TECHNICAL NOTES

Egress Modelling in Health Care Occupancies

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Keywords: egress modelling, health care occupancy, smoke compartment, means of egress

Abstract

A proposed change for the 2015 edition of NFPA 101, *Life Safety Code,* would increase the maximum allowable size of a smoke compartment in health-care occupancies from 22,500 ft^2 (2,090 m^2) to 40,000 ft^2 (3,700 m^2) – almost double the size (the maximum travel distance of 200 ft (61 m) to smoke barrier would remain the same).

This change could affect the evacuation/relocation of patients during an emergency in a health-care facility. In this work, the computational model STEPS is used for analysing different scenarios for sleeping areas in health care facilities. The results will provide input to the technical committee regarding the potential impact of this change.

1. Introduction

The proposed change in the size of smoke compartments for health care facilities (from 22,500 ft^2 to 40,000 ft^2) will lead to an increase in the number of patients inside that smoke compartment. It is important to understand how this may impact the relocation process in health care occupancies.

The relocation - or evacuation - procedure in a health care facility is complex and a well-defined strategy and an effective execution is necessary. It should be noted that most of the occupants in these environments are patients that are being treated for some illness and they are not capable to evacuate by themselves (self-evacuation). For this reason, the health care personnel have to be ready and trained to assist (assisted evacuation) the patients in their relocation to a another smoke compartment – or safe place.

It is well known that evacuation models are powerful tools to study the evacuation process in different scenarios and applications [1-5]. We can find several reviews [1, 3] that show the capabilities and limitations of these types of models. These reviews show that, apart from their use in the field of transportations (ships, aircraft and trains) [6-8], most of the egress models have been employed mainly for application to buildings. Apart from their possibilities, most of these models have been developed to consider the self-evacuation process instead of assisted evacuation.

Unfortunately, just a few resources have been found related to assisted evacuation in these scenarios. Golmohammadi and Shimshak performed one interesting study [9]. They showed an analytical approximation to analyse the horizontal and vertical evacuation time, considering three types of patients: Type 1 (ambulant patients), Type 2 (nonambulant patients who use wheelchair) and Type 3 (nonambulant patients who are moved in their beds). Assuming a defined strategy (the staff members know exactly who has to relocate/evacuate and in which order) and based upon some basic evacuation principles, this analytical model permits the user to consider the number and category of patients and the number of personnel and availability of the elevator. Another study simulated the evacuation process in a hospital using the model G-HES - Glasgow – Hospital Evacuation Simulator [10].

Although the modelling of this problem is scarce and limited, generally, it is agreed that it is necessary to differentiate between ambulant and nonambulant patients. Furthermore, all the patients have a preparation time that may depend on the type of illness or treatment. In some cases, this preparation time includes the processes to disconnect the patients from equipment, the movement of the patient from the bed to a wheelchair, stretcher or similar device or just other common pre-relocation activities such as getting dressed or gathering their belongings. It should be noted that the evacuation movement is also different in this kind of assisted evacuation or relocation.

In this case, the health care personnel will relocate the patients and in many cases they will transport them in wheelchairs, stretchers or other transportation devices. Currently, there is a lack of data related to these preparation times and transportation speeds. Just a few papers present some ranges and limited values for these parameters. For example, Hunt, Galea and Lawrence present in [11] a study undertaken to quantify the preparation time and transportation speed of trained hospital staff in evacuating people with reduced mobility using different assistance devices. Other works such as [12] and [13] show possible ranges and values for preparation times considering different types of patients for the sleeping areas.

The goal of the project was to analyse the impact of an increase in smoke compartment size on horizontal relocation of patients on a sleeping room floor in a health care facility.

Based upon preliminary input data and a dedicated calibration of the model inputs in STEPS for the specific scope of this project, diverse scenarios were selected and modelled considering the proposed change in the smoke compartment. Furthermore, since the number of health care personnel can significantly vary in the same scenario, different ratios of patients to health care personnel members were studied to show the impact of this parameter in the relocation process of patients in this kind of environment.

2. Description of the evacuation model

The evacuation model STEPS – Simulation of Transient Evacuation and Pedestrian movementS – version 5.1 (June 2012) from Mott MacDonald [14] has been used for this Project. STEPS is a behavioural model [1] that has the capability to implement random input variables for the pre-evacuation and/or preparation times and unimpeded and/or transport speeds based on probability distribution function.

STEPS permits the simulation of occupants in a normal or emergency situation within different types of buildings. Most current evacuation models, including STEPS, are mainly developed for simulating a self-evacuation process and they present several limitations for modelling an assisted evacuation process. The capabilities of STEPS in *normal conditions mode* permit the user to define task and routes for each occupant (patients and health care personnel) representing the transport of patients.

3. Occupant characteristics

For this study, we considered two types of occupants: health care personnel and patients. It should be noted that other kind of occupants could be found in this scenarios such as visitors, doctors, other staff, etc. For this study, we considered the worst-case scenario, the night time for sleeping areas when only health care personnel and patients are assumed to be in the area.

In any case, it would not be appropriate to model visitors and other transient occupants as part of the emergency relocation process.

3.1 Type of occupants

Health Care Personnel

These individuals will be responsible for assisting with the removal and the relocation of patients. The number of health care personnel may depend on the specific type of care provided by the hospital (or hospital floor). It can change depending on the use area (sleeping room / treatment room) or time of day. It should be noted that for this study we considered the worst-case scenario, the night time for sleeping rooms when the staff available for evacuation is presumed to be at the minimum.

Patients

Based on their ability to evacuate by themselves, we considered the following type of patients:

- Type 1 – Ambulant patient with reduced mobility.
- Type 2 - Nonambulant patients who need to be assisted using a wheelchair or similar device.

  Type 3 - Nonambulant patients who need to be assisted by using a stretcher, blanket or similar device and that may have to be moved using a blanket drag. It is assumed that this type of patient may include the patients connected to any medical equipment.

For the evacuation or relocation process, all the patients in the hospital were assumed to be assisted by health care personnel.

