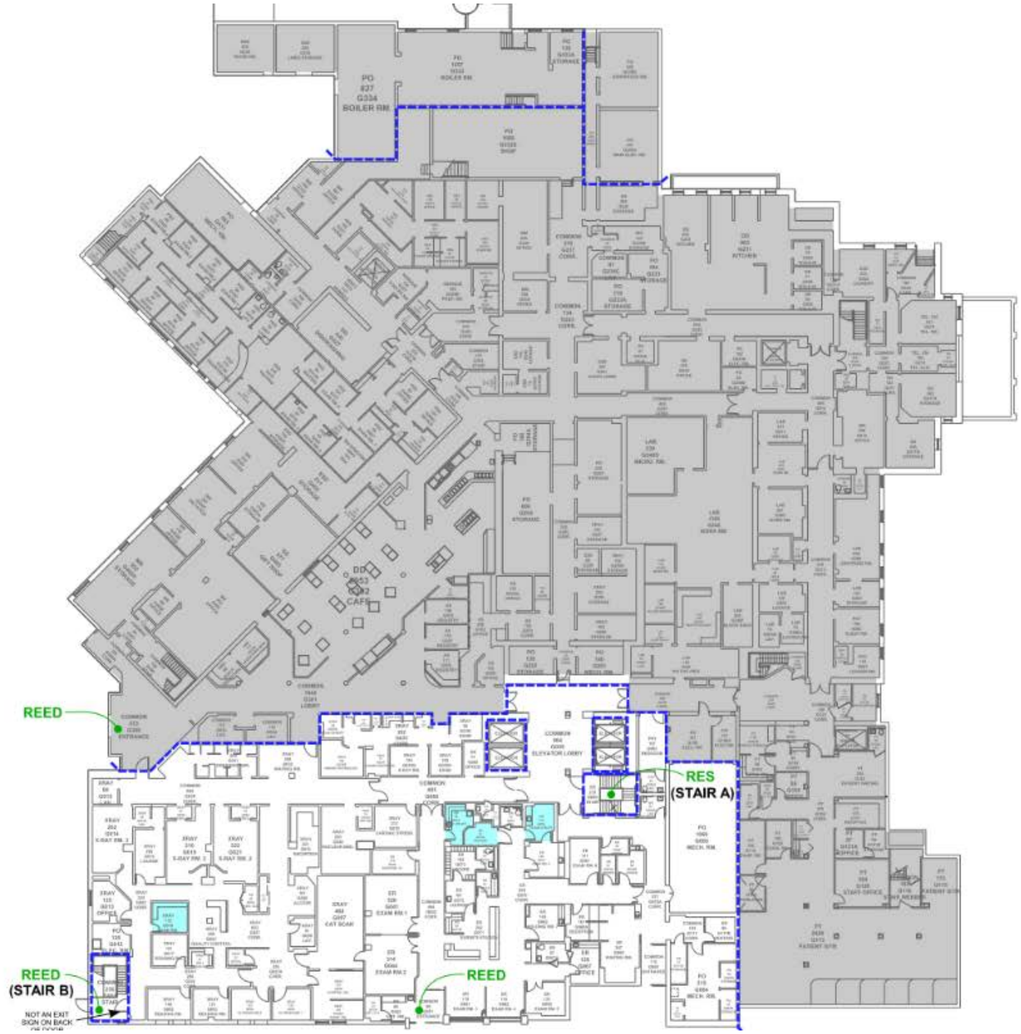


WW-4: West Wing, Floor 4

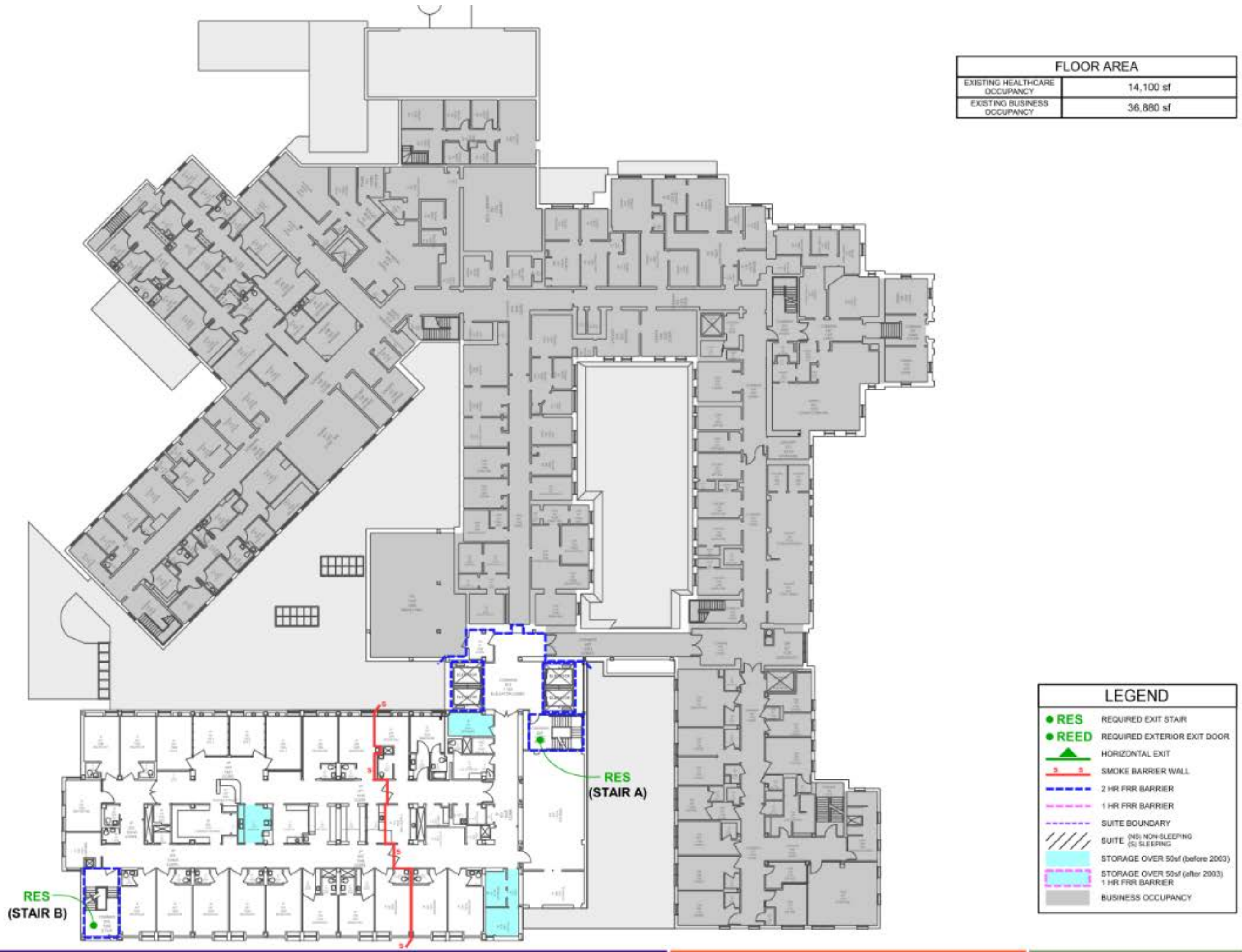


Appendix C-2: From Eugene Cable

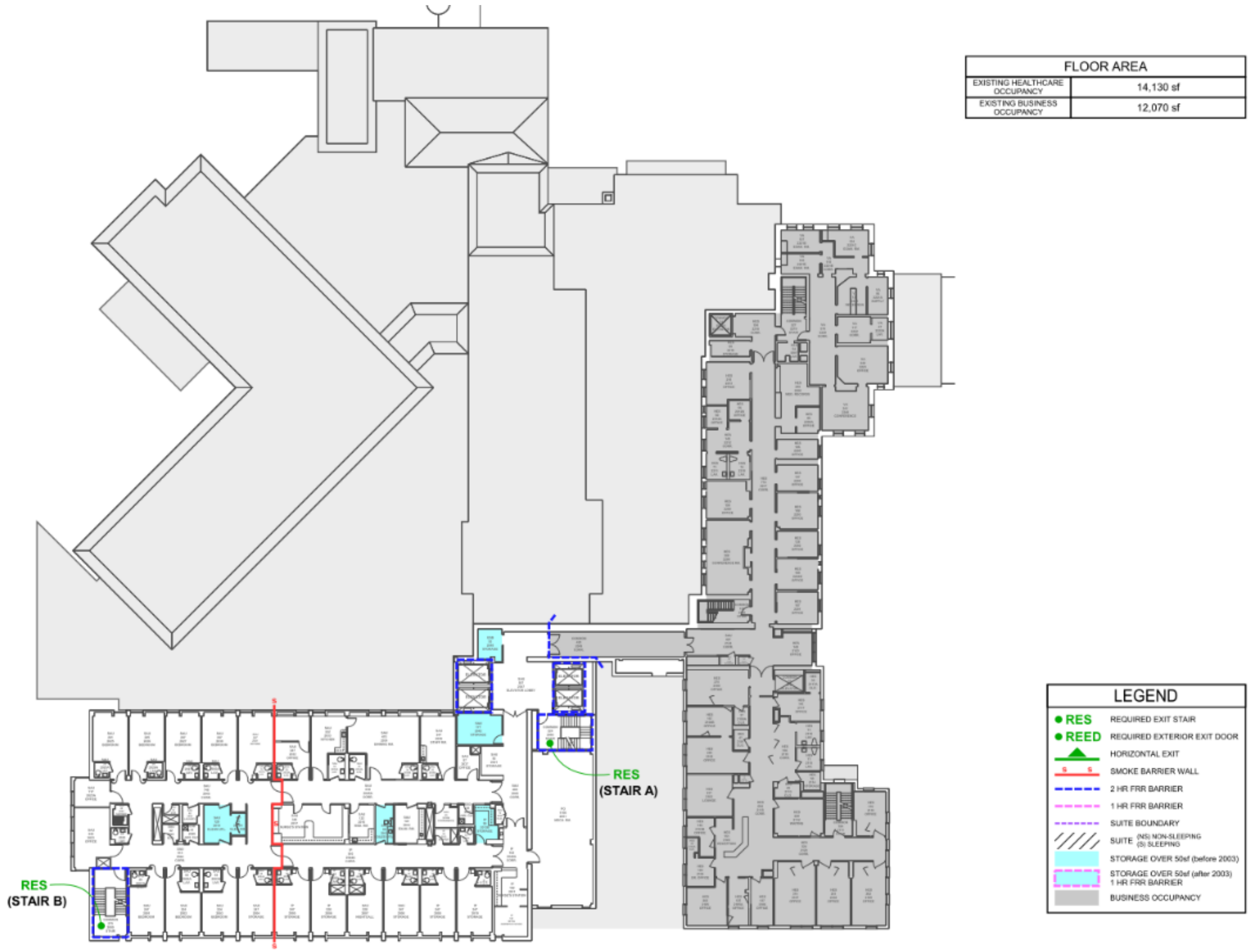
Hospital A



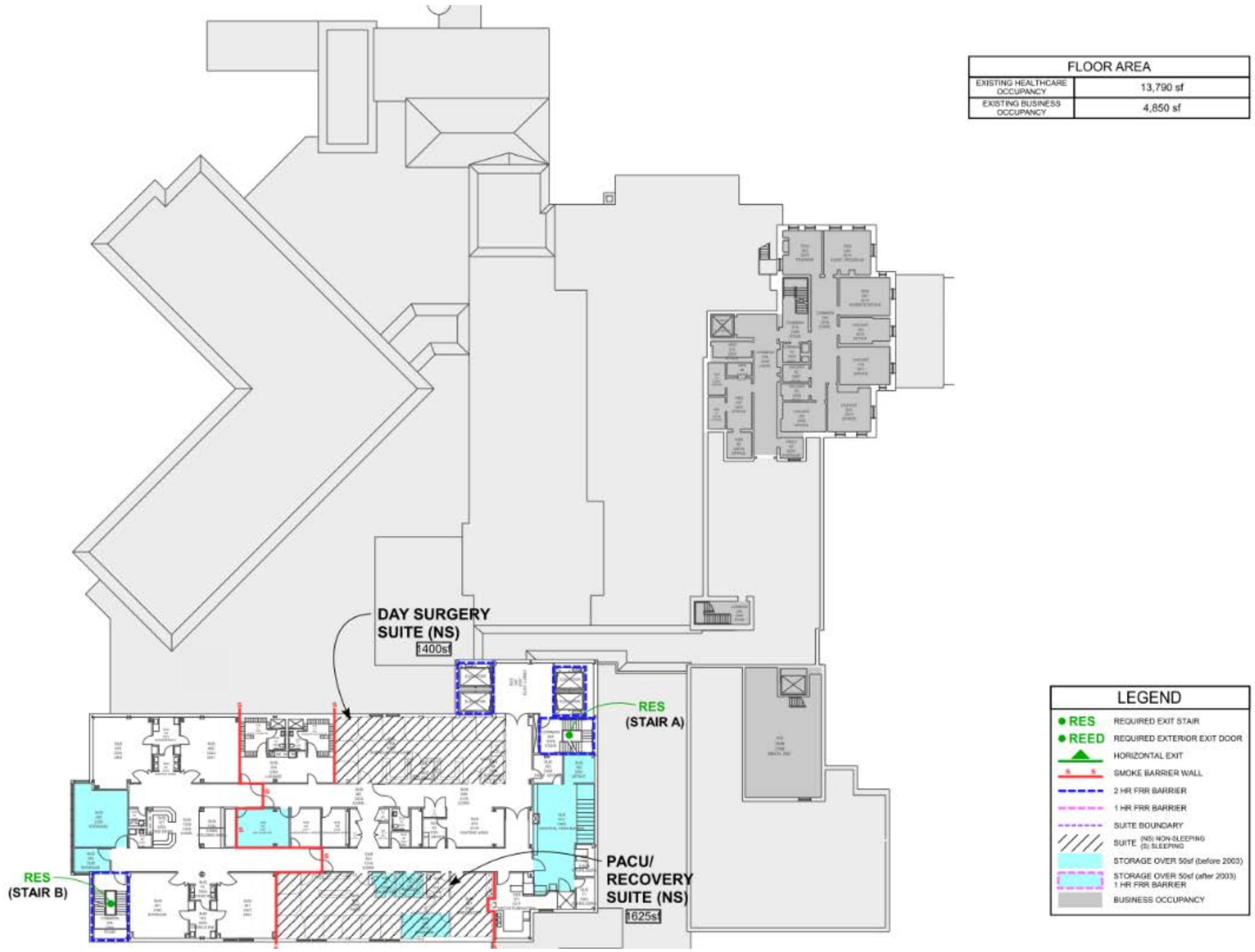
FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	18,140 sf
EXISTING BUSINESS OCCUPANCY	50,690 sf

