# EGRESS FROM A HOSPITAL WARD: A CASE STUDY

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## ABSTRACT

There are many issues in a hospital evacuation, related both to patients conditions and to building complexity. Moreover, as consequences of the fire, there may be delays in surgeries and in medical diagnoses or interruption of treatment for both inpatients and outpatients.
This work identifies and assesses problems that arise in the egress from the ward located at third floor of the University Hospital Campus Bio-Medico of Rome, using Pathfinder and its powerful tools.
First of all the structural design of the ward has been set, loading the maps in the software. The occupants have been described by their standards patterns (i.e.: nurse, doctor, geriatric inpatient, visitor) giving the real situation observed in a 2/3 days' survey of the ward.
A maximum of 116 person could be found in the ward at its full capability. Five variables have been used to describe each type of occupant: speed, shoulder width, current door preference, reduction factor, comfort distance, giving to all the other variable the default value.
Two different fire scenarios were created (fire in the electrical room and fire in the local kitchen) and consequently people had a different behavior in each one.
Finally, on the basis of the different type of actions that could be set in the software, a sequence of actions was created (for instance: wait, go to) for every single person.
It was found that the time needed to fully evacuate the ward was of approximately 8 minutes, far behind the fire resistance time of the structures.
More than that, there was an overcrowded area in the ward that acted as a bottleneck: the smoke proof enclosure; this area is intended to separates the two nearby wards and, although built according to the Italian fire department regulation, it holds back people and beds.
Some structural and technological solutions have been suggested on the basis of this outcomes.

## INTRODUCTION

Modern fire protection engineering methods require more advanced software to perform complex analysis. Fire and evacuation simulators are powerful computer modeling tools that can be used to provide answers to questions that more traditional approaches to analysis might not give.
Fires are not predictable, so the decision to evacuate must often be made very quickly, while whit tornados, hurricanes, and flooding the decision teams have time prior to the event to make evacuations decisions.
There are many factors that affect evacuation time of an hospital: the number of patients, the mix of patient acuity, the available staff, the available exit routes within the hospital, the patient transportation requirements, the available transportation resources (vehicles and the necessary accompanying staff, equipment and supplies), the entry or egress points at the hospital and the location of receiving care sites [1].
It is the nature of major incidents that they are unpredictable and each will present a unique set of challenges.
Deciding whether to preemptively evacuate or shelter-in-place, requires taking into consideration many factors: the nature of the event, including the magnitude and the area of impact. How long a hospital can shelter-in-place if critical infrastructures are damaged?
There are many issues in a hospital evacuation, related both to patients' conditions and to building complexity that should be considered.

*Number of patients and patient acuity mix*

The risks of moving medically unstable patients are high, and physicians and decision teams must weigh the risks of moving these patients from the threatened ward to another hospital against the risks of moving them into another ward. Medically unstable patients are particularly resource-intensive and may need to be transferred with several care givers (to provide manual ventilation, monitor cardiac status and so on).
The total number of patients who need assistance to evacuate safely will typically be substantially fewer than the total patient census. Some patients will be medically stable and likely to self-evacuate or evacuate with family members. Other patients will be ambulatory and able to walk out of the hospital only with assistance, while others will require wheelchairs. Some will require sophisticated equipment and handling if they are to survive the evacuation, and a few very ill patients will be unlikely to survive if moved.
Transportation resources include not only the vehicle, but also the required accompanying staff, equipment, and supplies.

*Available staff*

Hospitals also typically have significantly fewer staff on hand during night and weekend shifts, which would greatly affect the ability to quickly move patients out of the hospital in an urgent evacuation. Some hospitals rely more heavily than others on staff from temporary agencies, or "traveling" staff who contract for short assignments (especially nurses and technicians). Such staff may not be as readily available as full-time hospital employees during an emergency. Volunteers, visitors, and family members may be available to assist in evacuating some patients. Volunteers must be assigned appropriate tasks, as trained medical staff are required to move and transport most patients with intensive care needs.
The evacuation process drastically reduces the number of staff available to stay in the hospital and care for patients, as some staff must join transport team. Staff are required to move patients out of the hospital and may be needed to see patients out during transport to a receiving care site. Depending on the type of disaster, there will probably be staff shortages. It is helpful to try to pre-estimate the attrition rate of a hospital's workforce during a disaster, as many employees may become victims of the disaster themselves, or may have family responsibilities that interfere with their ability to staff the hospital (e.g. evacuating dependent children).

