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The simulation of assisted evacuation in hospitals

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Abstract

Fire evacuation in hospitals is a challenging process that involves the evacuation of patients that are not able to evacuate by themselves and may require assistance. Health-care personnel is generally responsible for assisting the patients during this process. Assisted evacuation in a hospital relies on a pre-determined procedure that defines the priority of patients. The evacuation will depend upon the personnel actions and decisions during the procedure. Evacuation models are powerful tools to investigate evacuation strategies and they have been applied to different types of scenarios. Based upon the self-evacuation approach, the input variables typically used in different scenarios are pre-evacuation times, walking speeds, route selection and exit flows. However, hospitals involve different factors that may potentially affect the evacuation times such as the time to prepare, the evacuation priority (the assignment of the patients to each staff member) based on the protocol, the time to reach a patient, the time to prepare the patient before starting the evacuation movement or the time to move each patient. In addition, some of the existing models are capable of modelling wheelchair users; however in hospitals, non-ambulant patients may need to be assisted also by using a stretcher, blanket or similar device that may have to be moved using a blanket drag. This paper proposes a modelling strategy to simulate a hospital evacuation. The capabilities of two commercial evacuation models, STEPS and Pathfinder, are explored to evaluate their ability to simulate this type of scenarios. This includes the study of the issues concerning the simulation of horizontal hospital evacuation (i.e. calibration issues, capabilities and limitations). A case study is presented in this paper by using STEPS model.

1. Introduction

Fire evacuation in hospitals is a complex process that requires a well-defined strategy and an effective execution. The strategies generally involve evacuation assistance of those patients that are not able to evacuate by themselves.

Evacuation models are powerful tools that can be used to investigate evacuation strategies and they have been used for different scenarios [1], [2]. Different evacuation models reviews [3]–[5] show that these models were mostly developed for the assessment of building environments. However, their flexibility allows them to be adapted to other types of scenarios such as transportation environments (e.g., ships, aircrafts, trains, tunnels) [6]–[10] or even large scale evacuation [11], [12]. Apart from their capabilities, most of these models have been developed to consider the self-evacuation process instead of assisted evacuation. In fact, just a few studies can be found on assisted evacuation in these scenarios [13]–[16].

Despite the scarce and limited investigation of this problem, it is generally agreed that it is necessary to differ patients between ambulant and non-ambulant. All patients have a preparation time that may depend on the typology of illness or treatment.

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-evacuation activities such as get dressed or gathering belongings. The assisted evacuation is different to self-evacuation, where occupants are able to move. The health care personnel will relocate/assist 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. Only a few works present some ranges and limited values for these parameters. Hunt et al. presented in [15], [16] 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 [13], [14] showed possible ranges and values for preparation times considering different types of patients for the sleeping areas.

Even if the real data on hospital evacuation is very limited, it is important to explore if current models are capable to represent this process or if new or updated models are required. The goal of this paper is to explore the capabilities of two commercial evacuation simulation tools (STEPS [17] and Pathfinder [18]) by analysing the issues concerning the calibration of simulation of horizontal evacuation. A modelling strategy was proposed in order to adapt the evacuation models to the specific issues of hospital evacuation. In particular, STEPS and Pathfinder attributes were analysed to define their capabilities and limitations in the simulation of assisted evacuation. A case study was developed in order to apply the modelling strategy with STEPS. This application case is a hypothetical hospital floor plan for sleeping rooms. The ratio number of patients/number of staff members assisting a total of 22 patients has been investigated. This scenario has been chosen since it is representative of a typical floor plan of a hospital.

2. Occupant characteristics

To simulate the assisted evacuation process, the type of occupants that might be found in these kind of scenarios needs to be defined. Two types of occupants are considered, health care personnel and patients. Visitors, doctors and other staff might also be found in hospitals; however, these occupants are out of the scope of this paper since the focus is on the assisted evacuation procedure.

2.1 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 area usage (sleeping room / treatment room) or time of the day.

This paper is focused on the worst-case scenario, i.e., the night-time for sleeping rooms, when the staff available for evacuation is assumed to be at the minimum.