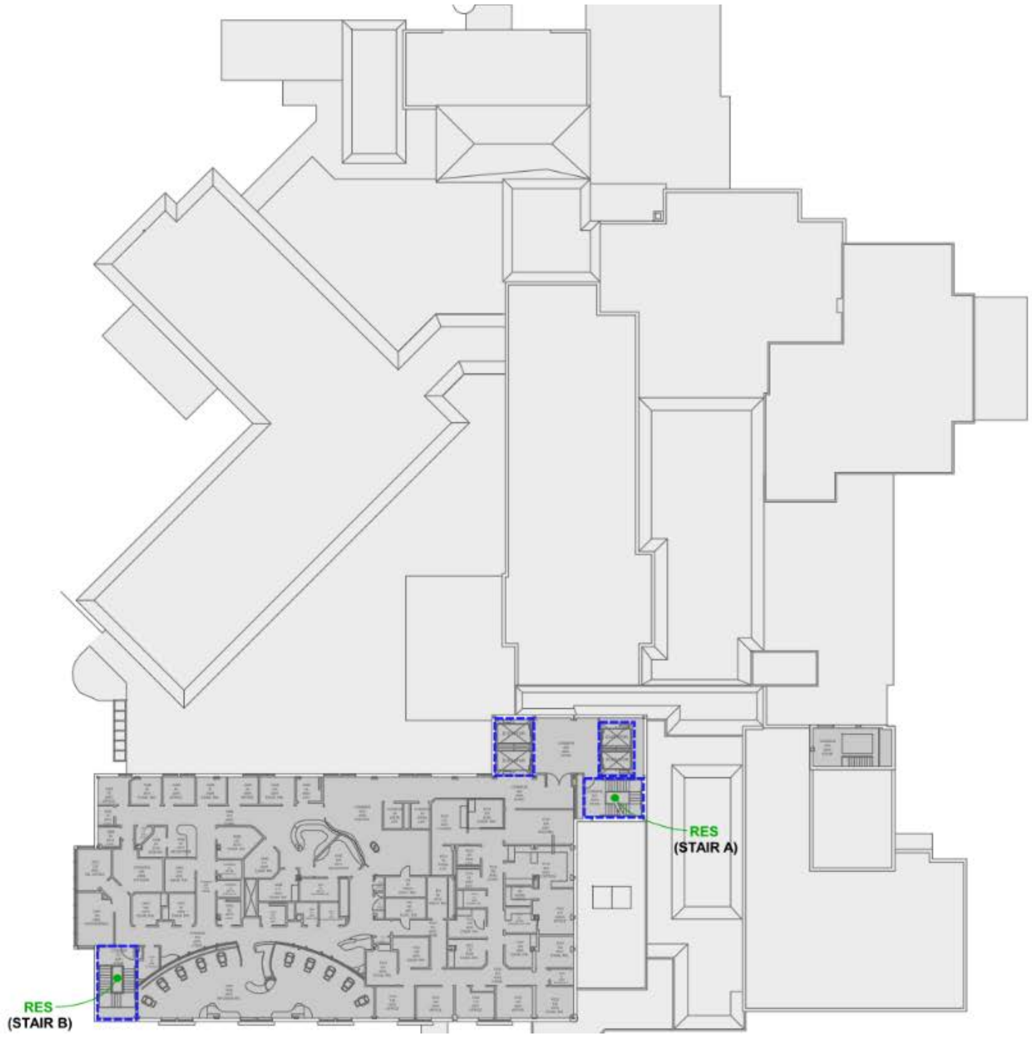


FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	14,100 sf
EXISTING BUSINESS OCCUPANCY	36,880 sf


RES
(STAIR A)
RES
(STAIR B)
FLOOR AREA
EXISTING HEALTHCARE OCCUPANCY 14,130 sf
EXISTING BUSINESS OCCUPANCY 12,070 sf
LEGEND
RES REQUIRED EXIT STAIR
REED REQUIRED EXTERIOR EXIT DOOR
HORIZONTAL EXIT
S S SMOKE BARRIER WALL
2 HR FRR BARRIER
1 HR FRR BARRIER
SUITE BOUNDARY
SUITE (NS) NON-SLEEPING (S) SLEEPING
STORAGE OVER 50sf (before 2003)
STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
BUSINESS OCCUPANCY

FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	13,790 sf
EXISTING BUSINESS OCCUPANCY	4,850 sf



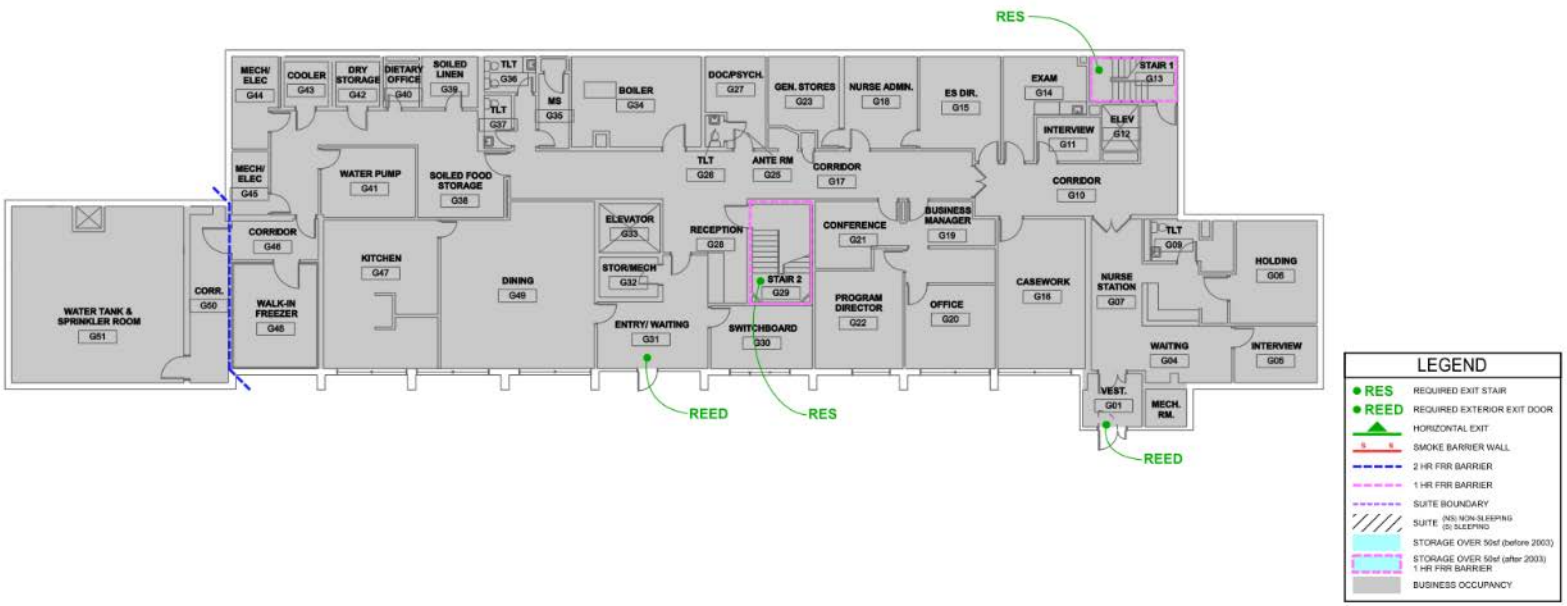


FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	0 sf
EXISTING BUSINESS OCCUPANCY	12,980 sf

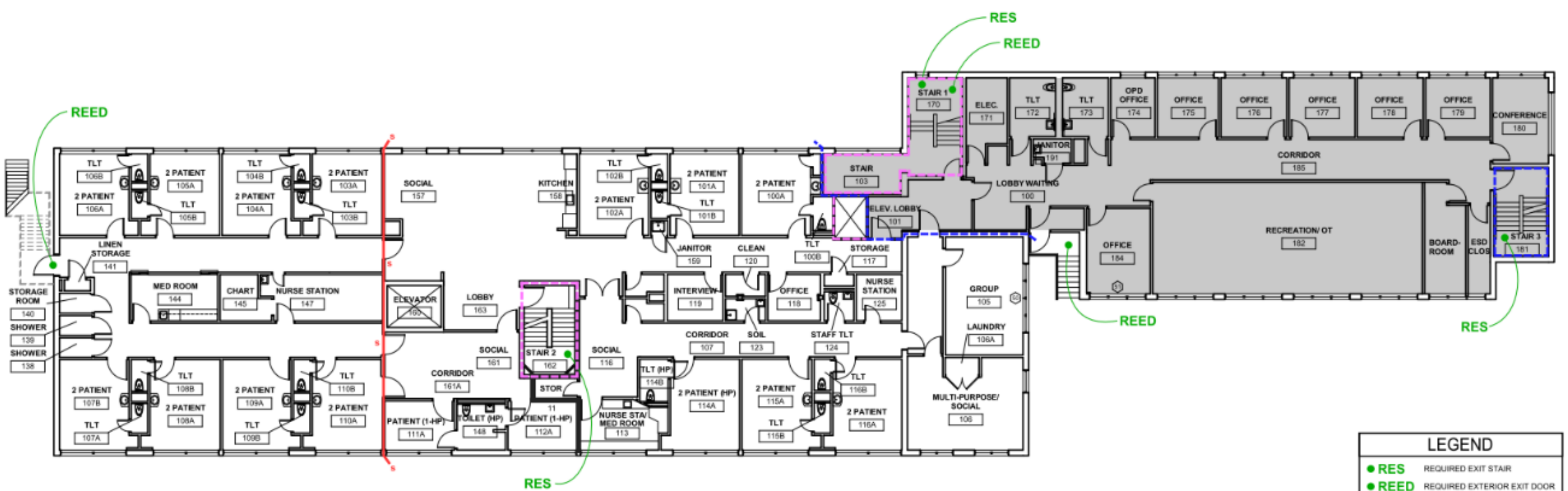
LEGEND	
● RES	REQUIRED EXIT STAIR
● REED	REQUIRED EXTERIOR EXIT DOOR
	HORIZONTAL EXIT
S S	SMOKE BARRIER WALL
	2 HR FRR BARRIER
	1 HR FRR BARRIER
	SUITE BOUNDARY
	SUITE (NS) NON-SLEEPING (S) SLEEPING
	STORAGE OVER 50sf (before 2003)
	STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
	BUSINESS OCCUPANCY

Hospital B

FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	0 sf
EXISTING BUSINESS OCCUPANCY	8,990 sf



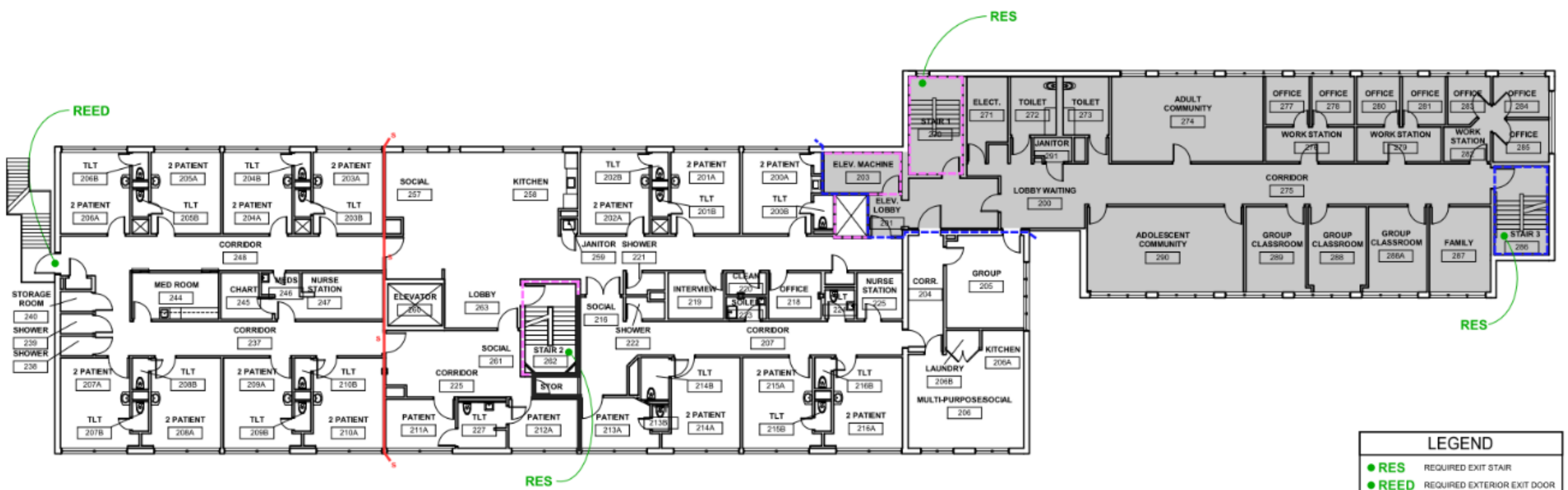
FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	7,550 sf
EXISTING BUSINESS OCCUPANCY	3,640 sf



LEGEND

● RES	REQUIRED EXIT STAIR
● REED	REQUIRED EXTERIOR EXIT DOOR
	HORIZONTAL EXIT
	SMOKE BARRIER WALL
	2 HR FRR BARRIER
	1 HR FRR BARRIER
	SUITE BOUNDARY
	SUITE (NS) NON-SLEEPING (S) SLEEPING
	STORAGE OVER 50sf (before 2003)
	STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
	BUSINESS OCCUPANCY

FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	7,580 sf
EXISTING BUSINESS OCCUPANCY	3,640 sf



LEGEND	
● RES	REQUIRED EXIT STAIR
● REED	REQUIRED EXTERIOR EXIT DOOR
	HORIZONTAL EXIT
	SMOKE BARRIER WALL
	2 HR FRR BARRIER
	1 HR FRR BARRIER
	SUITE BOUNDARY
	SUITE (NS) NON-SLEEPING (S) SLEEPING
	STORAGE OVER 50sf (before 2003)
	STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
	BUSINESS OCCUPANCY

Hospital C

FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	0 sf
EXISTING BUSINESS OCCUPANCY	45,280 sf

LEGEND	
RES	REQUIRED EXIT STAIR
REED	REQUIRED EXTERIOR EXIT DOOR
	HORIZONTAL EXIT
	SMOKE BARRIER WALL
	2 HR FRR BARRIER
	1 HR FRR BARRIER
	SUITE BOUNDARY
	SUITE (NS) NON-SLEEPING (S) SLEEPING
	STORAGE OVER 50sf (before 2003)
	STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
	BUSINESS OCCUPANCY

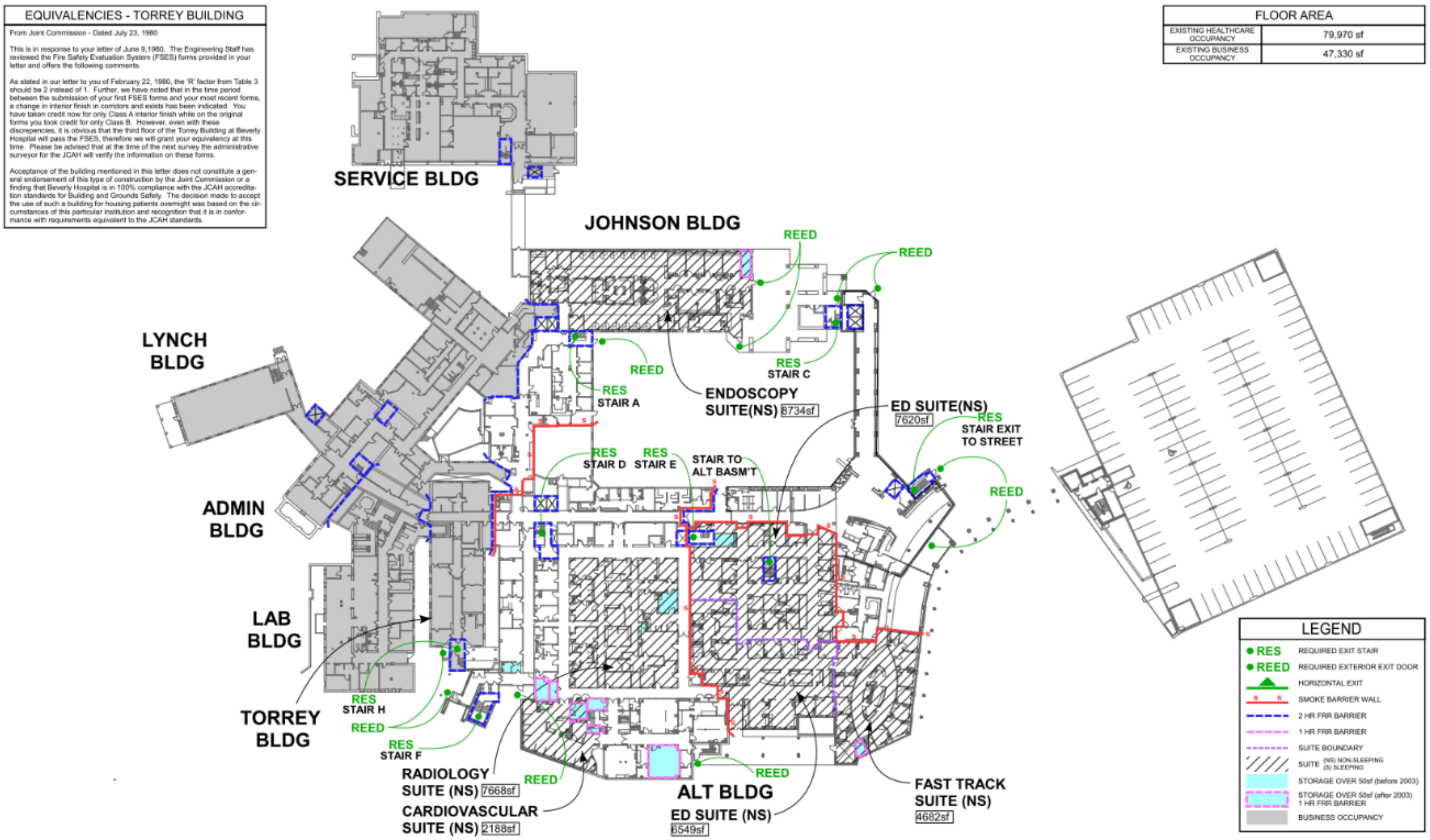
FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	15,000 sf
EXISTING BUSINESS OCCUPANCY	21,400 sf