3.2 Main parameters

Apart from the corresponding scenario and its characteristics (location of exits, dimensions, number of personnel, travel distances to the exit, etc.), the assisted relocation process in a health care facility can be described by several parameters that define the behaviors and movement of each health care personnel:

- Pre-relocation time(t_{pre_S}). The time elapsed until each health care personnel member starts movement to relocate the patients. For this study, it was assumed that the personnel are already assembled in the corresponding smoke compartment and prepared for performing relocation processes.
- Preparation time(t_p). The required time for preparing the patient for relocation. This time depends on the type of preparation and the ability of the corresponding personnel to be ready to move the patients:
  - With no devices (ambulant patients)
  - Move to a wheelchair
  - Move to a stretcher
  - Move to a blanket
- Unimpeded walking speed(w_S). The walking speed of health care personnel moving toward a patient or returning to the next patient.
- Transportation speed (w_p). The walking speed of health care personnel while transporting the patient to another safe compartment or while walking with the patients (ambulant patients).

These parameters defined the behaviors of the personnel for performing the relocation process. Furthermore, based on his/her physical and psychological characteristics each member of the personnel will have his/her own pre-relocation time and unimpeded walking speed and the model employed a preparation time and transportation speed for each patient. It is well known that the evacuation process is a highly stochastic phenomenon [15, 16] due to the randomness of human behavior and the development of the emergency.

The most realistic manner to represent this randomness is by considering the behavioral parameters (Pre-relocation time, preparation time, unimpeded walking speed and transportation speed) as a random variable. This means that the parameters will be defined by density distribution law and statistical parameters. Currently, there is a lack of data regarding these behavioral parameters. However, in order to accomplish this analysis, Tables 1 and 2 show some values for the input parameters based on different available studies. (The references for the study are shown in the table.)

In general, the gathered data for preparation times for Type 1, 2 and 3 show a range of values. In order to use these parameters as random variables, it was assumed that they are normally distributed with a standard deviation of 3 sigma. Pre-relocation and preparation time, in contrast, is assumed to be log-normally distributed, with the mean and standard deviation shown in Table 1.

Category	Distribution law	Mean [s]	Sigma [s]	Range [s]
Health care personnel [9]	Log-normal	70.8	60	
Type 1 [7]	Normal	60	20	30-90
Type 2[7]	Normal	110	36	100-120
Type 3[7]	Normal	360	40	180-900

Table 1. Pre-relocation and preparation time for patients

	Distribution law	Mean [m/s]	Sigma [m/s]	Range [m/s]
Unimpeded speed for health care personnel members [10]	Normal	1.35	0.25	0.65- 2.05
Speed for ambulant patients with reduced mobility [10]	Uniform	1.12	0.28	0.84-1.40
Transportation speed for wheelchair [10]	Normal	0.63	0.04	
Transportation Speed for stretcher [10]	Normal	0.40	0.04	

Table 2. Unimpeded and transportation velocities for health care facilities

There is also a lack of data regarding the transportation speed for a blanket carry. However, it should be noted that for transportation using blankets, two health care personnel members per patient are needed for the relocating process; therefore, for evacuation modelling purposes these patients were considered as Type 3.

3.3 Evacuation priority

The evacuation process in a health care facility is a defined procedure established in the emergency plans of each hospital. In general, all areas or smoke compartments have a person in charge that will assign the responsibilities to each of the health care personnel in an emergency. Based on the corresponding number, types and location of patients each health care personnel member will relocate specific patients from their initial location (room) to a defined safe area.

For this study, it was assumed that at the point the responsible persons established the necessity of relocating the patients from the affected smoke compartment, the health care personnel were gathered in a common meeting area within the compartment to receive specific instruction (evacuation procedure or priority). The emergency plans of hospitals usually establish a "triage" for getting as many patients out as possible. The default priority in these situations may be assumed as:

- Patients in immediate danger (near the fire)
- Ambulant patients - Type 1
- Patients requiring some transport assistance (wheelchair) - Type 2
- Patients requiring transport assistance (stretcher/blanket) - Type 3
- Patients who are being treated and/or would be difficult to relocate/evacuate (i.e. ICU, obese or psychiatric). These types of patients were not considered for this study

This default priority was used as the relocation sequence for the modelling.

3.4 The application floor plan

As explained above, the aim of this study was to show the potential impact on the relocation/evacuation process of a health care facility of increasing the size of the smoke compartment. It should be noted that health care facilities are complex environments that combine different kinds of activities and areas in the same facility such as treatment areas, sleeping areas, administration areas, etc.

This report is focused on the analysis of varying the smoke compartment size in sleeping areas during night time, when, theoretically, the occupancy is higher and the number of health care personnel is limited. Several examples of actual health care floor plans were made available for this study and included different typologies of areas (treatment areas, sleeping areas, administrative areas, waiting areas, etc.). In order to create the smoke compartments that most closely represent the current area limit (22,500 ft^2) and the proposed limit (40,000 ft^2), one of the floor plans was adapted to obtain a hypothetical floor plan for a sleeping area.

The hypothetical floor plan for a sleeping area (see Figure 1) had a plus-shape with four smoke compartments of approximately 20,000 ft^2 (19,172 ft^2). Furthermore, this configuration maintained the 200 ft travel distance from the most remote point to an exit for each compartment. As Figure 1 shows, each of the smoke compartments in the middle section contained 18 rooms.