Patients

Based on the ability to evacuate by themselves, we can consider the following types of patients:

- Type (A) – Ambulant patient with reduced mobility.
- Type (B) – Non-ambulant patients who need to be assisted using a wheelchair.
- Type (C) – Non-ambulant patients who need to be assisted by using a stretcher, blanket or anything else and that may have to be moved using a blanket drag. It is assumed that this type of patients may include the patients connected to any medical equipment.

Based on the assumptions of the work presented in this paper, all patients in the hospital were requiring assistance by health care personnel.

2.2 Occupants characteristics

The assisted evacuation process in a health care facility can be described by several variables that define the behaviours and movement of each health care personnel:

- Pre-evacuation time (t_{pm_S}). The time elapsed until each health care personnel member starts the movement to relocate the patients. It was assumed that the personnel members are already assembled in the corresponding smoke compartment and prepared for performing relocation processes.
- Preparation time (t_p). The time required 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: 1) with no devices – ambulant patients- (Type (A) 2) to a wheelchair, (Type B) 3) to a stretcher (Type C) or 4) to a blanket (Type C).
- 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 personnel while transporting the patient to another safe compartment or while walking with the patients (ambulant patients).

The evacuation process is a highly stochastic phenomenon [19]–[21] due to the randomness of human behaviour and the possible developments of the emergency scenarios. For this reason, these variables are represented using pseudo-random sampling from distributions. There is a lack of data regarding these behavioural factors. However, in order to allow the case study to be conducted, Tables 1 and 2 show possible values for the input distributions based on different available studies [13], [14], [16]. The gathered data for preparation times for Type 1, 2 and 3 are represented as truncated normal distributions (i.e. a range of possible values is adopted). In order to obtain random values for these variables, it was assumed that they are normally distributed with a standard deviation of 3 sigma.

Table 1. Response and preparation time for patients.

Typology	Distribution law	Mean [s]	Sigma [s]	Range [s]
Health care personnel [13]	Log-normal	71	60	
Type 1 [14]	Normal	60	20	30-90
Type 2[14]	Normal	110	36	100-120
Type 3[14]	Normal	360	40	180-900

Table 2.Unimpeded and transportation velocities for health care facilities.

	Distribution law	Mean [m/s]	Sigma [m/s]	Range [m/s]
Unimpeded speed for health care personnel members [16]	Normal	1.35	0.25	0.65 - 2.05
Speed for ambulant patients with reduced mobility [16]	Uniform	1.12	0.28	0.84 - 1.40
Transportation speed for wheelchair [16]	Normal	0.63	0.04	
Transportation Speed for stretcher [16]	Normal	0.40	0.04	

There is also a lack of data regarding the transportation speed for a blanket carry. It is assumed that two health care personnel members per patient are needed for the transportation process using blankets; therefore, these patients were assumed to be equal to Type 3 for evacuation modelling purposes.

2.3 Evacuation priority in a health care facility

The evacuation process in a health care facility is a defined procedure established in the emergency plans of each hospital. All areas or smoke compartments have a person in charge that will assign the fixed procedure 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.

Once the responsible persons have established the need of evacuating or relocating the patients, it can be assumed that the health care personnel are gathered in a common meeting area in order to receive specific instructions (evacuation procedure or priority). The emergency plans from 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 (i.e., in the proximity of the fire)
- Ambulant patients - Type A
- Patients requiring some transport assistance (wheelchair) - Type B
- Patients requiring transport assistance (stretcher/blanket) - Type C

- Patients who are being treated and/or would be difficult to relocate/evacuate (i.e. ICU, bariatric). These patients might require specific procedures due to the complexity and severity of their situation and they are out of the scope of this paper.

3. Model strategy for an assisted evacuation

The health care facilities are complex scenarios where occupants may require to be assisted to conduct an evacuation. Most of the current models are mainly designed for self-evacuation. This means that occupants can evacuate by themselves without requiring third parties help. How to model or calibrate a model for simulating assisted evacuation depends on the model and the level of understanding of the process. This paper presents a calibration method that can be applied for mimicking assisted hospital evacuation.