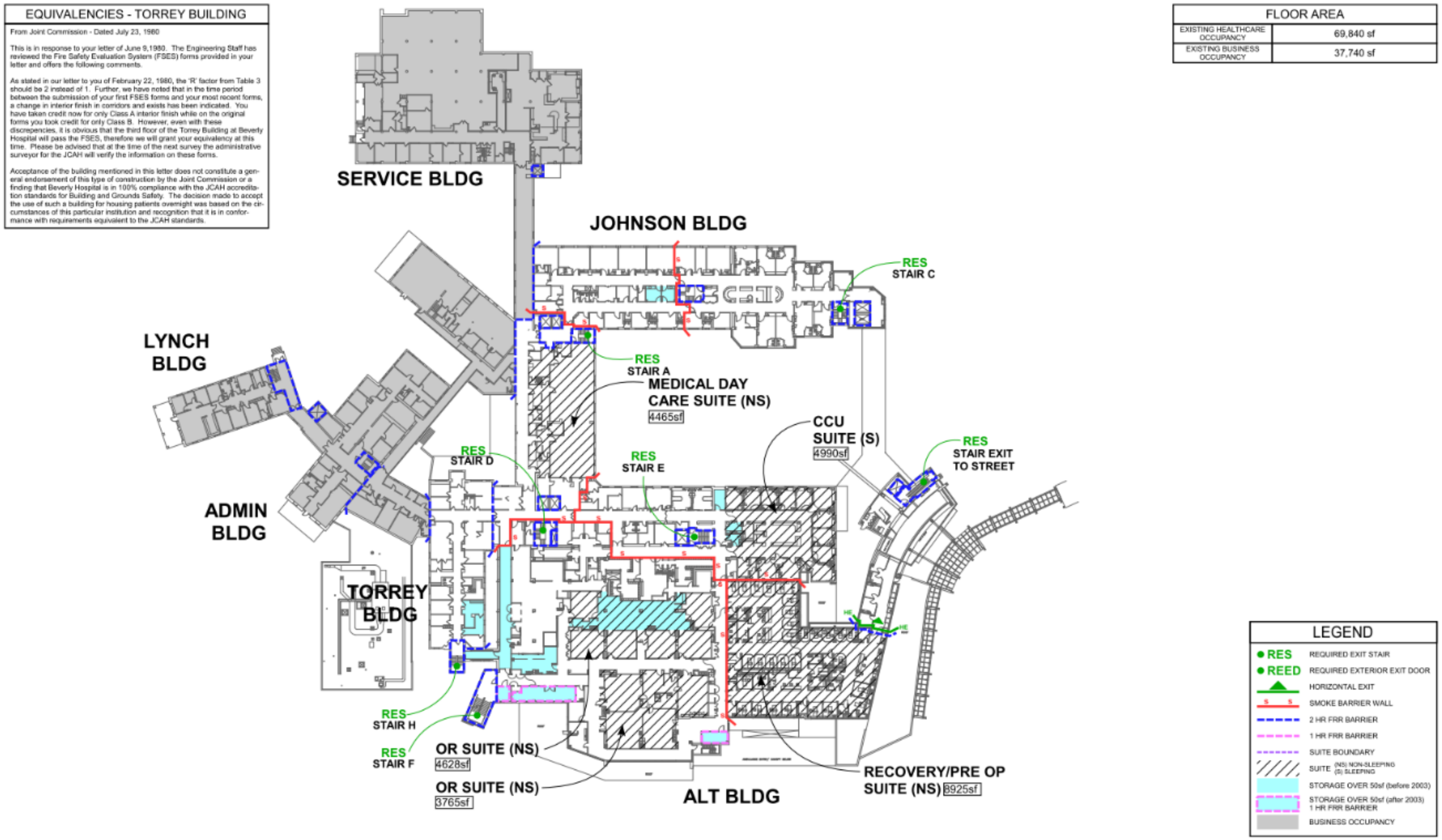
FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	0 sf
EXISTING BUSINESS OCCUPANCY	14,560 sf

LEGEND

● RES	REQUIRED EXIT STAIR
● REED	REQUIRED EXTERIOR EXIT DOOR
	HORIZONTAL EXIT
	SMOKE BARRIER WALL
	2 HR FRR BARRIER
	1 HR FRR BARRIER
	SUITE BOUNDARY
	SUITE (NS) NON-SLEEPING (S) SLEEPING
	STORAGE OVER 50sf (before 2003)
	STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
	BUSINESS OCCUPANCY

Hospital D


EQUIVALENCIES - TORREY BUILDING
From Joint Commission - Dated July 23, 1980
This is in response to your letter of June 9,1980. The Engineering Staff has reviewed the Fire Safety Evaluation System (FSES) forms provided in your letter and offers the following comments.
As stated in our letter to you of February 22, 1980, the 'R' factor from Table 3 should be 2 instead of 1. Further, we have noted that in the time period between the submission of your first FSES forms and your most recent forms, a change in interior finish in corridors and exists has been indicated. You have taken credit now for only Class A interior finish while on the original forms you took credit for only Class B. However, even with these discrepencies, it is obvious that the third floor of the Torrey Building at Beverly Hospital will pass the FSES, therefore we will grant your equivalency at this time. Please be advised that at the time of the next survey the administrative surveyor for the JCAH will verify the information on these forms.
Acceptance of the building mentioned in this letter does not constitute a general endorsement of this type of construction by the Joint Commission or a finding that Beverly Hospital is in 100% compliance with the JCAH accreditation standards for Building and Grounds Safety. The decision made to accept the use of such a building for housing patients overnight was based on the circumstances of this particular institution and recognition that it is in conformance with requirements equivalent to the JCAH standards.
FLOOR AREA
EXISTING HEALTHCARE OCCUPANCY 79,970 sf
EXISTING BUSINESS OCCUPANCY 47,330 sf
SERVICE BLDG
JOHNSON BLDG
LYNCH BLDG
ADMIN BLDG
LAB BLDG
TORREY BLDG
ALT BLDG
REED
RES STAIR A
RES STAIR C
RES STAIR D
RES STAIR E
STAIR TO ALT BASM'T
RES STAIR EXIT TO STREET
RES STAIR H
RES STAIR F
ENDOSCOPY SUITE(NS) 8734sf
ED SUITE(NS) 7620sf
RADIOLOGY SUITE (NS) 7668sf
CARDIOVASCULAR SUITE (NS) 2188sf
ED SUITE (NS) 6549sf
FAST TRACK SUITE (NS) 4682sf
LEGEND
RES REQUIRED EXIT STAIR
REED REQUIRED EXTERIOR EXIT DOOR
HORIZONTAL EXIT
SMOKE BARRIER WALL
2 HR FRR BARRIER
1 HR FRR BARRIER
SUITE BOUNDARY
SUITE (NS) NON-SLEEPING (S) SLEEPING
STORAGE OVER 50sf (before 2003)
STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
BUSINESS OCCUPANCY


EQUIVALENCIES - TORREY BUILDING
From Joint Commission - Dated July 23, 1980
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SERVICE BLDG
JOHNSON BLDG
RES
STAIR C
LYNCH BLDG
RES
STAIR A
MEDICAL DAY CARE SUITE (NS)
4465sf
CCU SUITE (S)
4990sf
RES
STAIR D
RES
STAIR E
RES
STAIR EXIT TO STREET
ADMIN BLDG
TORREY BLDG
RES
STAIR H
RES
STAIR F
OR SUITE (NS)
4628sf
OR SUITE (NS)
3765sf
ALT BLDG
RECOVERY/PRE OP SUITE (NS)
8925sf
FLOOR AREA
EXISTING HEALTHCARE OCCUPANCY 69,840 sf
EXISTING BUSINESS OCCUPANCY 37,740 sf
LEGEND
RES REQUIRED EXIT STAIR
REED REQUIRED EXTERIOR EXIT DOOR
HORIZONTAL EXIT
S S SMOKE BARRIER WALL
2 HR FRR BARRIER
1 HR FRR BARRIER
SUITE BOUNDARY
SUITE (NS) NON-SLEEPING (S) SLEEPING
STORAGE OVER 50sf (before 2003)
STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
BUSINESS OCCUPANCY

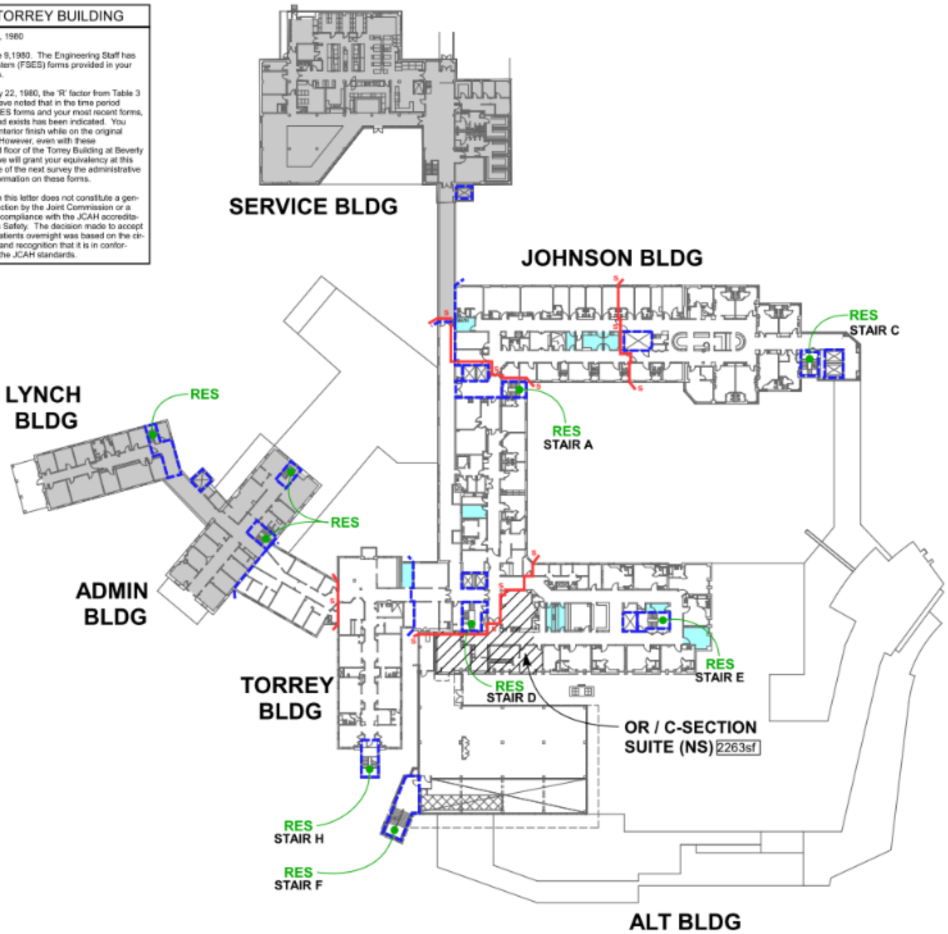
EQUIVALENCIES - TORREY BUILDING

From Joint Commission - Dated July 23, 1980

This is in response to your letter of June 9,1980. The Engineering Staff has reviewed the Fire Safety Evaluation System (FSES) forms provided in your letter and offers the following comments.

As stated in our letter to you of February 22, 1980, the 'R' factor from Table 3 should be 2 instead of 1. Further, we have noted that in the time period between the submission of your first FSES forms and your most recent forms, a change in interior finish in corridors and exists has been indicated. You have taken credit now for only Class A interior finish while on the original forms you took credit for only Class B. However, even with these discrepencies, it is obvious that the third floor of the Torrey Building at Beverly Hospital will pass the FSES, therefore we will grant your equivalency at this time. Please be advised that at the time of the next survey the administrative surveyor for the JCAH will verify the information on these forms.

Acceptance of the building mentioned in this letter does not constitute a general endorsement of this type of construction by the Joint Commission or a finding that Beverly Hospital is in 100% compliance with the JCAH accreditation standards for Building and Grounds Safety. The decision made to accept the use of such a building for housing patients overnight was based on the circumstances of this particular institution and recognition that it is in conformance with requirements equivalent to the JCAH standards.

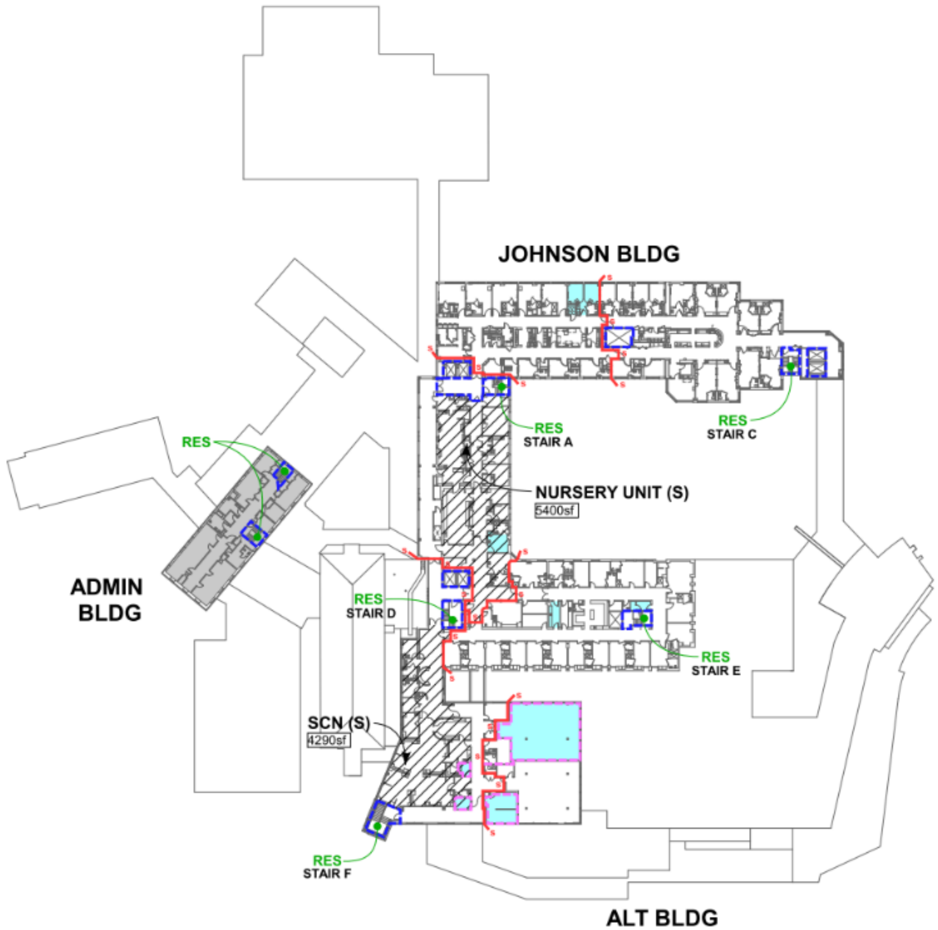


FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	48,380 sf
EXISTING BUSINESS OCCUPANCY	19,830 sf