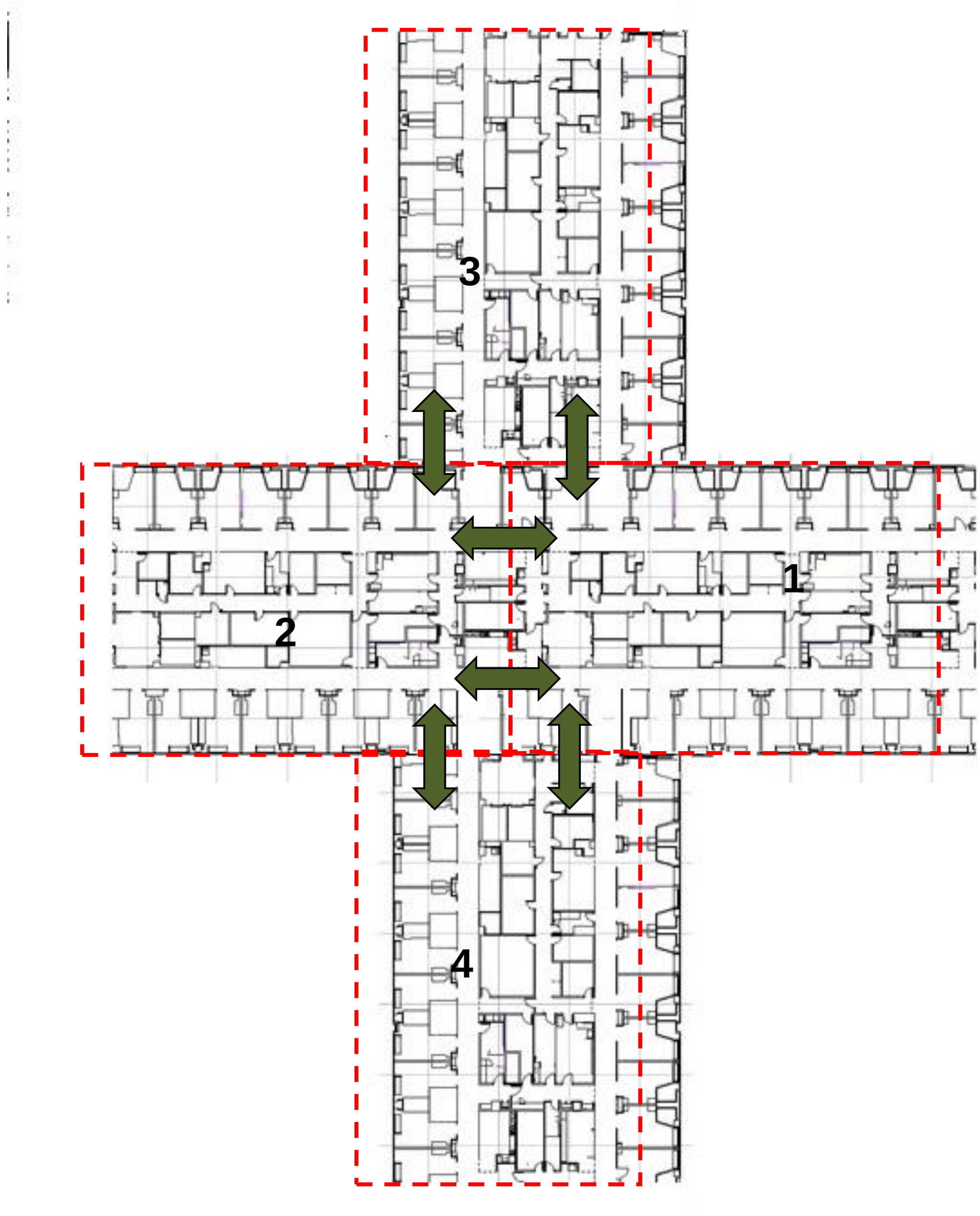

Figure 1. Layout of adapted sleeping area floor plan

To study the impact of increasing the size of the smoke compartment, the smoke barrier between compartments 1 and 2 was removed in order to consider these two areas as one large smoke compartment (39,424 ft^2). The following scenarios were considered.

Scenario 1

A fire situation in smoke compartment 1 leading to the relocation of patients to the adjacent smoke compartments (see Figure 2).

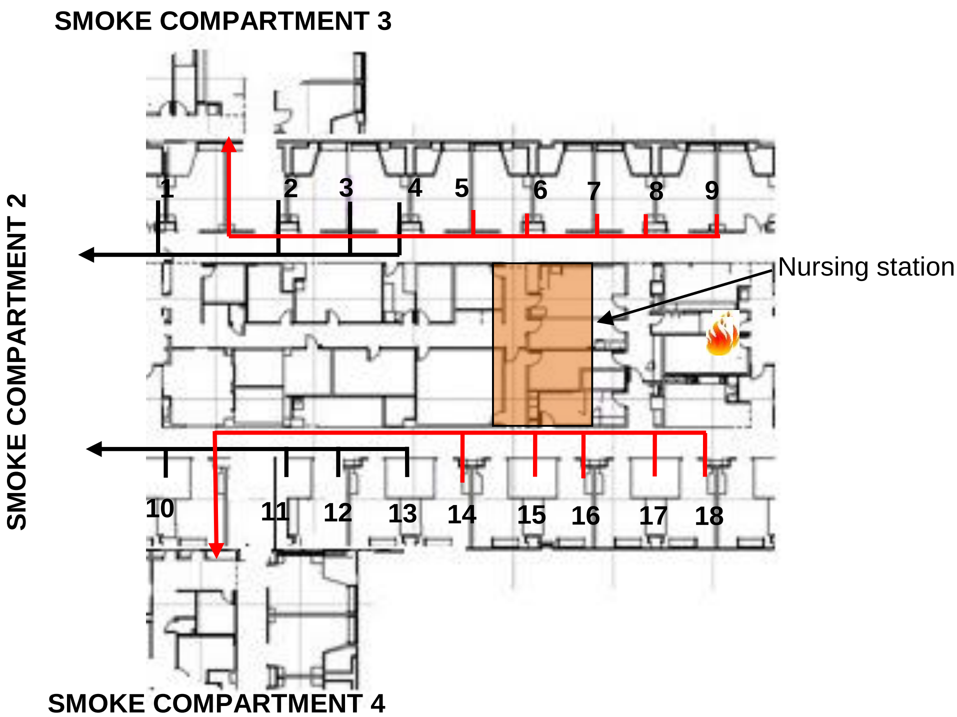

Figure 2. Layout of Scenario 1

The patients from the 18 rooms were relocated to the smoke compartments 2, 3 and 4. Furthermore, each side of the floor plan had two exits (at the same distance). It was assumed that the relocation of the patients were divided evenly into the adjacent areas causing a minimum impact in the other smoke compartments as follows:

- Patients from room 1 to room 4 were relocated to smoke compartment 2
- Patients from room 5 to room 9 were relocated to smoke compartment 3
- Patients from room 10 to room 13 were relocated to smoke compartment 2

- Patients from room 14 to room 18 were relocated to smoke compartment 4

In general, the rooms in health care facilities are single or double occupancy. For Scenario 1, the rooms 2, 6, 14 and 16 were considered as a double occupancy. This means that there were 22 patients inside the smoke compartment 1 (Scenario 1). Furthermore, it was assumed that 3 patients were Type 1, 4 patients were Type 2 and 15 patients were Type 3. It was not possible to know previously the distribution of patients in each room.

For this reason, the patients were randomly assigned to the room. To do this, a random generator software created a series of 22 numbers corresponding with the numbers of the room. It should be noted that numbers from 19 to 22 correspond with the double occupancy rooms. The numbers output from the random generator software established where the patients were located: the initial 3 numbers indicated the number of room for patients type 1, the following 4 corresponded with patients type 2, and the last 15 numbers corresponded with patients type 3. The established distribution of the patients can be seen below in Figure 3. This was input manually into STEPS. It should be noted that the location of patients will define the evacuation procedure (the order of patient´s evacuation). To reproduce the evacuation procedure, the defined evacuation routes should be implemented into the model manually by the user, for this reason the location of patients should be known before performing the simulations.