Although it might be not the only possible method, this approach has been applied successfully by the National Fire Protection Association in the US (NFPA) for analysing the impact of increasing the size of smoke compartment in health care facilities [22]. The use of alternative calibration methods are out of the scope of this paper. In addition, the following sections analyse the capabilities of STEPS and Pathfinder to simulate the evacuation process by using the proposed calibration method.

This paper proposes the following steps for mimicking the assisted evacuation in hospitals by using computer evacuation models which are focused on self-evacuation.

1- Evacuation simulation starts with all the personnel gathered in an initial point (i.e. nursering station). This point is assumed as the area where the personnel will receive the information about the evacuation procedures: which patients to be assisted and the evacuation order.
2- At least two personnel members will assist each patient (emergency groups). This will be represented in the model as one sole agent moving towards a patients or returning to the next patient.
3- Each agent (emergency group) has his/her own Pre-evacuation time, before starts its movement towards the patients’ rooms from the initial location.
4- Each agent has his/her own unimpeded walking speeds towards a patient or returning to the next patient.
5- The agent will wait in the room a time equivalent to the preparation time. This represents the time required for preparing the patient before starting the relocation process.
6- After the preparation time, the agent will start the evacuation movement with a walking speed similar to the transportation time. This step aims at mimicking the transportation process of patients.
7- Once the agent has reached the area considered as a safe place (i.e. another smoke compartment), the agent will move towards the next patient with his/her unimpeded walking speed.

Steps 3 to 7 will be repeated until each agent (emergency group) has completed their defined evacuation procedure.

3.1 Application of STEPS model for hospitals

STEPS [17] is a model developed by Mott MacDonald. It is a movement/partial behaviour model. It is an agent-based model in which the path to the exit is calculated through a grid. The model assumes that each occupant occupies one grid cell (05x05m by default). Based on this approach and as the initial purpose of the model was to simulate different types of buildings, STEPS does not present any relevant limitation for representing a hospital.

3.1.1 Build the human scenario

- Occupant behaviour
  Each agent moving within the scenario has certain attributes assigned with the aim of representing behaviours such as awareness of the modelled building, patience levels in a queue, association to other members of a group and pre-evacuation time. Regarding the calibration methodology for hospitals, the pre-evacuation time corresponds to t_{pm_S}. Note that this pre-evacuation time is the time elapsed before starts the evacuation movement so that it can be only assigned once during the simulations (the other attributes are not relevant in the proposed methodology). In order to represent the preparation times with STEPS, the user needs to implement a *delay point* within each room equals to the corresponding preparation time.

- Occupant movement.
  Based upon the proposed calibration methodology, only the health care personnel movement has to be simulated with STEPS. The following aspects are to be considered:

  - Wayfinding or assisted evacuation routes. The evacuation priority at hospitals is pre-defined before starting the evacuation process. This means that each agent (emergency group) knows which rooms they need to evacuate and the evacuation order. With STEPS, the user can implement different checkpoints in order to define the initial and final points, representing the evacuation order. In addition, during the evacuation, each agent will travel between checkpoints through the defined route (those routes cannot be randomly defined). Note that in this calibration method, the simulation will finish when the last agent has reached the final point after visiting all the checkpoints.
  - Walking speed. Two types of walking speeds needs to be modelled in hospital evacuation, unimpeded walking speeds and transportation speeds. STEPS allows the user to define each individual unimpeded walking speed as a pseudo-random number obtained from a distribution w_S. The user cannot define different walking speeds to each agent, i.e., the unimpeded walking speed is assigned to each individual at the beginning of the simulation. To represent the transportation walking speed, a predefined route is defined for each agent with a decreasing coefficient $k_{i.}$ assigned in order to reduce the unimpeded walking speed on that route. This was obtained by doing backwards calculations on the path length and the transportation speeds for each type of patient. The coefficients in Table 3 aim at representing the transportation velocities for each type of patients (Table 2).

Table 3. Coefficient assigned to the routes employed by each type of patients.

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

3.1.2 Calibration method for STEPS model

Based upon the key elements described above, Figure 1 summarizes the calibrated method for simulating evacuation procedures at hospitals for each emergency group/agent within STEPS.