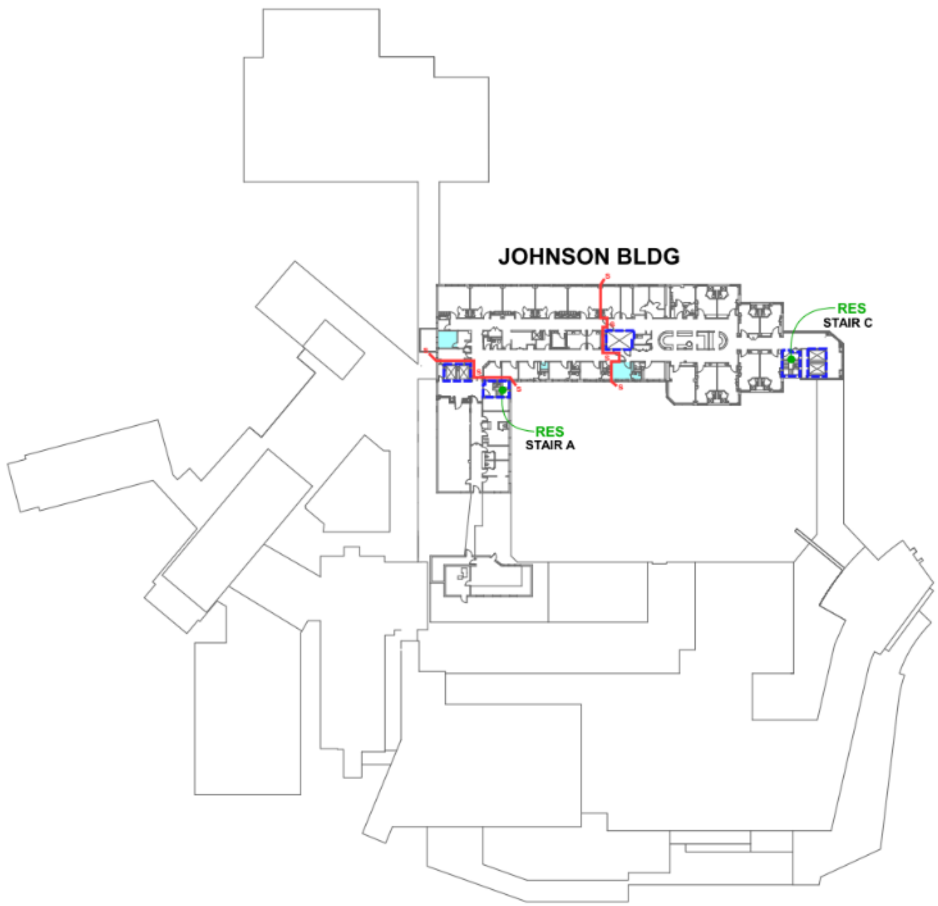
LEGEND

● RES	REQUIRED EXIT STAIR
● REED	REQUIRED EXTERIOR EXIT DOOR
	HORIZONTAL EXIT
S S	SMOKE BARRIER WALL
	2 HR FRR BARRIER
	1 HR FRR BARRIER
	SUITE BOUNDARY
	SUITE (NS) NON-SLEEPING (S) SLEEPING
	STORAGE OVER 50sf (before 2003)
	STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
	BUSINESS OCCUPANCY

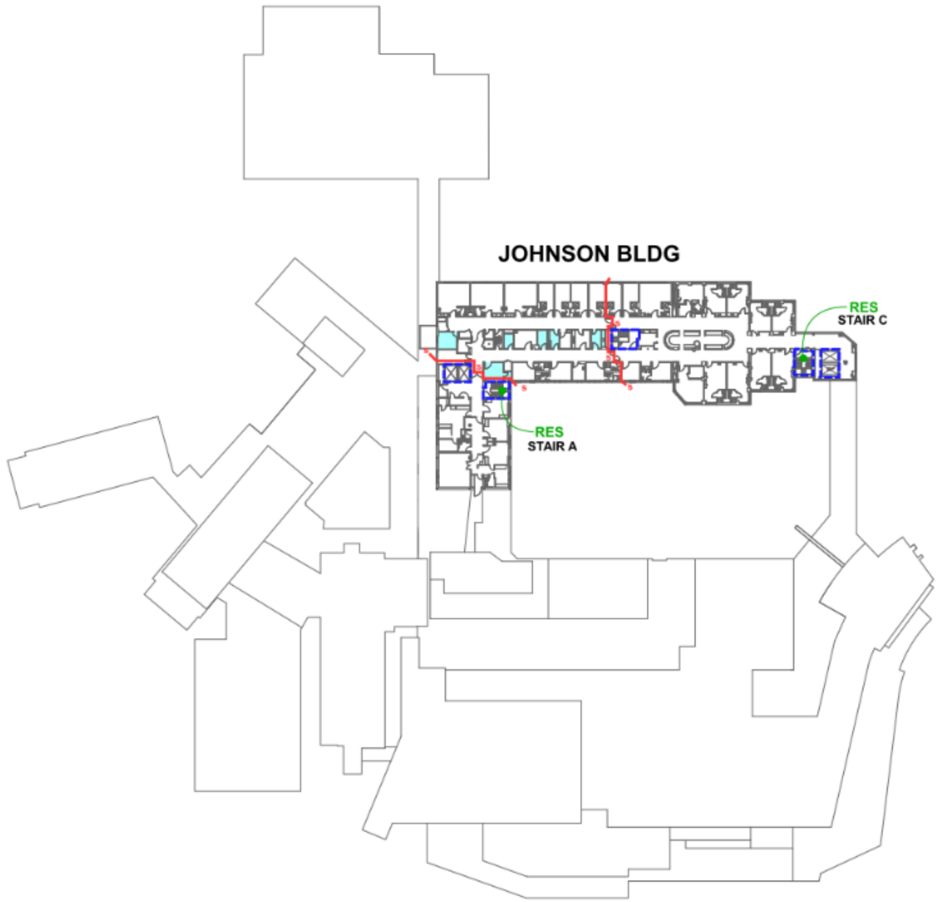
FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	41,430 sf
EXISTING BUSINESS OCCUPANCY	3,350 sf



FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	17,470 sf
EXISTING BUSINESS OCCUPANCY	0 sf