Figure 3. Distribution of patients in scenario 1

Different ratios of health care personnel were analyzed in order to show the impact of this parameter for assisted evacuation procedures. As it has been shown above, the type of patient defines the number of required personnel for their relocation (one or two) and in many cases two persons are required for preparation of patients although just one is required for his/her relocation.

For this reason, emergency groups formed by two health care personnel members were considered as follows (it is assumed that two staff members are required for relocating each patients):

- Scenario 1.1: 6 emergency groups (12 health care personnel).
- Scenario 1.2: 4 emergency groups (8 health care personnel).
- Scenario 1.3: 3 emergency groups (6 health care personnel).

Based on the number of emergency groups (EG) and the "triage", Table 3 shows the relocation procedure simulated for each scenario.

Scenario 1.1								
	Rooms							
EG 1	9	2 (T1)	5	2 (T3)				
EG 2	8	7	4					
EG 3	6 (T1)	6 (T3)	3	1				
EG 4	18	14 (T2)	16($T3_1$)	11				
EG 5	17	15	13	10				
EG 6	14 (T1)	16 ($T3_2$)						
Scenario 1.2								
	Rooms							
EG 1	9	2 (T1)	7	5	3	1		
EG 2	8	6 (T1)	6 (T3)	4	2 (T3)			
EG 3	18	14 (T1)	14 (T2)	16($T3_1$)	12	10		
EG 4	17	15	16($T3_2$)	13	11			
Scenario 1.3								
	Rooms							
EG 1	9	17	2 (T1)	7	6 (T3)	4	2 (T3)	1
EG 2	18	6 (T1)	15	16($T3_1$)	5	12	11	
EG 3	8	14 (T1)	14 (T2)	16($T3_2$)	13	3	10	
EG –Emergency Group, T1 – Type 1, T2 – Type 2, T3 – Type 3, Tx_1 and Tx_2 – patients from double occupancy rooms								

Table 3. Relocation process for Scenario 1

Scenario 2

For Scenario 2 the smoke barrier between smoke compartments 1 and 2 was removed considering a smoke compartment of 39,424 ft^2 (see Figure 4). A total of patients in 36 rooms had to be relocated to smoke compartments 3 and 4 through four exits.

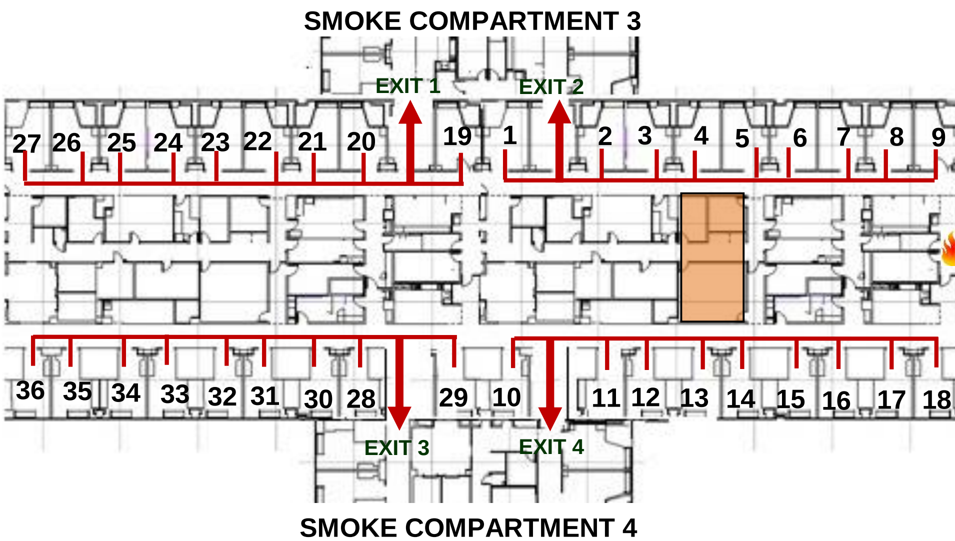

Figure 4. Layout of scenario 2

Considering the use of the nearest exit and that all the exits were available, the relocation procedure was:

- Room 1 to room 9 use the Exit 2 to the smoke compartment 3
- Rooms 19 to room 27 use the Exit 1 to smoke compartment 3
- Rooms 10 to room 18 use the Exit 4 to smoke compartment 4
- Rooms 28 to room 36 use the Exit 3 to smoke compartment 4

Figure 5. Distribution of patients in scenario 2

For Scenario 2, rooms 2, 6, 14, 16, 20, 24, 32 and 34 were considered as a double occupancy. This means that there were a total of 44 patients to relocate in the adjacent smoke compartments. In this case, it was assumed that there are 6 patients Type 1, 8 patients Type 2 and 30 patients Type 3. The patients were randomly distributed in the rooms generating a series of 44 number with a random number generator (see Figure 5). Similar to Scenario 1, for Scenario 2 different ratios of patients to health care personnel were simulated (it is assumed that two staff members are required for relocating each patient):

- Scenario 2.1: 12 EG (24 health care personnel)
- Scenario 2.2: 8 EG (16 health care personnel)
- Scenario 2.3: 6 EG (12 heath care personnel)

Scenario 2.1								
	Rooms							
EG 1	9	16 ($T3_1$)	11	25				
EG 2	18	16 ($T3_2$)	1	34 (T3)				
EG 3	17	6 (T3)	10	26				
EG 4	8	14 ($T3_1$)	19	35				
EG 5	31	14 ($T3_2$)	28	27				
EG 6	23	5	29	36				
EG 7	6 (T2)	4	21	20 (T3)				
EG 8	15	13	30	24 (T3)				
EG 9	20 (T2)	3	22					
EG 10	24 (T2)	12	32 ($T3_1$)					
EG 11	34 (T2)	2 ($T3_1$)	32 ($T3_2$)					
EG 12	7	2 ($T3_2$)	33					
Scenario 2.2								
	Rooms							
EG 1	9	20 (T2)	14 ($T3_2$)	11	30	26		
EG 2	18	24 (T2)	5	1	22	35		
EG 3	17	34	13	10	24 (T3)	27		
EG 4	8	7	4	19	32 ($T3_1$)	36		
EG 5	31	16 ($T3_1$)	3	28	32 ($T3_2$)			
EG 6	23	16 ($T3_2$)	12	20 (T3)	33			
EG 7	6 (T2)	6 (T3)	2 ($T3_1$)	29	25			
EG 8	15	14 ($T3_1$)	2 ($T3_2$)	21	34			
Scenario 2.3								
	Rooms							
EG 1	9	6 (T2)	16 ($T3_1$)	13	11	29	32 ($T3_2$)	27
EG 2	18	15	16 ($T3_2$)	4	1	21	33	36
EG 3	17	20 (T2)	6 (T3)	3	10	30	25	
EG 4	8	24 (T2)	14 ($T3_1$)	12	19	22	34	
EG 5	31	34	14 ($T3_2$)	2 ($T3_1$)	28	24 (T3)	26	
EG 6	23	7	5	2 ($T3_2$)	20 (T3)	32 ($T3_1$)	35	
EG –Emergency Group, T1 – Type 1, T2 – Type 2, T3 – Type 3, Tx_1 and Tx_2 – patients from double occupancy rooms								