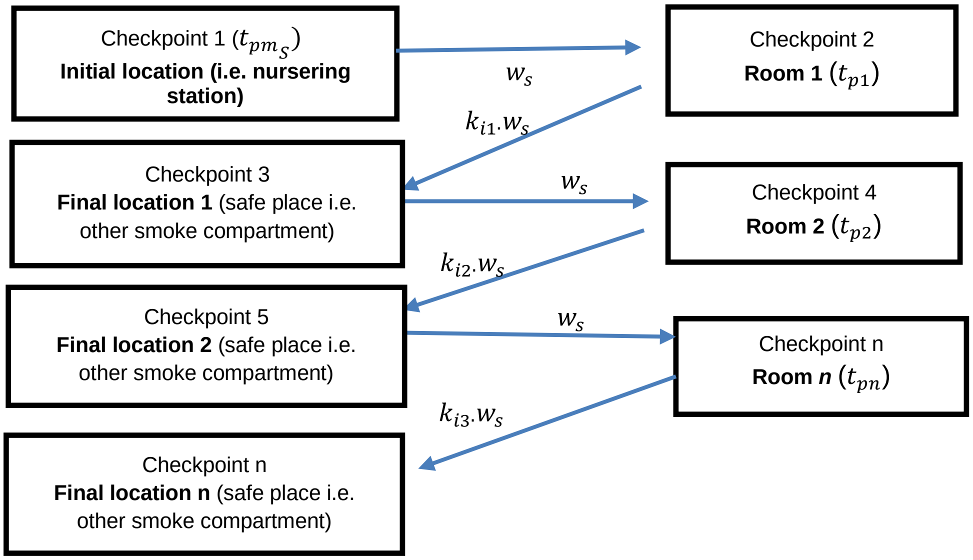

Figure 1. Calibration method proposed for horizontal evacuation process of patients at hospitals by using STEPS model

The checkpoint 1 was the initial starting point, or the place where the health care personnel member goes to get the instruction about the relocation procedure (i.e. nursering station). Each member has his own pre-evacuation time (t_{pm_S}) and unimpeded walking speed (w_s). From the initial point, the health care personnel members walk through the first room that is defined by the evacuation procedure. In the room, a random preparation time $t_{pi}\big|_{i=1,..Room\ n}$ is required, to get the patient ready for the relocation to the other smoke compartment and it is represented in the model as a delay point at the room. During the evacuation of patients, each health care personnel member transported the patient through the defined route. These routes are assigned with a decreasing coefficient $k_{i.}$ in order to reduce the unimpeded walking speed of the health care personnel in that route. Once the emergency group has reached the final location for each patients, they will travel through the next checkpoint (room) with their unimpeded walking speeds.

3.2 Application of Pathfinder model

Pathfinder 2016 [18] is a movement/partial behaviour model developed by Thunderhead Engineering. Occupants are represented in horizontal floors as circles moving inside a continuous 2D space represented by adjacent triangular navigation meshes.

Based on this approach, Pathfinder allows the user to create any building or directly import complex geometries from CAD drawings so that it does not present any relevant limitation in the representation of a hospital geometric configuration.

3.2.1 Build the human scenario

Pathfinder defines two sets of variables related to human actions and decisions: Occupant profile and occupant behaviours. Those variables need to be calibrated in order to simulate the assisted evacuation at hospitals.

- Occupant profile. This is used to control the occupant speed, size and visual distributions. Other preferences can be defined such as the use of stairs, ignore one-way door restrictions, and walk on escalators. Regarding hospital evacuation, the profile allows the user to establish the unimpeded walking speed of each agent (or emergency group) as a pseudo-random variable obtained from a distribution.

  On horizontal evacuation, the unimpeded walking speed in Pathfinder is affected during the evacuation process by occupant's density (number of people/m^2) and/or by the geometry (use of stairs or ramps), obstacles, etc. In the proposed calibration method, the simulation of the transportation speed would require to manually decrease the walking speed in certain areas over time using the *Speed Modifier* function of the model.