FLOOR AREA	
EXISTING HEALTHCARE OCCUPANCY	18,250 sf
EXISTING BUSINESS OCCUPANCY	0 sf

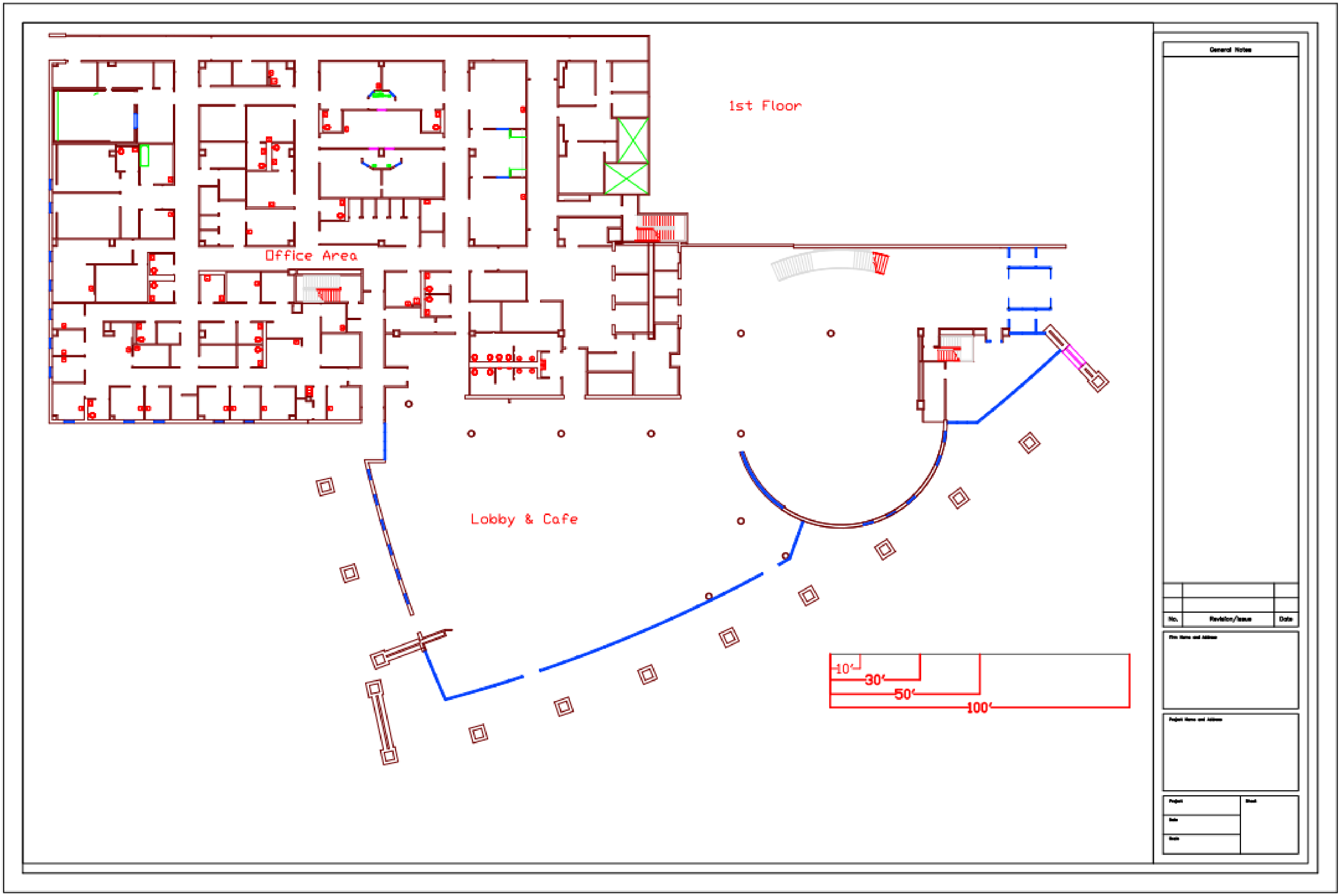


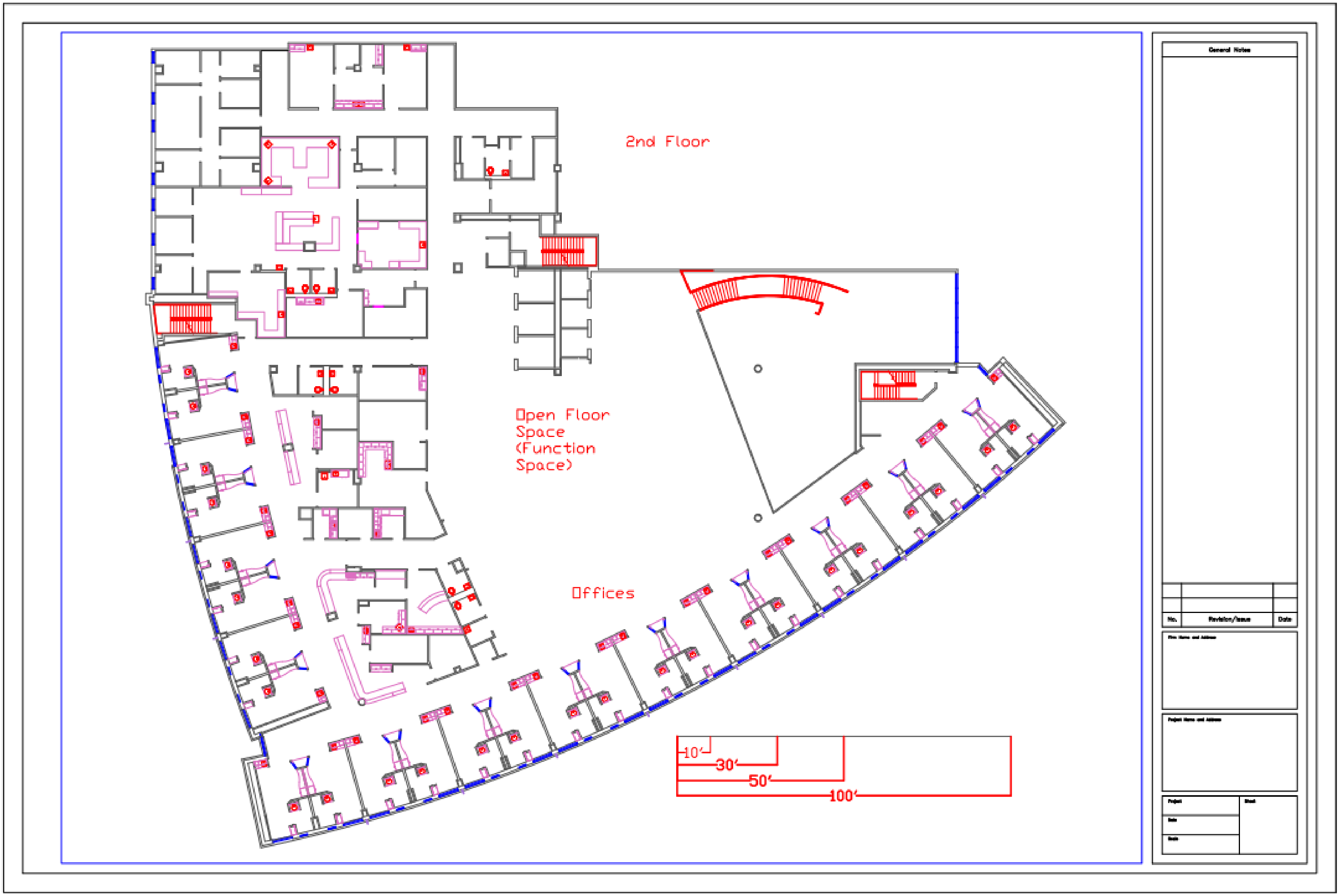
LEGEND

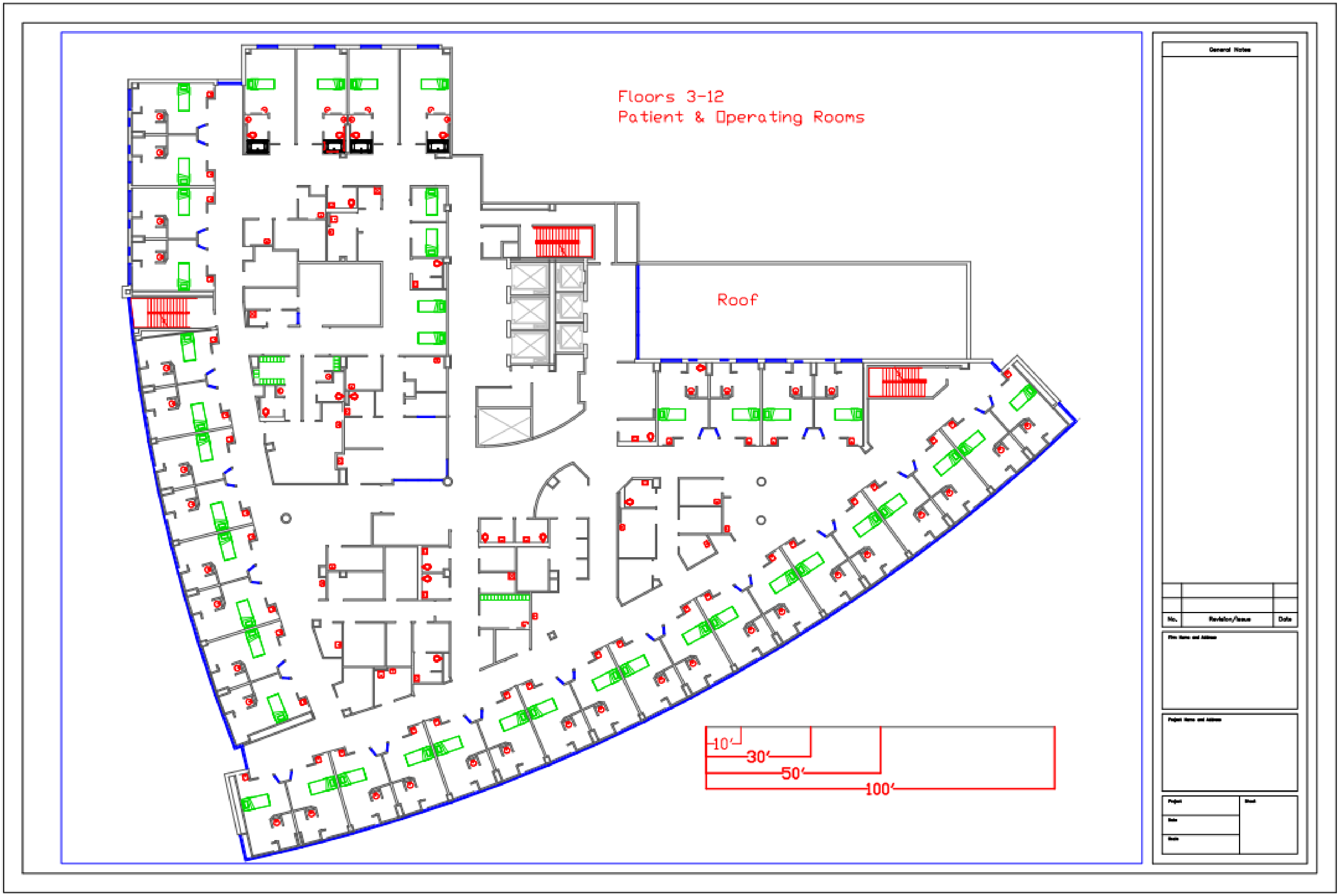
RES	REQUIRED EXIT STAIR
REED	REQUIRED EXTERIOR EXIT DOOR
	HORIZONTAL EXIT
S S	SMOKE BARRIER WALL
	2 HR FRR BARRIER
	1 HR FRR BARRIER
	SUITE BOUNDARY
	SUITE (NS) NON-SLEEPING (S) SLEEPING
	STORAGE OVER 50sf (before 2003)
	STORAGE OVER 50sf (after 2003) 1 HR FRR BARRIER
	BUSINESS OCCUPANCY

Appendix C-3: From WPI Classes

Trauma Center

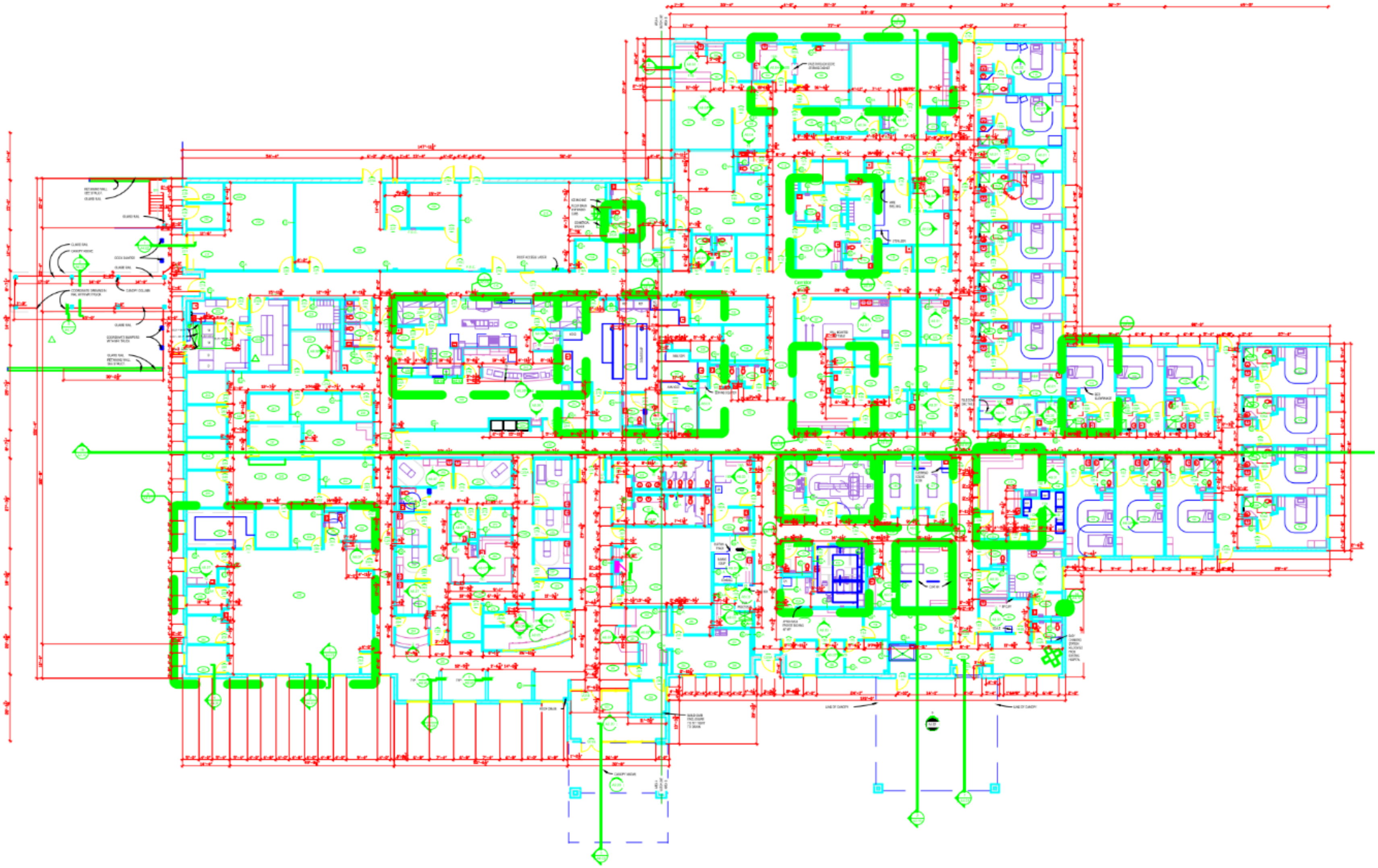



2nd Floor
Open Floor Space (Function Space)
Offices
10'
30'
50'
100'
General Notes
No.
Revision/Issue
Date


Floors 3-12
Patient & Operating Rooms
Roof
10'
30'
50'
100'
General Notes

Appendix C-4: From Other Sources

Hospital 1



Appendix D: Presentation Slide Stack for Client

Evaluation of Smoke Compartment Size in Healthcare Facilities:

ICC Code Evaluation Guidance Report

Drew Martin & Mary Long, Graduate Students, Worcester Polytechnic Institute, Fire Protection Engineering

Brian Meacham, PhD, PE, FSFPE, CEng FIFireE
Associate Professor, Fire Protection Engineering

With Support From Fire Safe North America (FSNA)

Acknowledgements

- We extend our deep appreciation to the graduate students at WPI who have contributed significantly to this effort: Mary Long and Drew Martin
- We sincerely thank the members of FSNA who have given us expert advice and guidance: Vickie Lovell, Mark Lund
- We thank our the Professor Brian Meacham
- We are deeply appreciative of the time and effort that Eugene Cable has donated to this project.
- We would like to acknowledge support for this research from Fire Safe North America (FSNA)

Disclaimer

- The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing WPI

Project Advisory Panel Meeting, February 2015 3

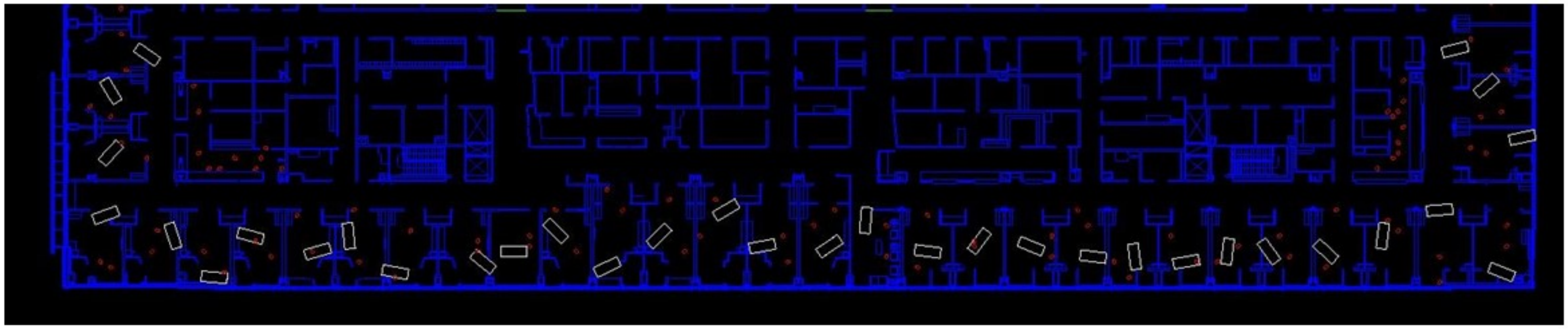
Worcester Polytechnic Institute

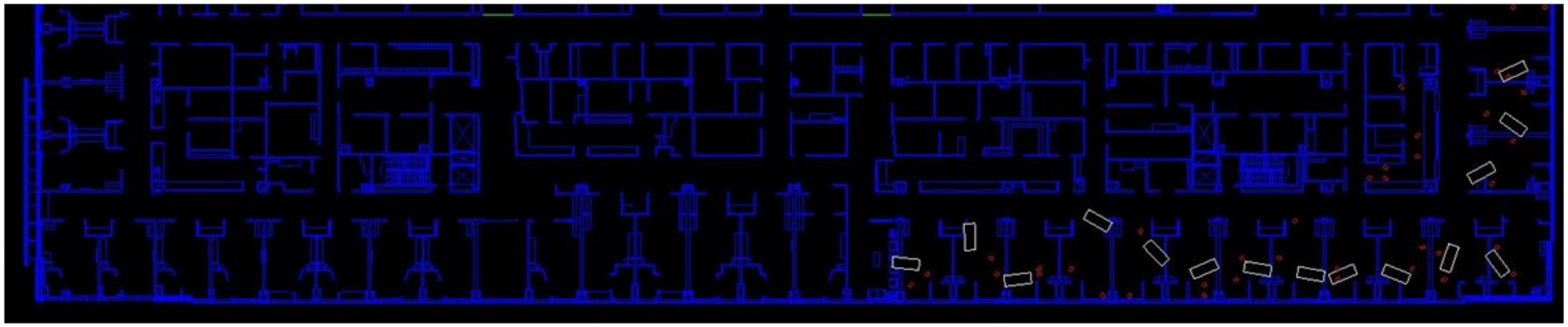
Smaller Smoke Compartments Mean...

- Less Patients to Evacuate
- Shorter Distance to Move Patients
- Higher Number of Staff to Assist
- Easier to Contain Fire
- More Compartments on Each Floor

Worcester Polytechnic Institute

Less Patients to Evacuate





Worcester Polytechnic Institute

Shorter Distance to Move Patients

- 180 Feet vs 200 Feet
- Moving a farther distance for more patients

Worcester Polytechnic Institute

Higher number of Staff to Assist

- More staff in adjacent ‘safe’ compartments to assist with evacuation
- Not enough data to be represented in timed evacuation models

Worcester Polytechnic Institute

Easier to contain fire

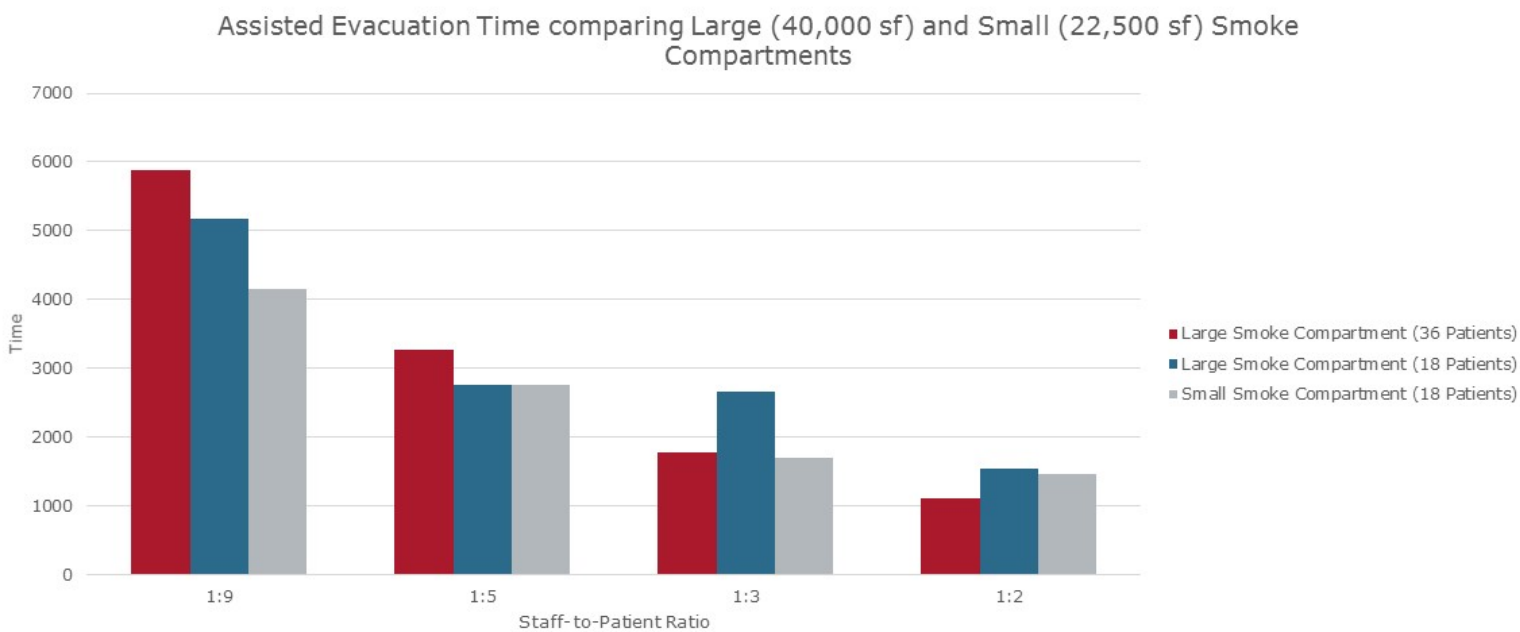
Worcester Polytechnic Institute

More Compartments on Each Floor

- More Compartments for secondary and tertiary migrations

Worcester Polytechnic Institute

Evidence From Timed Evacuation Modeling



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Evidence From Timed Evacuation Modeling

Smoke Compartment Size	Time	Staff-to-patient Ratio	# of Staff	# of Patients
Large	928	1:2	18	36
Large	1090	1:2	8	18
Small	1215	1:2	8	18
Small	1293	1:3	6	18
Large	1475	1:3	12	36
Large	1870	1:3	6	18
Small	1977	1:5	4	18
Large	2041	1:5	4	18
Large	2222	1:5	8	36
Small	3996	1:9	2	18
Large	4161	1:9	2	18
Large	4460	1:9	4	36