Table 4. Relocation process for Scenario 2

Table 4 shows the relocation procedure for the different scenarios considering the number of emergency groups and the "triage". It is assumed that the staff members serve the whole compartment in Scenario 2.

4. Computational modelling

4.1 Introduction

This section/chapter presents the implementation of the inputs for the computational modelling of the defined scenarios with the STEPS model. STEPS permits the user to import CAD files (*.DXF) in order to build the geometry of the floor plan. The model represents the geometry by default as a fine network of 0.5 x 0.5 m (see Figure 6). Note that the size of the cell may impact on the results, however this discussion is out of this work [17].

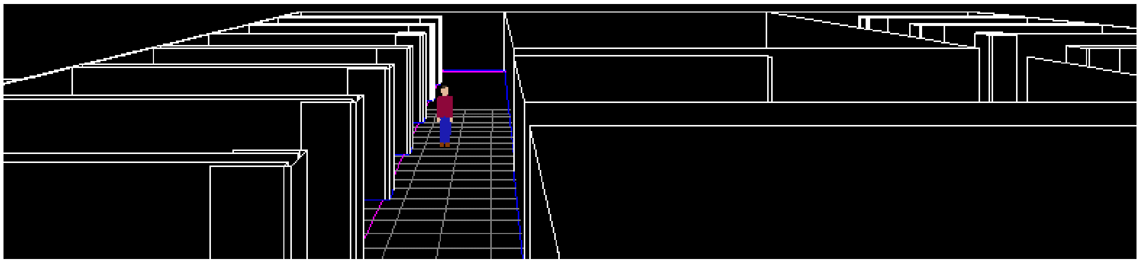

Figure 6. Geometry used in STEPS of a sleeping area in a health care facility

The model STEPS [14] in *normal conditions mode* permits the implementation of different tasks adjusted to routes and sub-routes for each occupant. These routes are based on the prefixed relocation procedures for each emergency group (Table 3 and 4).

It was simulated that each health care personnel member used the prefixed routes to reach the different checkpoints - rooms and final destination or other smoke compartment. The schema of relocation for each health care personnel member is shown in Figure 7.

As Figure 7 shows, the checkpoint 1 was the initial starting point, or the place where the health care personnel member goes to get the instruction (relocation procedure). Furthermore, each member has his own pre relocation time (t_{pre_S}) and unimpeded walking speed (w_s) – these parameters are generated by STEPS based upon the probability distribution functions and statistical parameters shown in tables 1 and 2.

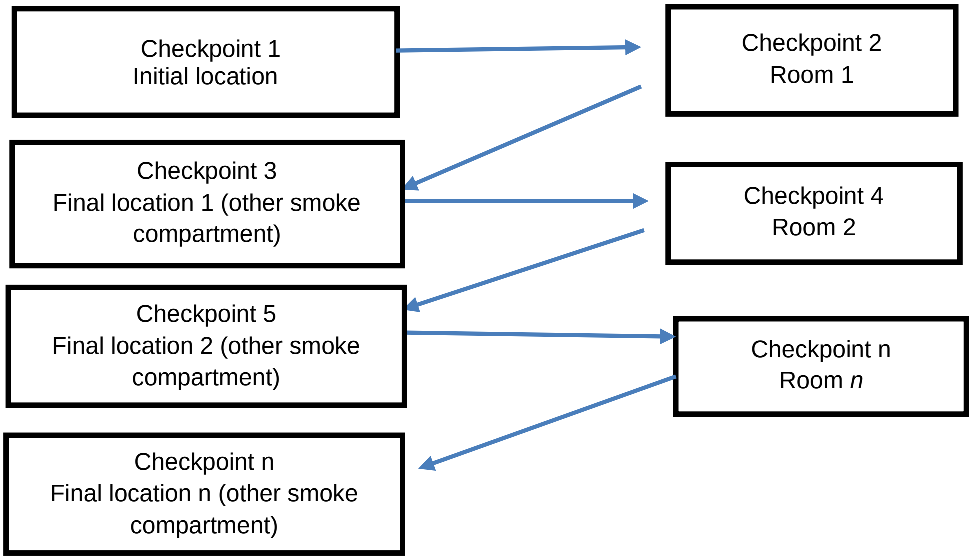

Figure 7. Schema for evacuating patients by using STEPS model

From the initial location (checkpoint 1), the health care personnel members used the defined routes to reach the corresponding locations/ rooms in the defined order.

The type of patient defined the random preparation time inside each room. After the preparation time $t_{pi}\big|_{i=1,..Room\ n}$, each health care personnel member transported the patient through the defined route. This route was assigned with a coefficient that decreased the unimpeded walking speed of the health care personnel member – the transportation walking speed could not be directly assigned to the routes. Based on data from Table 2, the following coefficients were obtained:

Type of patients	Coefficient
Type 1	0.83
Type 2	0.47
Type 3	0.30

Table 5. Coefficient assigned to the routes employed by each type of patients

4.1 Results

In order to obtain a significance sample of evacuation times, 100 simulations were run for each scenario. Furthermore, these samples were statistically treated in order to obtain the mean value and standard deviation. Likewise, 90th and 95th percentiles were obtained to show a most confidence values for evacuation/ relocation times.

4.1.1 Scenario 1

For Scenario 1.1, 22 patients were relocated and assisted by 6 emergency groups based on the evacuation procedure shown in Table 3. Table 6 shows the results for the evacuation times.