- Occupant behaviours. Pathfinder allows the user to define the behaviours that will be applied to the agents. An initial delay can be applied to agents representing the t_{pm_S} at hospitals. On the top of that, pathfinder has the capability to define a pre-defined route (representing the evacuation priority of patients for each agent) by using *GoToRoom* option at each room. In order to simulate the preparation time, after defining each *GoToRoom* point, a *wait* option can define a delay time in each room.

Pathfinder considers that a simulation has finished when all the agents have used the final exit. A *GoToWay* can be defined close to the final exit in order to represent this as the final location for patients. In addition, when the agent (emergency group) goes to the last room, the final location is considered as the final exit and the simulation will finish.

3.2.2 Calibration method for Pathfinder model

Figure 2 summarizes the calibrated method for simulating the evacuation procedure at hospitals for each emergency group/agent with Pathfinder.

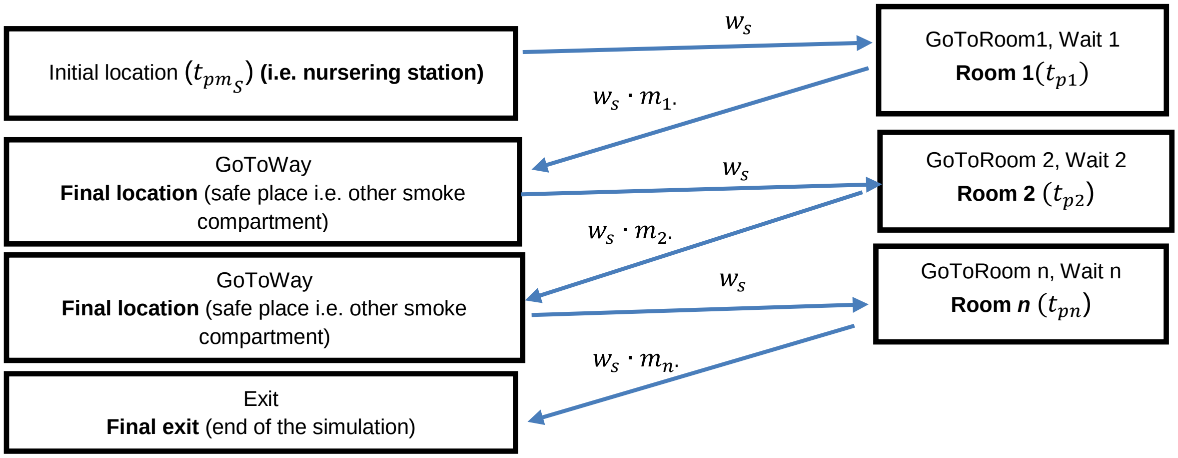

Figure 2. Calibration method proposed for horizontal evacuation process of patients at hospitals by using Pathfinder model.

The initial location is the starting point considered as the place where the health care personnel member goes to get the instructions about the relocation procedure (i.e. nursering station). Each member has his/her own pre-evacuation time (t_{pm_S}) and unimpeded walking speed (w_s). From that initial point, the emergency group (agent) go to first room (GoToRoom 1) that is defined by the evacuation procedure.

In the room, a random preparation time $t_{pi}\big|_{i=1,..Room\ n}$ is obtained from a distribution (wait 1), to get the patient ready for the assisted evacuation. After that, the agent will walk through the final destination (i.e. a place of relative safety defined as GoToWay) with a transportation speed (adapted using the speed modifier m_i).

Once the final destination is reached, the agent will travel through the next goal defined in the evacuation priority (GoToRoom 2). The simulation finishes when the agent has visited the last room defined by their evacuation priority and then has left the hospital using the final exit.

4. Model case study

In order to explore the predictive capabilities of evacuation models for hospitals, the calibration method with STEPS has been used for simulating the horizontal evacuation process in a hypothetical hospital floor plant for a sleeping area.