*Available egress routes from within the hospital*
While being an unlikely problem during an “orderly and planned” evacuation, egress from a hospital may be severely constrained during a “drop everything and go” evacuation. Stairwells or exits may be obscured by smoke or unavailable because of fire. Stairwells may be dark if backup power has failed. Elevators can also be out of service, lengthening the time required to move all patients out of the hospital.
For instance, because elevators were not operating, patients at Memorial Hermann Hospital in Houston, Texas, were carried down 10 flights of stairs on backboards without overhead lighting or air-conditioning. Up to five infants were secured to one backboard. Several adults were needed to carry out each adult patient. Evacuation was temporarily halted when staff and volunteers were exhausted, so as to avoid injuries.
In an orderly and planned evacuation, there is time to move patients in a manner that maximizes safety for all patients and staff. In a “drop everything and go” evacuation, on the other hand, patients and staff are in immediate danger and must exit the unit and/or hospital as quickly as possible. In this case, optimal procedures for safely moving patients may be abandoned in favor of the fastest possible egress.
Having in mind all these considerations, we decided to create and run a model and to verify it with a real evacuation drill to assess the effectiveness of the software predictions.

## MODEL PREDICTIONS

We decided to model the egress from the ward located at third floor of the University Hospital Campus Bio-Medico of Rome, using Pathfinder (featured by Thunderhead Engineering).
We focused on just one ward because in Italy a shelter-in-place is preferred, for buildings such as hospital, which are designed to be fire resistant for at least 120 minutes [8]. Two hours is considered more than enough for fire brigades to come, evacuate the whole building and try to extinguish the fire. We have an “interim plan” designed to bring patient to a location (in most cases the next ward) where they could then be carried out and loaded into vehicles more quickly-in effect a two-stage evacuation [9].
Moreover we wanted to compare the simulation with a real fire drill.
Bearing in mind that a hospital evacuation has to be planned differently depending on weather the entire area is being evacuated or just one ward, we knew that we just couldn’t run a fire drill in the whole hospital (working at its full capability); that’s why we focused on the evacuation of a single ward.
We supposed that the evacuation should be conducted as quickly as possible, so the most mobile patient should be evacuated first [5].
Fire and evacuation modelling is essential to assess the hazards associated to detailed fire scenarios.
At a practical level, we focused on two of the most likely scenarios (fire in the cooking facilities room, fire in the power control board and fire in a patient’s room) and we used Pathfinder to estimate some data of interest (e.g. evacuation time), having some others interesting findings from all the graphs and plots that Pathfinder provided.
A plan view of the ward space is presented in *Figure 1*.