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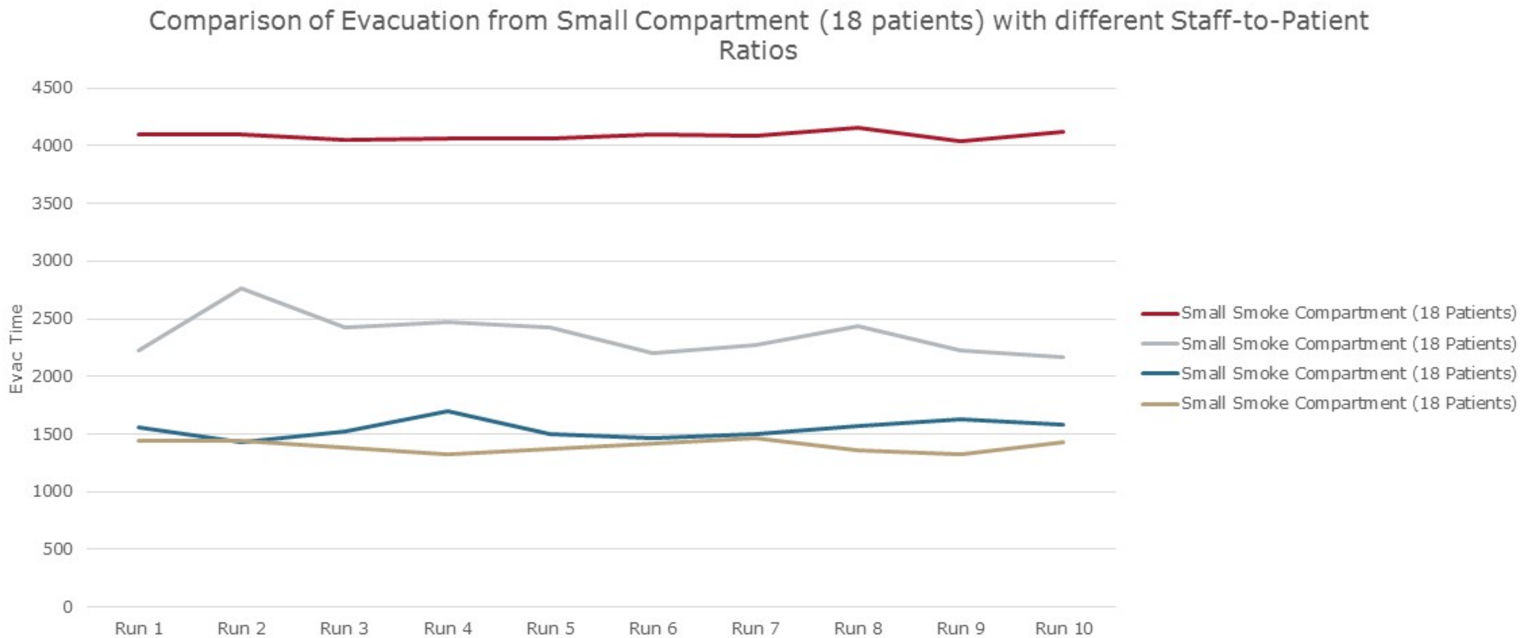
Evacuation Times of Small Compartment



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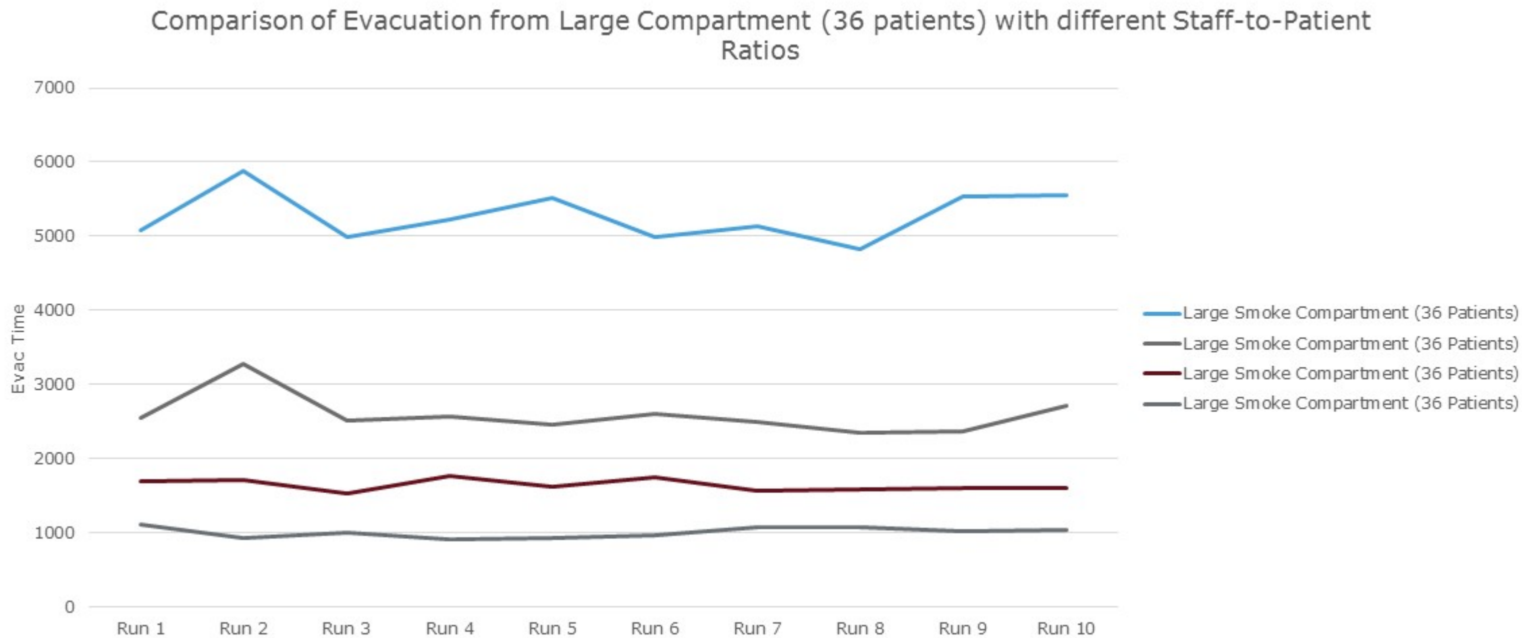
Evacuation Times of Large Compartment



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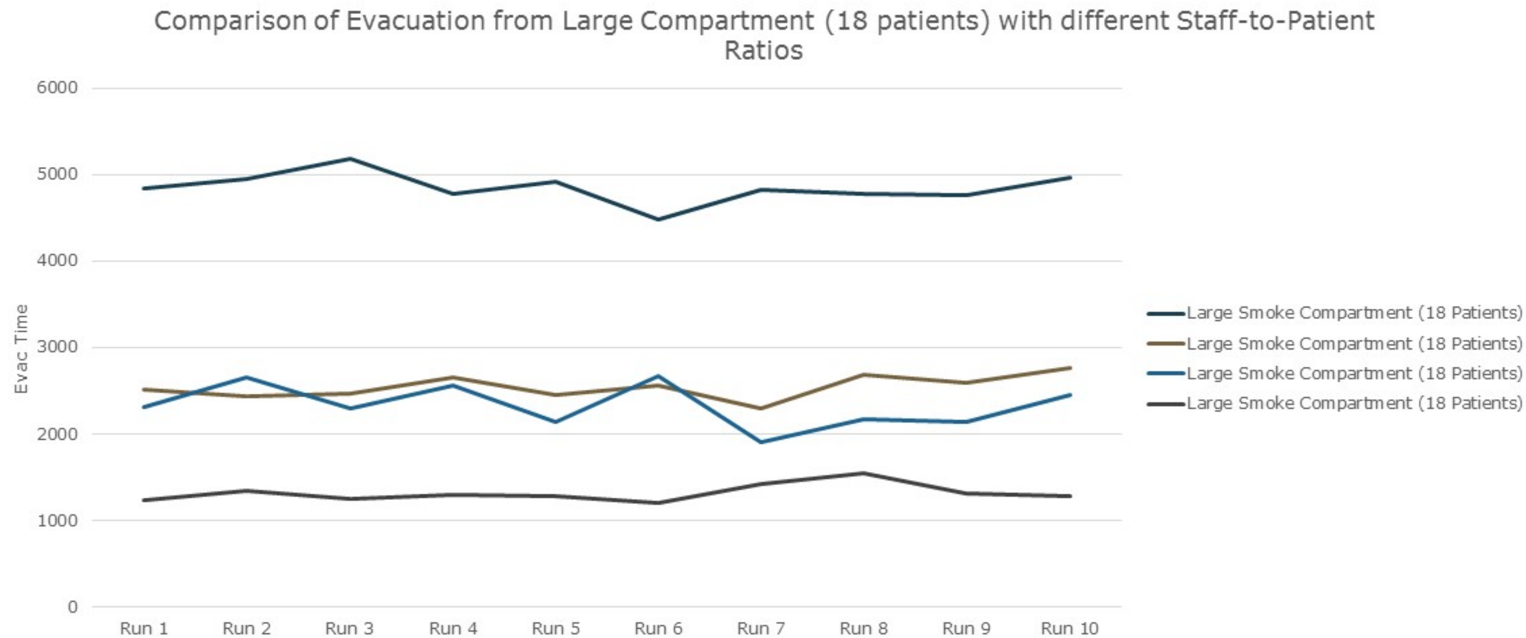
Evacuation Times of Large Compartment



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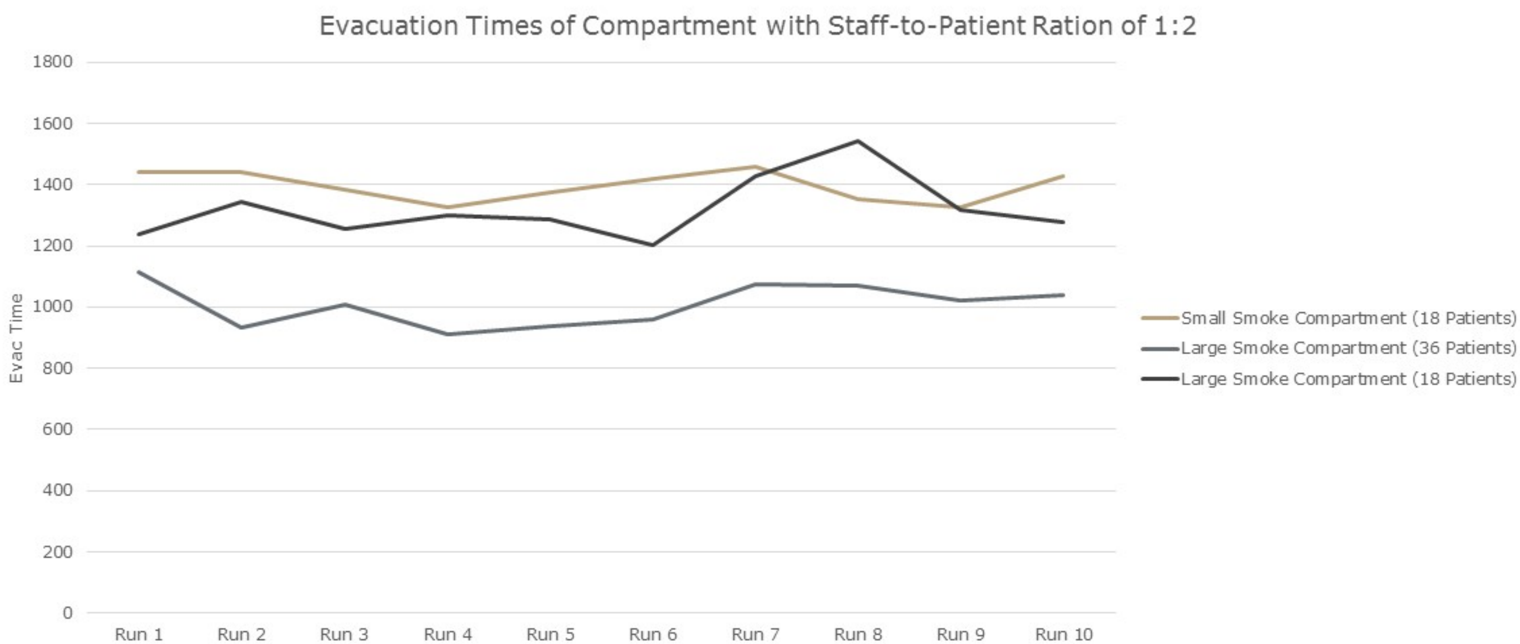
Evacuation Times with Ratio of 1:2



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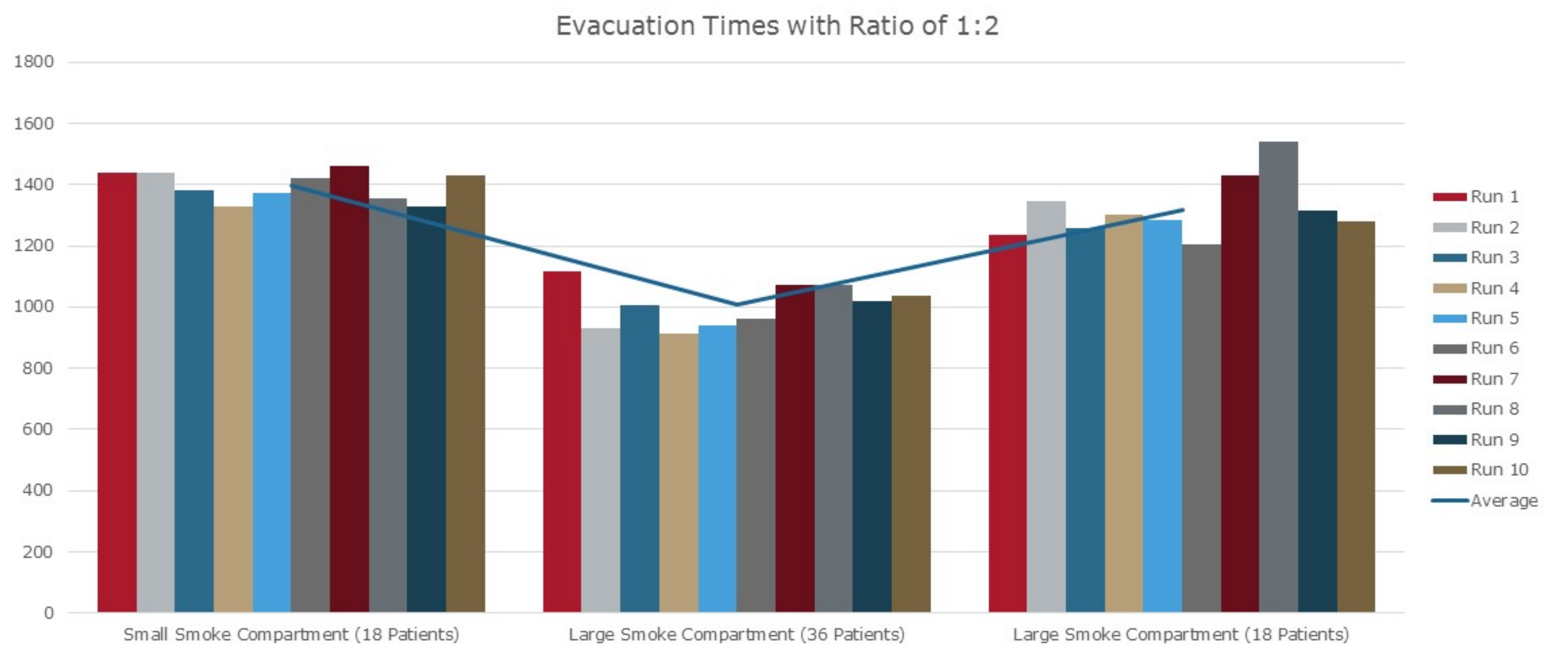