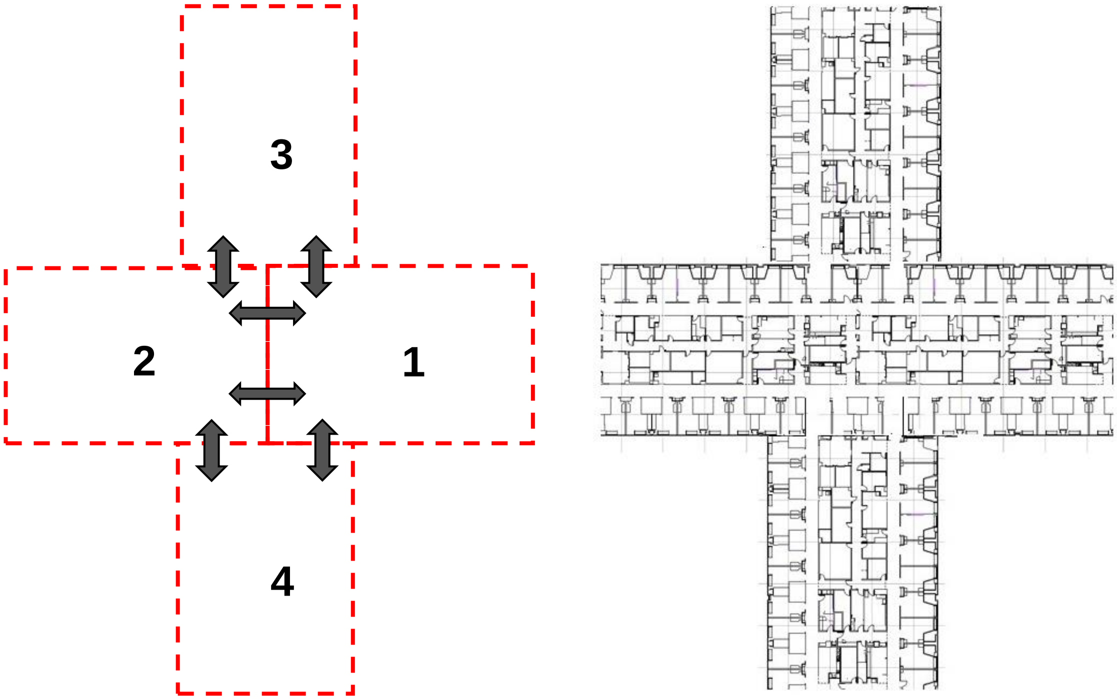

Figure 3. Layout of adapted sleeping area floor plan.

The application floor plan is extracted from [22] a project whose aim is to analyse the impact of increasing the smoke compartment from the current limit (22,500 ft^2) to almost double (40,000 ft^2). This study was conducted to evaluate a change in NFPA 101 2015 by simulating the assisted evacuation with STEPS. 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). This configuration maintained the 61 m (200 ft) travel distance from the most remote point to an exit. Each of the smoke compartments in the middle section contained 18 rooms.

4.1 Scenario

The evacuation scenario assumes a fire in smoke compartment 1 leading to the evacuation of patients to the adjacent smoke compartment (see figure 3). Different ratios of health care personnel were analysed in order to show the impact of this variable on the assisted evacuation procedures. The patients from the 18 rooms were evacuated 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 evacuation of the patients were divided evenly into the other 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 15 to room 18 were relocated to smoke compartment 4