Mean (min)	Standard deviation (min)	Percentile 90th (min)	Percentile 95th(min)	Minimum (min)	Maximum (min)
30:13	02:25	33:24	34:32	20:10	37:16

Table 6. Results for Scenario 1.1

As Table 6 and histogram in Figure 8 shows, the mean evacuation time for Scenario 1.1 is 30:13 min. with a range between 20:10 min. and 37:16 min. Furthermore, in order to obtain results with a defined confidence level, the percentiles 95th and 90th show evacuation times of 34:32 min. and 33:24min.

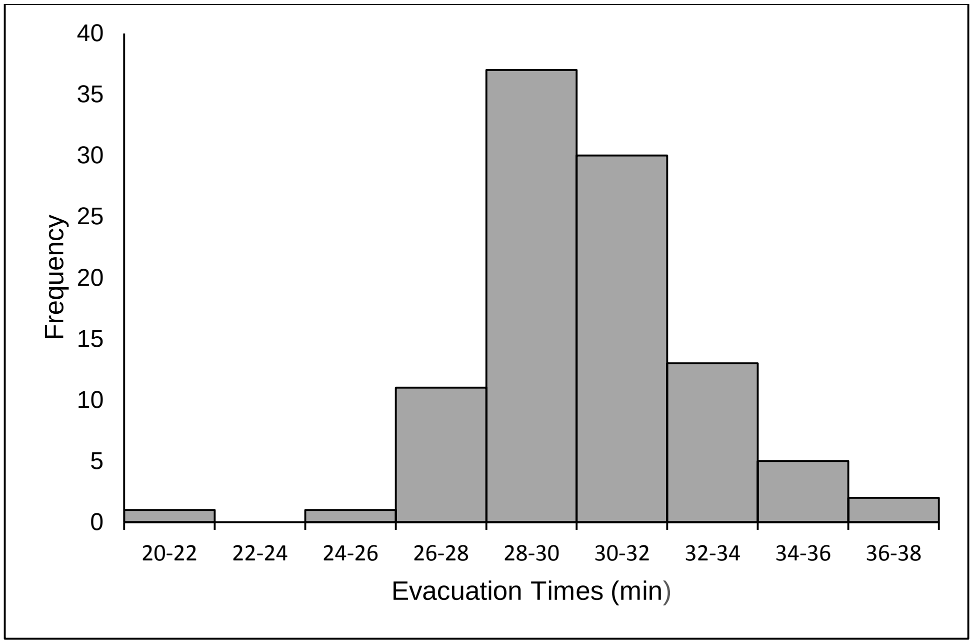

Figure 8. Histogram for Scenario 1.1

Table 7 and the corresponding histogram (Figure 9), show the relocation times for Scenario 1.2 where the 22 patients were relocated by 4 emergency groups. The mean evacuation time was 43:08 minutes with a 90th percentile of 46:13 min. and 95th percentile of 47:01 minutes.

Mean (min)	**Standard deviation (min)**	**Percentile 90th (min)**	**Percentile 95th(min)**	**Minimum (min)**	**Maximum (min)**
43:08	02:16	46:13	47:01	38:24	49:18

Table 7. Results for Scenario 1.2

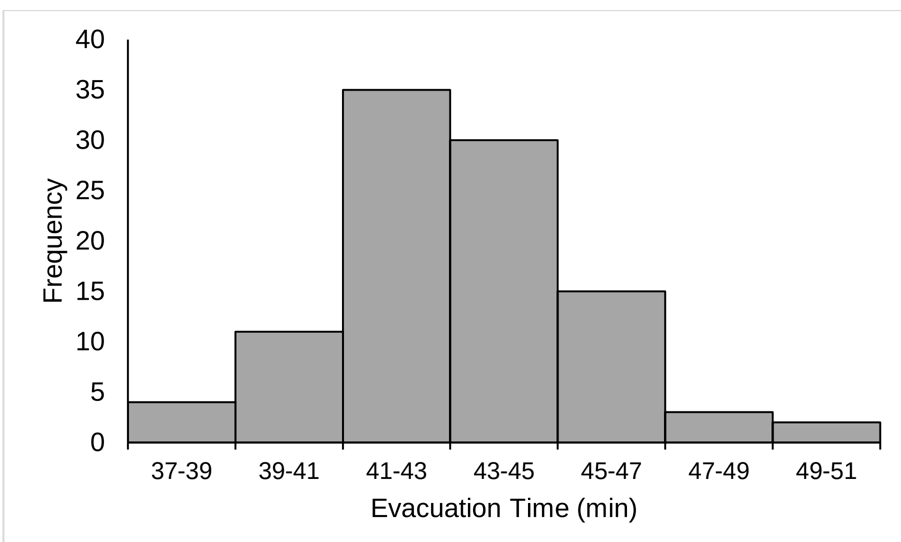

Figure 9. Histogram for Scenario 1.2

In scenario 1.3 (table 8 and figure 10), when the number of health care personnel is the lowest (3 emergency groups), the mean evacuation time is 59:34 with a 90th percentile of 65:04 min and a 95th percentile of 66:23 min.

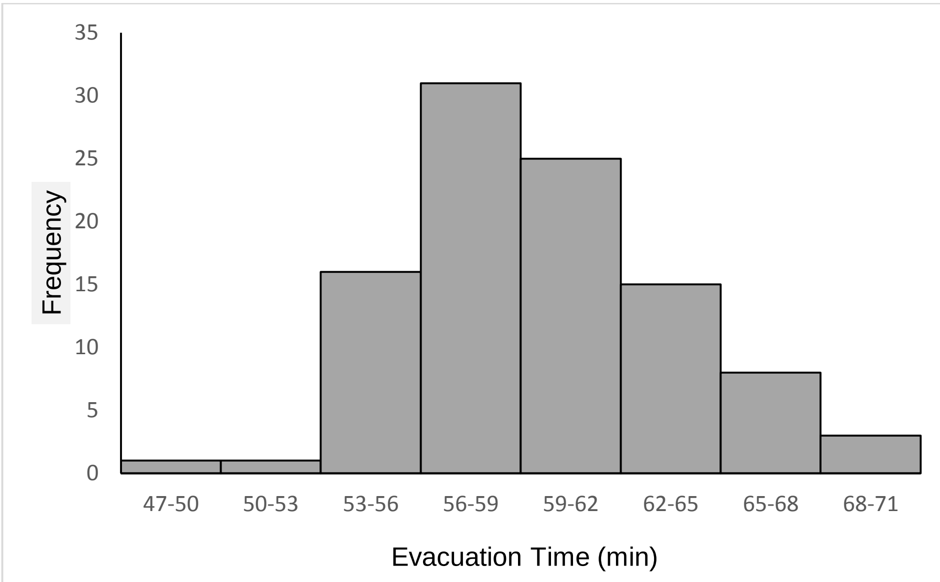

Figure 10. Histogram for scenario 1.3

Mean (min)	Standard deviation (min)	Percentile 90th (min)	Percentile 95th(min)	Minimum (min)	Maximum (min)
59:34	04:09	65:04	66:23	47:02	70:37

Table 8. Results for scenario 1.3

4.1.2 Scenario 2

In Scenario 2, the size of the smoke compartment has been increased to almost 40,000 ft^2 and there are 44 patients.