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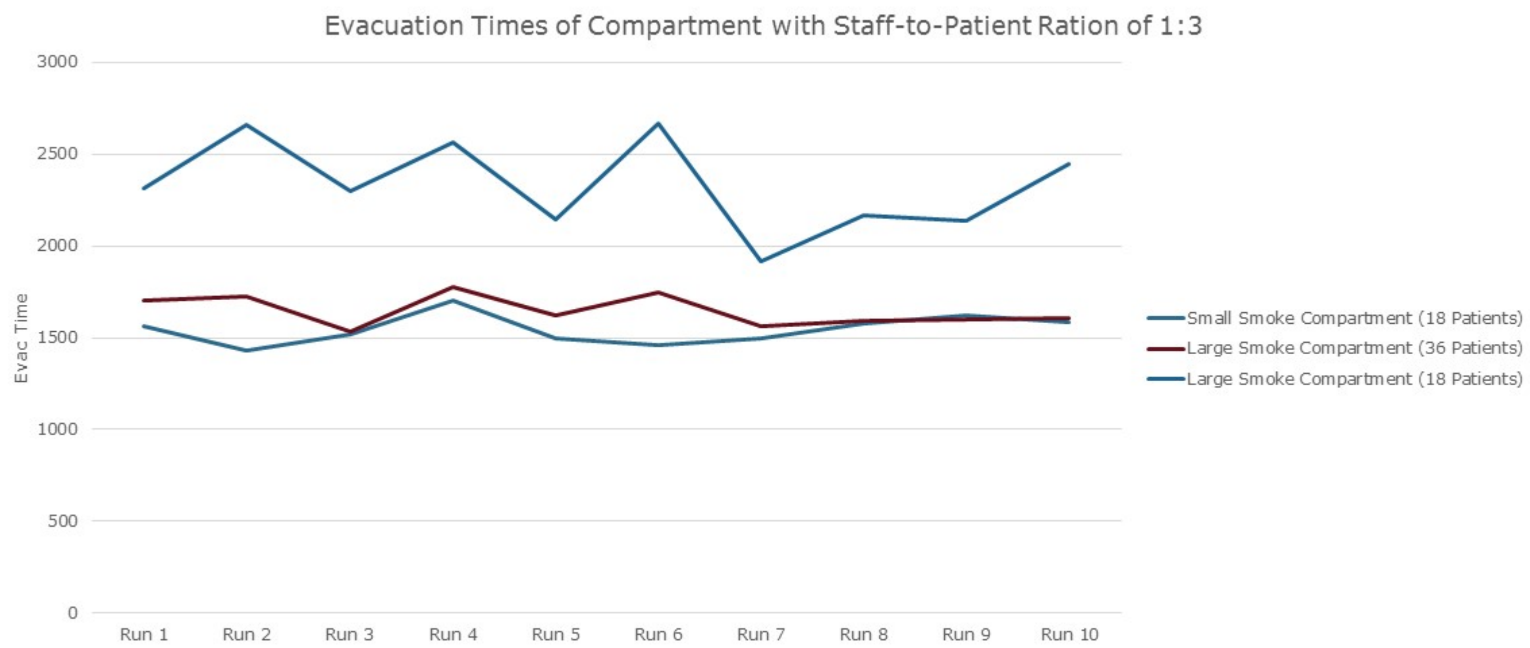
Evacuation Times with Ratio of 1:3



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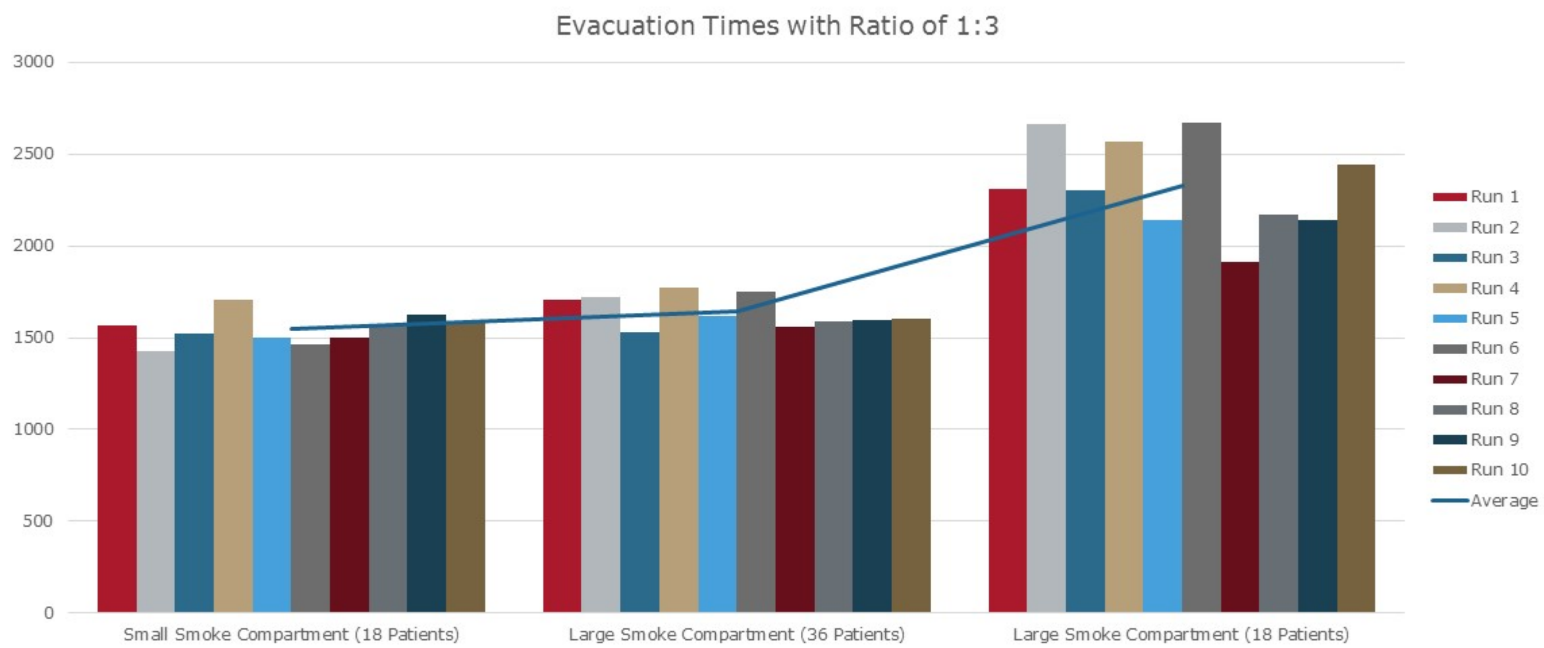
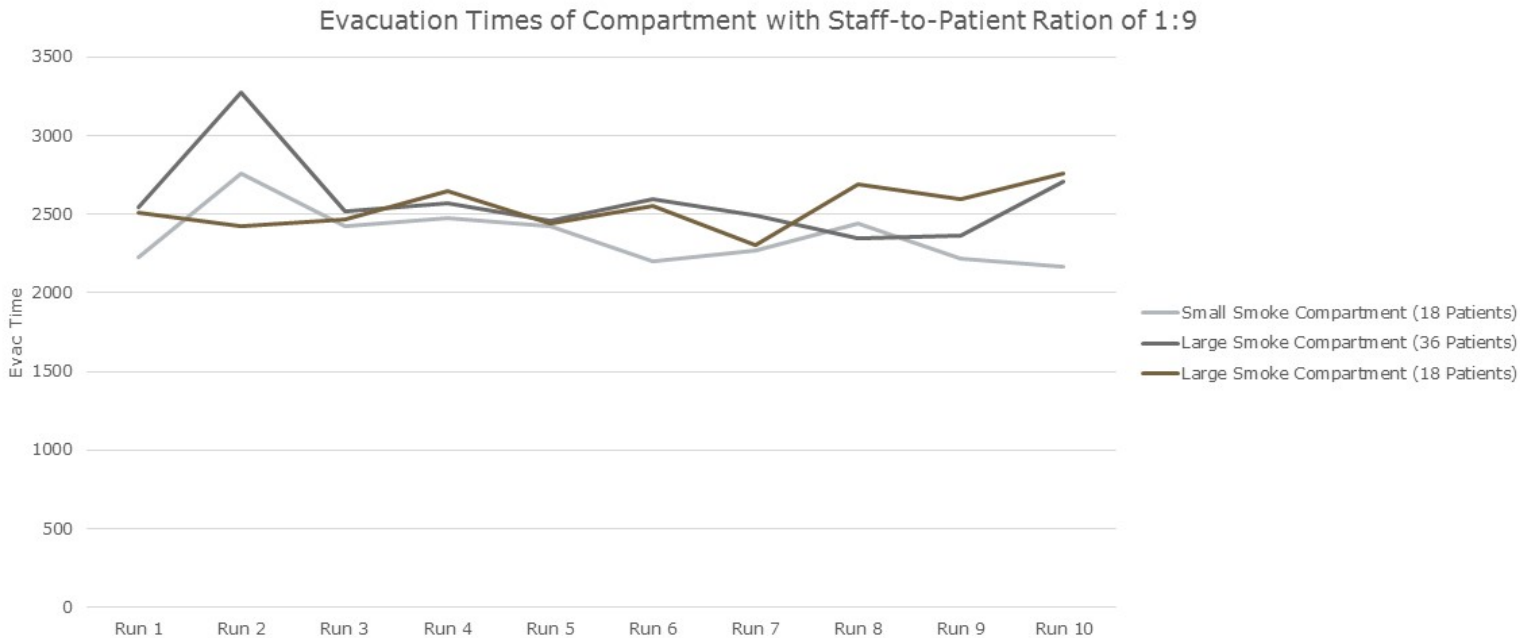

Evacuation Times with Ratio of 1:3
3000
2500
2000
1500
1000
500
0
Small Smoke Compartment (18 Patients)
Large Smoke Compartment (36 Patients)
Large Smoke Compartment (18 Patients)
Run 1
Run 2
Run 3
Run 4
Run 5
Run 6
Run 7
Run 8
Run 9
Run 10
Average

Evacuation Times with Ratio of 1:5



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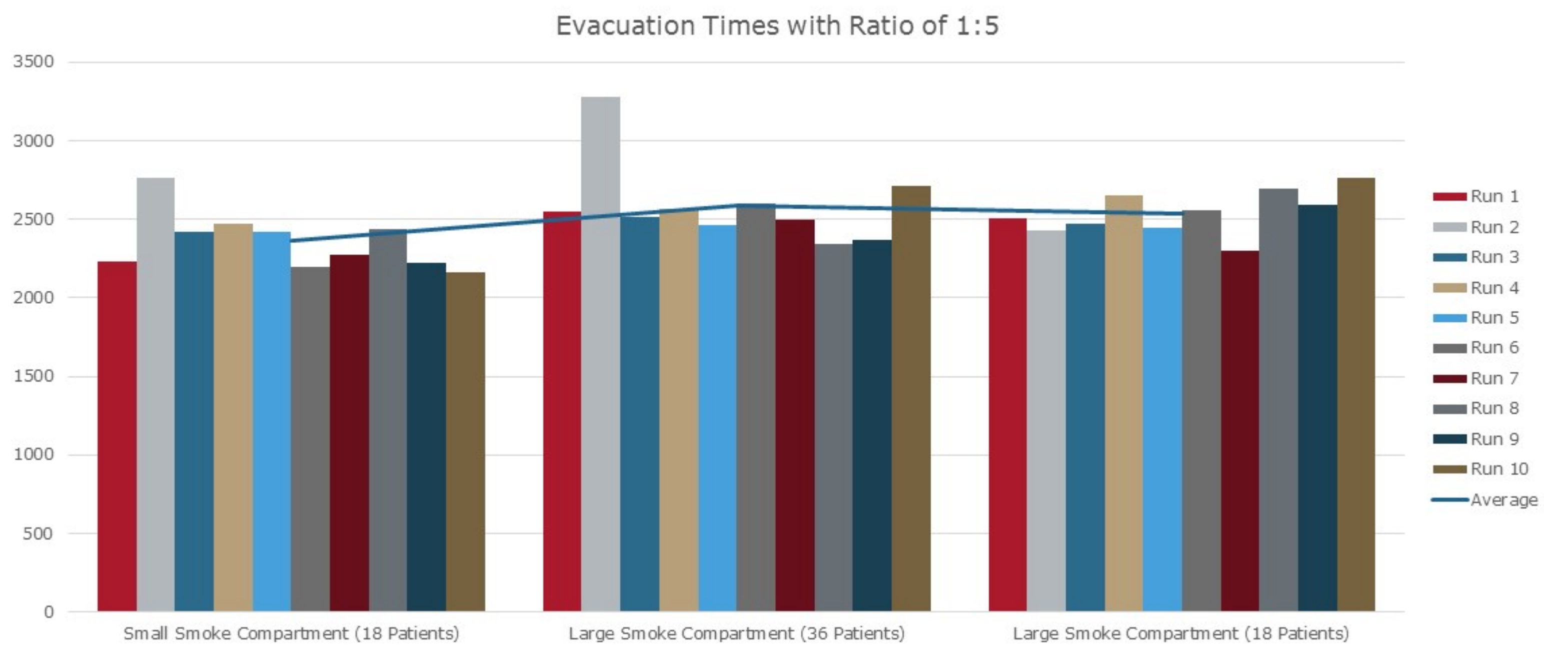

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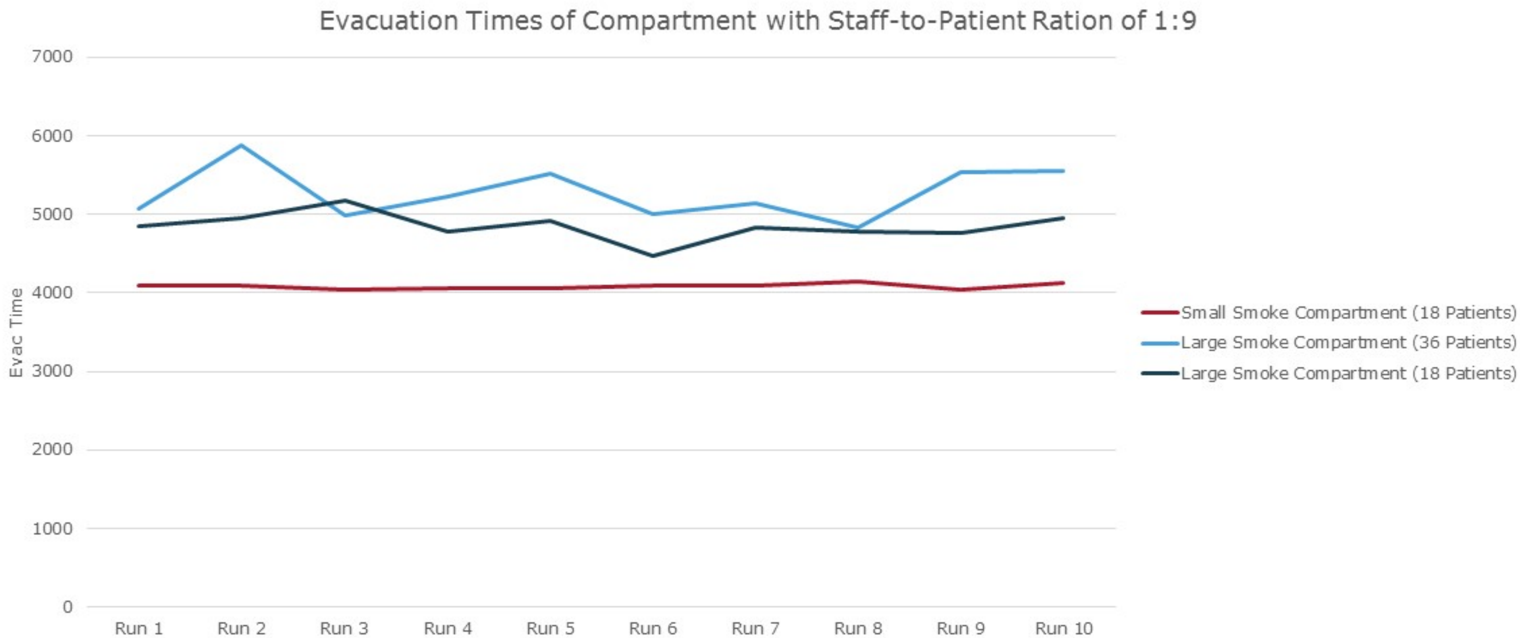
Evacuation Times with Ratio of 1:9