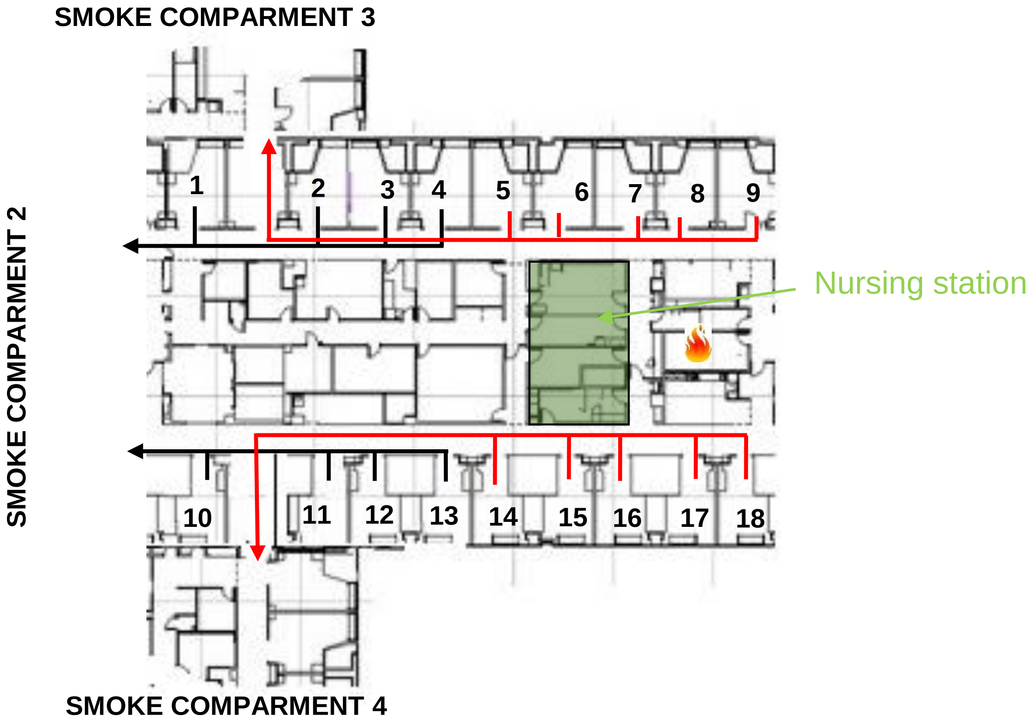

Figure 4. Layout of Scenario 1.

Single or double occupancy rooms are available in the hospital. For the case study, the rooms 2, 6, 14 and 16 were considered as a double occupancy so that a total of 22 patients are located in 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; thus, they were randomly assigned to the rooms (see Figure 3).

Preliminary inputs for t_{pm_S}, w_S and t_p are extracted from table 1 and table 2. In addition, decreasing coefficients shown in table 3 are used in the corresponding routes in order to represent the transportation speed w_p.

The type of patient considers the number of required personnel for their relocation (one or two). In addition, in many cases two persons are required for the 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:

- 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).

Figure 5. Distribution of patients in scenario 1.

Table 4 shows the relocation procedure simulated for each scenario. The nursing station is assumed as the common meeting area where the evacuation procedure is assigned.

Table 4. Relocation process of patients for Scenario 1.

		Rooms							
Scenario 1	**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 2									
	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 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	

4.2 Analysis and results

A total of 100 simulations were run for each scenario in order to consider the variability caused by the use of distributions. Other methods might have been used to assess the optimal number of repeated simulations [20]. The sample of total evacuation times was statistically treated in order to obtain the mean value and standard deviation.

Likewise, 90th and 95th percentiles were obtained in order to show confidence values for the evacuation times. Table 5 shows the results for the total evacuation time in scenarios 1 and 2.

Table 5. Results of the mean, 90th percentile and 95th percentile evacuation times for scenarios 1 and 2.

Scenario	**Mean evacuation time (min)**	**Standard deviation (min)**	**90th percentile of the evacuation time (min)**	**95th percentile of the evacuation time (min)**
1	30:13	02:25	33:24	34:32
2	43:08	02:16	46:13	47:01
3	59:34	04:09	65:04	66:23

Table 6 shows the high impact of the number of health care personnel in the assisted evacuation process. In Scenario 1 with a ratio 1:2 (30:13) the mean evacuation times decreased more than 12 minutes compared to scenario 2 (43:08 min) with a ratio 1:3 and more than 29 minutes for Scenario 3 (59:34 min.).

5. Discussion

This study provides an overview on how to calibrate evacuation models for assisted evacuation in hospitals. Two types of occupants are identified in an assisted evacuation, patients and health care personnel who are responsible for assisting those patients in case of a fire evacuation. Health care personnel are responsible for assisting the patients in case of a fire evacuation based on a predefined evacuation priority (usually a “triage”). This paper identifies the key parameters that defines the behaviour and movement of each staff member during the assisted evacuation.

Part of these parameters such as the Pre-evacuation time and unimpeded walking speed, are inherent to the health care personnel. However, the preparation time and transportation speed depends on the type of patients to assist. Based upon a number of research works [13], [14], this paper proposes a set of preliminary input values for the assisted evacuation parameters.