For Scenario 2.1, 12 emergency groups had to relocate the 44 patients to the smoke compartments 3 and 4. As Table 9 and the histogram in Figure 11 show, the mean evacuation time was 37:14 min. with a range of values between 31:43 min. and 44:08 min. Furthermore, in this case, the 90th and 95th percentiles were 40:21 min. and 40:39 min.

Mean (min)	Standard deviation (min)	Percentile 90th (min)	Percentile 95th(min)	Minimum (min)	Maximum (min)
37:14	02:21	40:21	40:39	31:43	44:08

Table 9. Results for Scenario 2.1

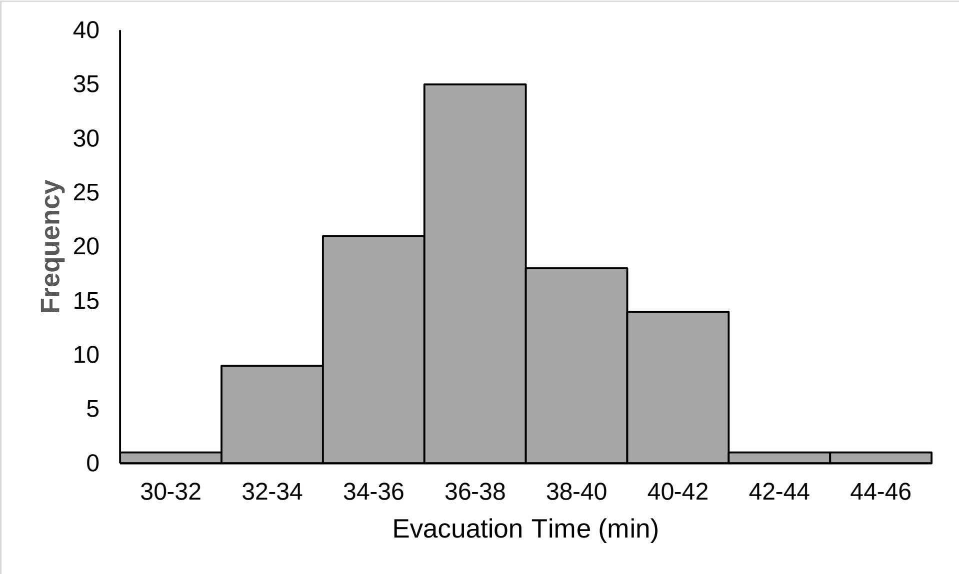

Figure 11. Histogram for Scenario 2.1

For Scenario 2.2 (Table 10 and Figure 12), the mean evacuation time for relocating the 44 patients by 8 EG was 49:31 min. Furthermore, the percentiles 90th and 95th of the evacuation time were 53:33 min and 54:47 min.

Mean (min)	Standard deviation (min)	Percentile 90th (min)	Percentile 95th(min)	Minimum (min)	Maximum (min)
49:31	02:51	53:33	54:47	43:46	57:08

Table 10. Results for Scenario 2.2

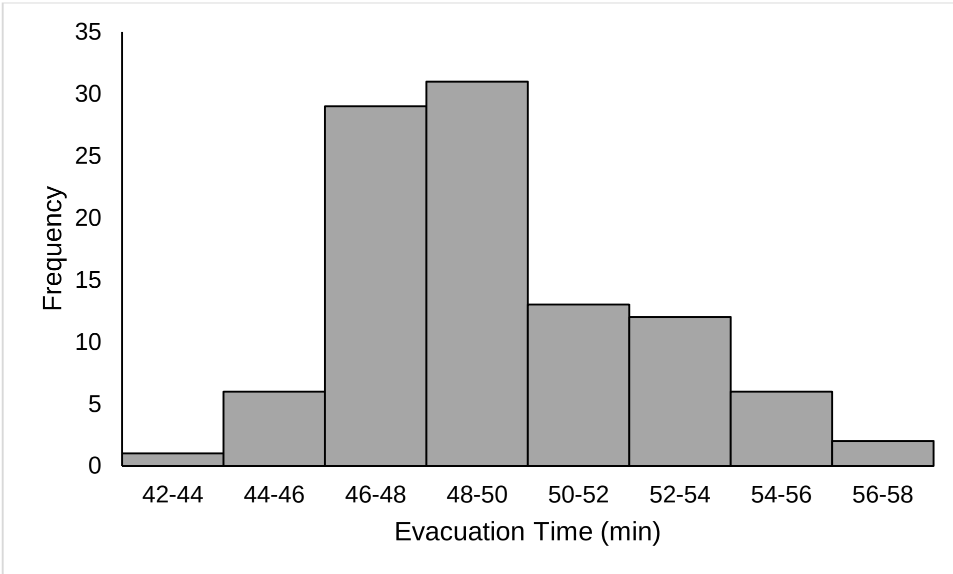

Figure 12. Histogram for Scenario 2.2

For the last Scenario 2.3 (Figure 13 and Table 11), 6 EG needed a mean evacuation time of 67:42 min. to relocate 44 patients. Furthermore, the 90th and 95th percentiles of the evacuation time are 72:39 min. and 76:59 min.