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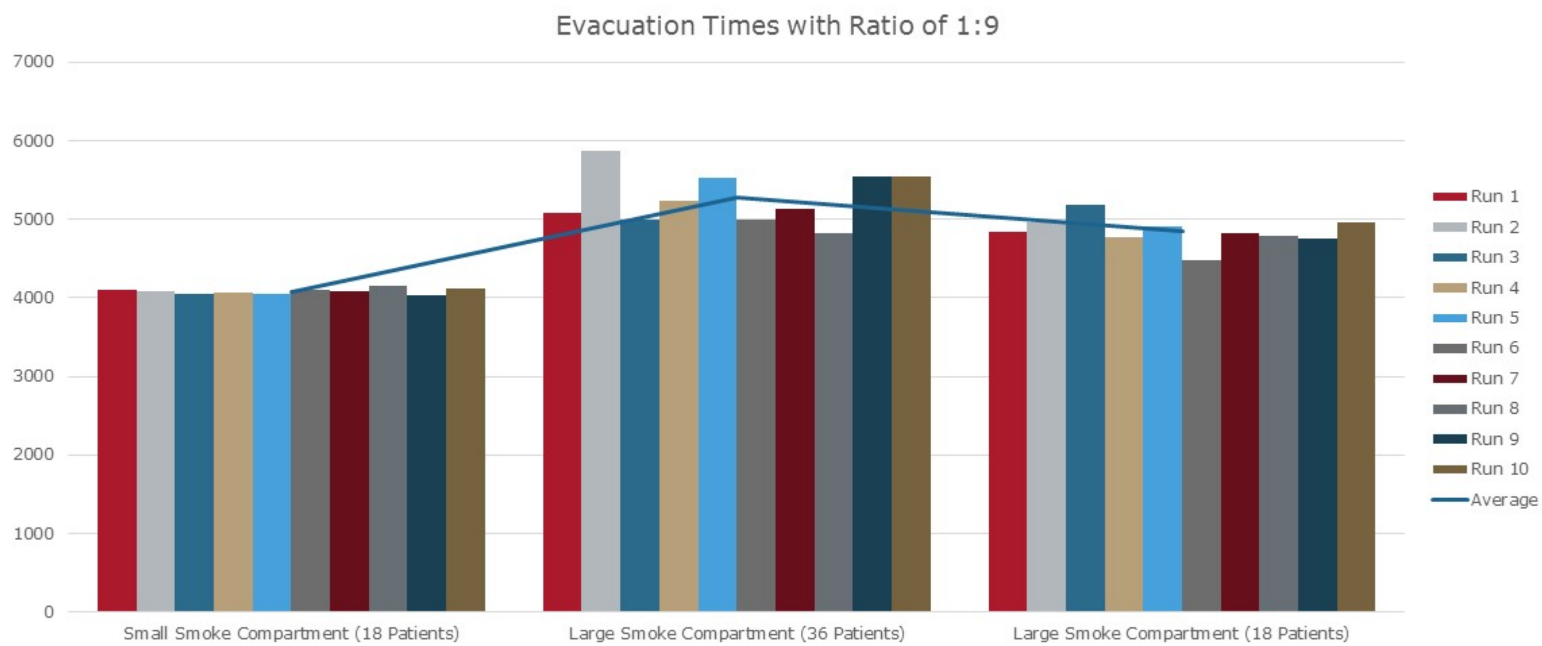
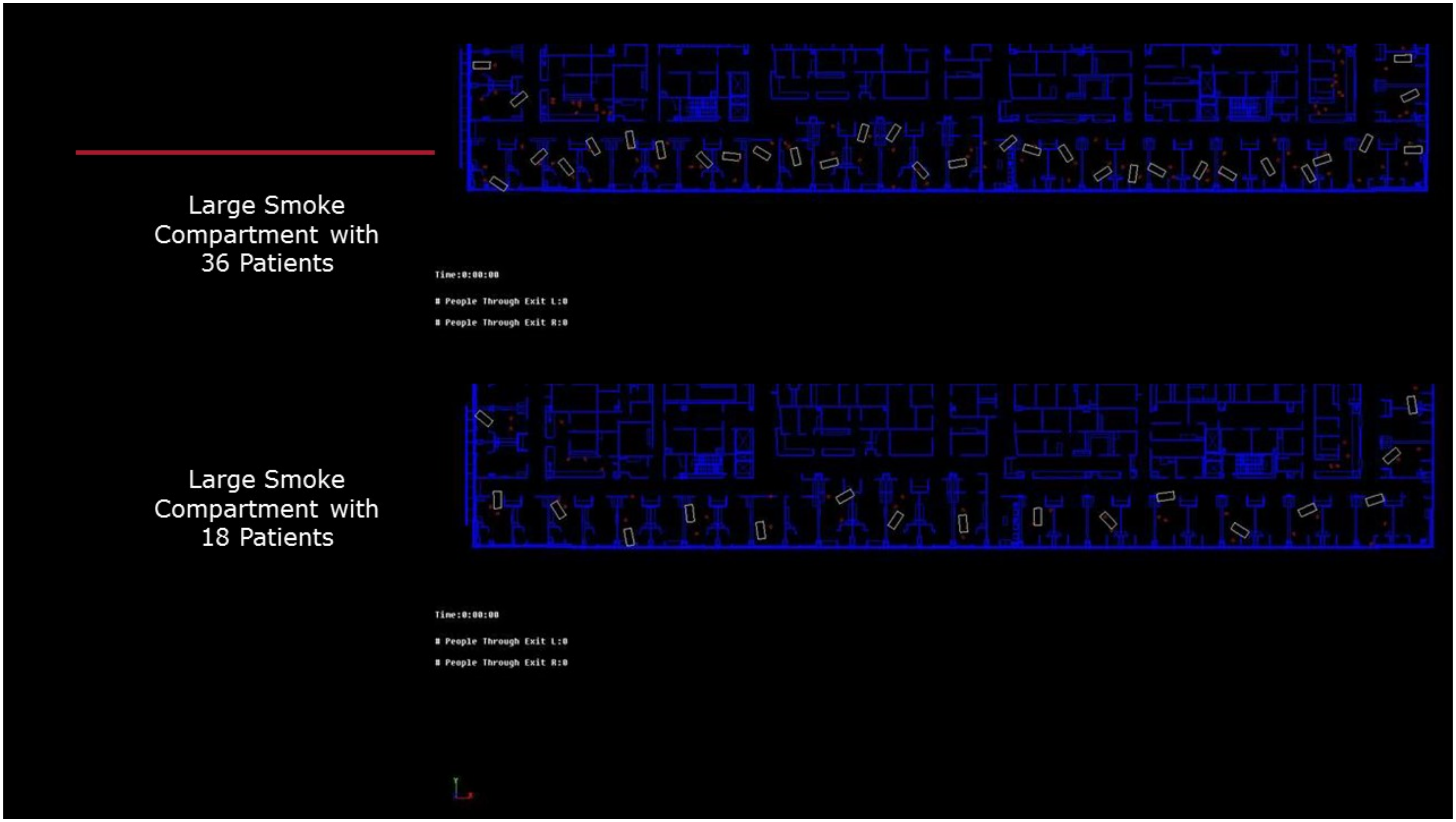
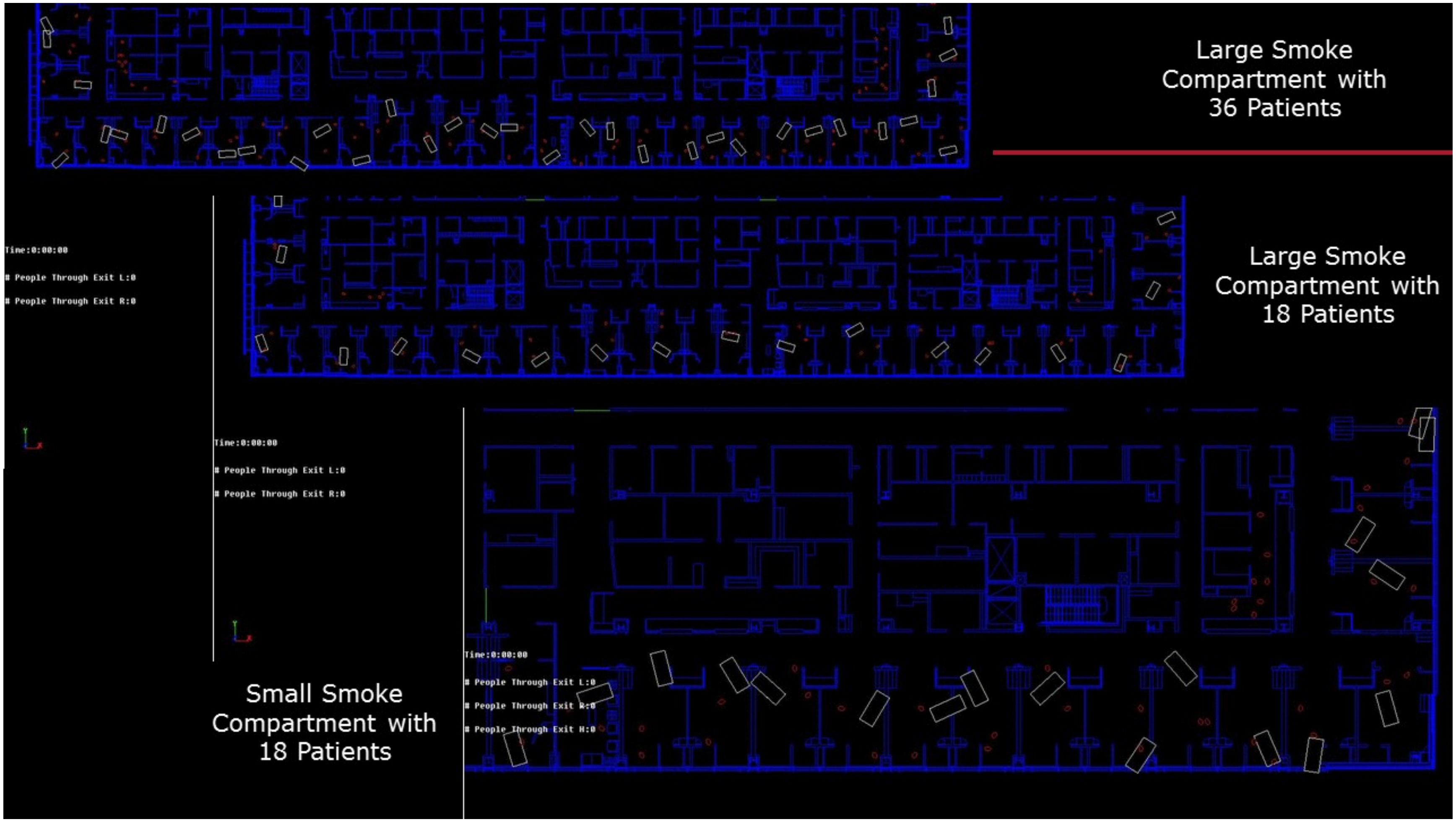
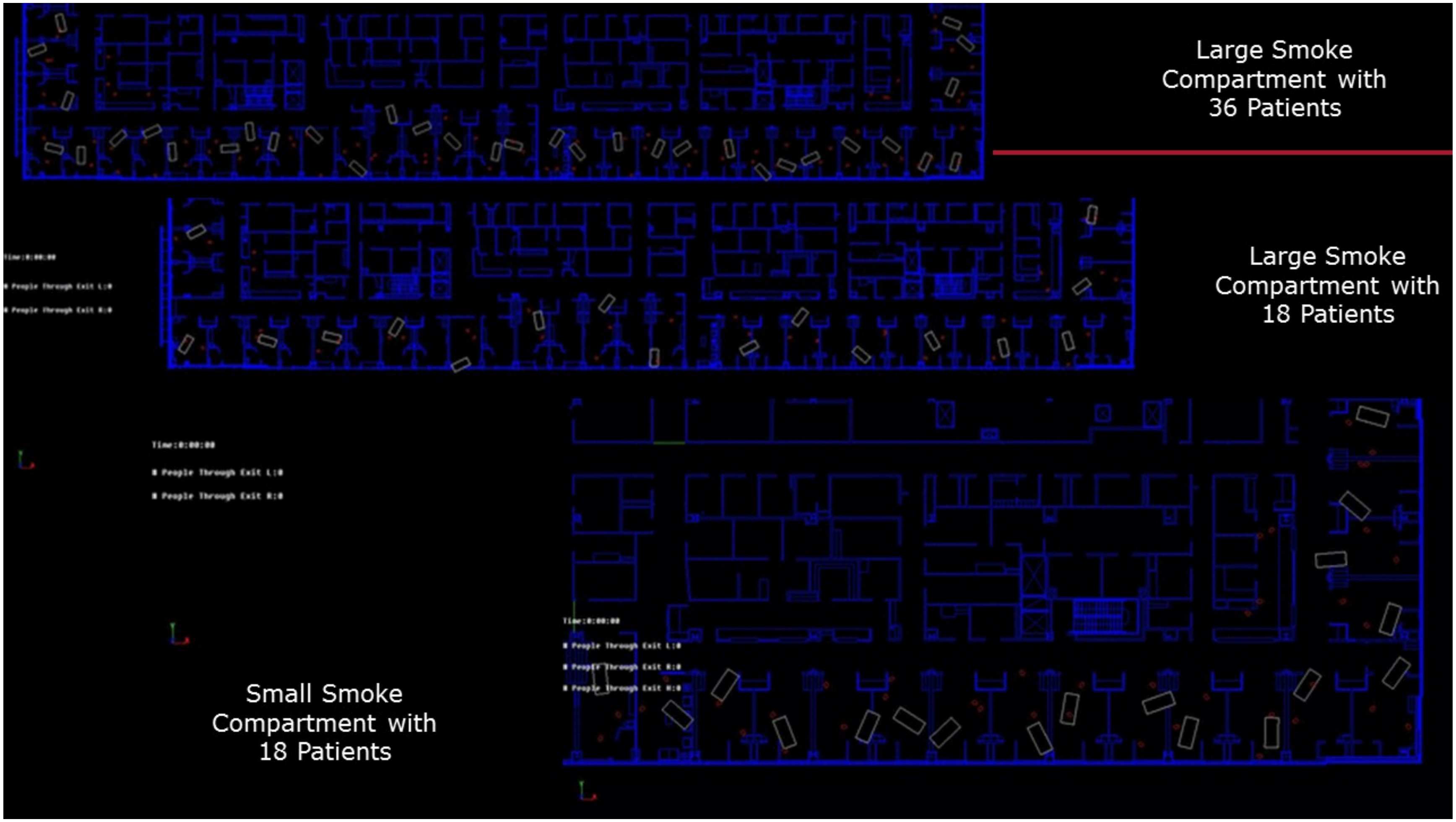

Evacuation Times with Ratio of 1:9
7000
6000
5000
4000
3000
2000
1000
0
Small Smoke Compartment (18 Patients)
Large Smoke Compartment (36 Patients)
Large Smoke Compartment (18 Patients)
Run 1
Run 2
Run 3
Run 4
Run 5
Run 6
Run 7
Run 8
Run 9
Run 10
Average


Large Smoke Compartment with 36 Patients
Time:0:00:00
People Through Exit L:0
People Through Exit R:0
Large Smoke Compartment with 18 Patients
Time:0:00:00
People Through Exit L:0
People Through Exit R:0


Large Smoke Compartment with 36 Patients
Large Smoke Compartment with 18 Patients
Small Smoke Compartment with 18 Patients
Time:0:00:00
People Through Exit L:0
People Through Exit R:0


Large Smoke Compartment with 36 Patients
Large Smoke Compartment with 18 Patients
Small Smoke Compartment with 18 Patients