Current evacuation models are mainly developed for simulating self-evacuation processes. However their flexibility might allow the user to calibrate them in order to mimic other scenarios (i.e. assisted evacuation) apart from those they were developed for. A model strategy for an assisted evacuation in hospitals is proposed in this paper.

Although it might not be the only possible strategy, this proposal covers the key elements of an assisted evacuation (occupant characteristics and the required evacuation priority). Based upon the proposed strategy, this paper analyses the capabilities of two commercial models, STEPS and Pathfinder, for the simulation of horizontal evacuation in hospitals.

The following table 6 presents which elements of modelling can be directly modelled, calibrated or cannot be represented by STEPS and Pathfinder under the proposed modelling strategy.

Table 6. Analysis of the key parameters used for modelling an assisted evacuation in hospitals under the proposed strategy.

	STEPS			**Pathfinder***		
	Directly modelled ?	Calibrated ?	Additional information	Directly modelled ?	Calibrated ?	Additional information
Geometry	YES	-	Limitations of fine network models	YES	-	
Pre-evacuation time	YES	-		YES	-	
Preparation time	NO	YES	*Delay points* in rooms	NO	YES	*Wait* in rooms
Unimpeded walking speed	YES	-		YES	-	
Transportation speed	NO	YES	Decreasing coefficient linked to a defined route	NO	YES	Using speed modifiers in certain areas
Evacuation priority	NO	YES	*checkpoints*	NO	YES	*GoToRoom*

**New features for assisted evacuation will be released in Pathfinder 2016.2*

Both, STEPS and Pathfinder were mostly developed for complex buildings and transportation environments (e.g. stations) so that they do not present any specific limitation for representing the geometry of a hospital.

Nevertheless, being STEPS a model based on a grid, the sensitivity of the results to the assumptions adopted on the cell size should be taken into consideration [23]. Regarding the other key elements discussed in this paper, both models can simulate the response time and unimpeded walking speed for health care personnel using pseudo-random sampling from distributions. Despite STEPS and Pathfinders are not directly developed to model an evacuation priority, the user can modify some model attributes in order to calibrate it and represent the evacuation priority or the defined order of room evacuation followed by the health care personnel (checkpoints in STEPS and GoToRoom in PathFinder).

The preparation time can be calibrated in STEPS and Pathfinder through the model attributes (delay points in STEPS and wait in Pathfinder). However, Pathfinder does not allow implementing this as a random variable. The transportation speed can be calibrated with STEPS by defining the evacuation routes and assigning a decreasing coefficient which aim at representing the transportation velocities for each type of patients. Walking speeds in Pathfinder are affected by the relationship with occupants' density or physical elements such as ramps and stairs and using a speed modifier function, which requires assumptions on the areas where people would walk.

A model case study is presented here in order to show the possibilities of the calibration method for STEPS. A hypothetical floor plan has been modelled by following the calibration method presented in section 3.1 analysing the impact of different of the number of health care personnel in the assisted evacuation process. Although the use of data from real events or fire evacuation drills are required for verifying the results obtained by STEPS, this case study demonstrates that assisted evacuation in hospitals can be simulated with evacuation modelling tools.

5. Conclusions

This paper studies the issues concerning the simulation of assisted evacuation in hospitals using two commercial evacuation models, STEPS and Pathfinder.

Evacuation models are generally focused on self-evacuation processes, which differs from the assisted evacuation required in case of fire in hospitals. However, STEPS and Pathfinder have sufficient flexibility to be calibrated and used for these kind of scenarios. In particular, both models can simulate the pre-evacuation time and unimpeded walking speeds of health care personnel and can be calibrated for representing the evacuation priority (evacuation order based on the triage) in case of fire.

The use of the model attributes delay point in STEPS and wait in Pathfinder, allows representing the preparation times of patients in each room. However, this attribute in Pathfinder is a deterministic input rather than a distribution. Regarding the transportation speed, STEPS has more flexibility than Pathfinder calibrating this variable. It has the capability of mimicking the change in the unimpeded walking speed, by defining the evacuation route and assigning a decreasing coefficient. Pathfinder instead allows the use of speed modifiers to be applied in certain areas. The analysis of both models shows that they can be calibrated for this kind of scenarios.

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