Mean (min)	Standard deviation (min)	Percentile 90th (min)	Percentile 95th(min)	Minimum (min)	Maximum (min)
67:42	04:37	72:39	76:59	59:42	83:40

Table 11. Results for Scenario 2.3

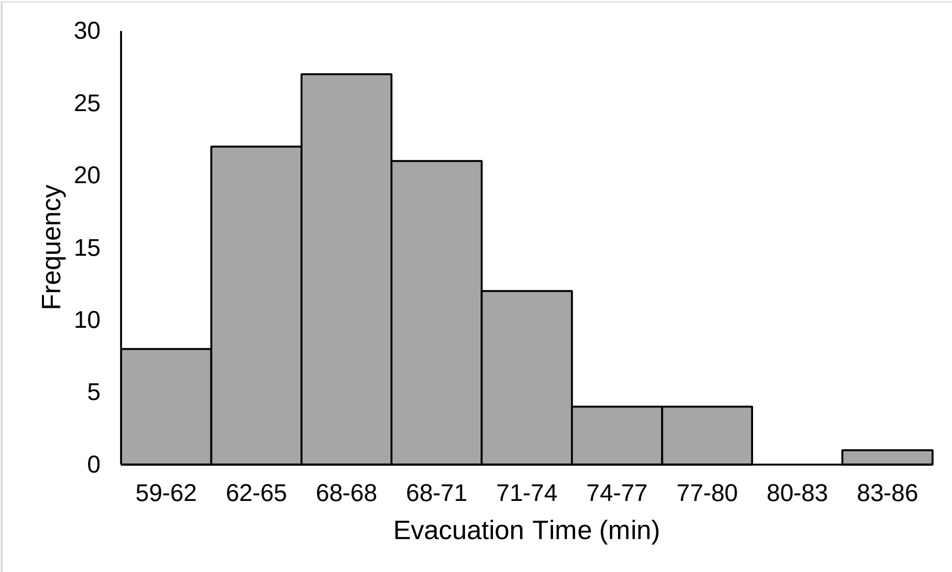

Figure 13. Histogram for Scenario 2.3

4.2 Discussion of results

Based on the modelling assumptions, the relocation times are summarized below in Table 12. The assumptions made included a random distribution of patients in each smoke compartment – distribution for Scenario 1 and 2 differed. Another assumption that was made was that the staff served all patients throughout the compartment, which led to longer travel distances for each staff member in Scenario 2 due to the larger compartment.

Scenario	Mean evacuation time (min)	90th percentile of the evacuation time (min)	95th percentile of the evacuation time (min)
1.1	30:13	33:24	34:32
2.1	37:14	40:21	40:39
1.2	43:08	46:13	47:01
2.2	49:31	53:33	54:47
1.3	59:34	65:04	66:23
2.3	67:42	72:39	76:59

Table 12. Comparison of evacuation times for all the scenarios

An interesting result obtained from this study was the high impact of the number of health care personnel in the relocation process. As Table 12 shows, for Scenario 1.1 (ratio 1:2) the mean evacuation times (30:13 min) decreased more than 12 minutes compared to scenario 1.2 (43:08

min) with a ratio 1:3 and more than 19 minutes for Scenario 1.3 (59:34 min.) with a ratio 1:4. These differences were similar for Scenario 2.

In this case, the mean evacuation time for Scenario 2.1 (37:14 min) decreased around 12 minutes compared to Scenario 2.2 (49:31 min) and up to 30 minutes for Scenario 2.3 (67:42 min).

As Table 12 shows, comparing the different sizes of the smoke compartments with equivalent ratios of patient/health care personnel (Scenario 1.1 - 2.1, 1.2 - 2.2 and Scenario 1.3 – 2.3) for sleeping areas, we can see that the mean evacuation times are up to 7 minutes longer – more than 23 %. (06:59 min. between scenarios 1.1 and 2.1, 06:23 min. between scenarios 1.2 and 2.2 and 8:08 min. for scenarios 1.3 and 2.3).

We can see that these differences were even bigger for the percentiles of evacuation times (more than 10 minutes between the 95^{th} percentiles of scenario 1.3 and 2.3). While the compartment size may play a role in this difference, the assumptions made during modelling may play a role as well including assumptions related to patient distribution and the area that each staff member served. Future work should consider these variables.

5. Future research

The development of this project has shown the necessity of further research regarding the assisted evacuation/relocation process. This would improve the understanding of this phenomenon, the effectiveness of the relocation strategies adopted to relocate patients during an emergency in a health care facility and its impact in the increase of the size of the smoke compartment in this kind of environment.

This work highlights the lack of actual data about the parameters that defines an assisted evacuation in a hospital. Future works should offer more reliable data about the preparation times and transportation speeds in this kind of scenarios. Experiments and drills would permit to collect and analyze these parameters in order to obtain the probability distribution function that defines these random variables.

The present work is focused on sleeping areas, it would also be necessary to analyze other types of areas within health care facilities such as treatment areas whose characteristics differ from the sleeping areas.

Another important issue is the limitation of the current models for assisted evacuation. The model STEPS permits the user to calibrate its inputs in order to overcome most of these limitations. However, some restrictions should be taken into account:

1- The number and category of patients, the evacuation procedures and the location per room have to be previously defined by user.
2- The relocation routes (from each room to the corresponding exit or smoke compartment) have to be previously defined by user.
3- The transportation speed is represented as a reduction of the walking speeds of the staff member not as a random variable itself.
4- STEPS does not reproduce the wheelchair / stretcher movement.

Further works should deal with these issues by including new modules to the current evacuation models or obtaining new models that permits to model an assisted evacuation process.

Any future work should consider the impact of the location of the patients on the relocation time as well as the impact of the staff service areas (i.e. if staff were limited to nursing station areas rather than serving a full smoke compartment).

6. Conclusions

The aim of this project was to study the impact of increasing the size of the smoke compartment in a health care facility and the impact of staff to patient ratios on the relocation process of patients. The evacuation or relocation process in these kind of scenarios is a complex phenomenon that needs a well-defined strategy and an effective deployment, especially in case of fire. This study was focused on the horizontal movement of the patients from the affected smoke compartment and assembling them in adjacent compartments. Furthermore, this work analysed the sleeping areas in a hospital during the night time, which was assumed to be worst case, considering all the rooms occupied and low ratios of patients/health care personnel.

The analysis of the different ratios of health care personnel assistance during an emergency showed that this is an important factor that can highly impact the evacuation procedure and the required times for relocation.

Based on the assumptions made during the analysis, including how patients were located and the service areas of the staff, results of evacuation modelling in a health care facility showed that changes to the parameters studied could have the potential to increase the evacuation time up to 8 minutes. As noted, this increase is affected by the distribution of patients in their rooms and the selected evacuation procedures, so these issues should be included in further study. As we can see in figure 5 and table 4, for Scenario 2 the distances traveled by the staff member during the relocation process may increase. For example in Scenario 2.1, the Emergency Group 1 relocates patients from rooms 9, 16, 11 and 25, once the EG has relocated the patients from room 11 to the adjacent smoke compartment, this EG has to travel a distances bigger than 200 ft. to reach the following patient located in room 25.

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