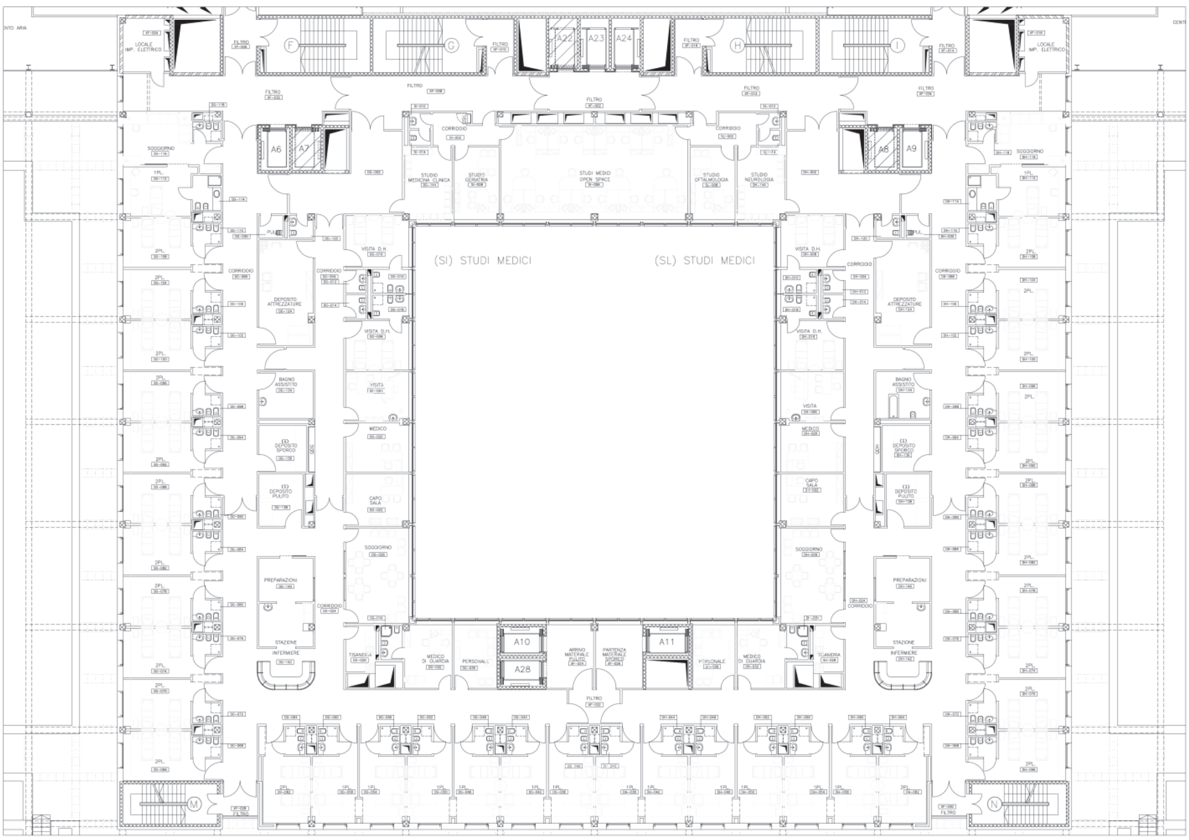


*Figure 1 plan view of the two hospital wards: 3rd East and 3rd West*

The space is made up of many rooms connected by a corridor. The area for each room is detailed in *Table 1*.

| room | area [m²] |
|---|---|
| two bed room | 12 |
| single bed room | 26 |
| outpatient room | 11 |
| medical staff room | 21 |
| nurse room | 12 |
| nurses station | 22 |
| night-watch room | 11 |
| staff room | 9 |
| cooking facilities room | 5 |
| warehouse | 22 |
| clean material dept | 8 |
| dirty material dept. | 7 |
| sluice | 2.5 |
| waiting room | 30 |
| power control board | 11 |
| bathroom | 1.4 |
| disabled bathroom | 11 |

*Table 1 type of room and area*

The real floor space on which occupants can walk was created importing the DWG file, setting all the obstructions in each room of the ward (beds, furniture, control desk) as holes in the floor and adding the doors (between two room or a room and a hallway) and the exits (the fire safety exits) to the model, so that every room was connected and no door or other connection was missing [6].

Once the base model was completed, its geometric elements and data inputs were authenticated to be error free, and then exported in order to run the simulation.

A 2/3 day survey was then conducted in the ward, in order to assess the medium number of staff (doctors, nurses, others) and the number and type of patients that can ordinarily be found [3]; results are shown in *Table 2*.

| job | fire marshals | shift | | |
|---|---|---|---|---|
| | | day | afternoon | Night |
| nurses | 5 | 4 | 4 | 3 |
| nurses students | - | 4 | 4 | - |
| paramedics | - | 2 | 2 | - |
| medical students and PhD | - | 10 | 10 | 1 |
| cleaning staff | - | 1 | - | - |
| waitress | - | 1 | - | - |
| visitors | - | - | 74 | - |

*Table 2 number of ward's occupants*

Visitors are allowed to enter the ward from 3.00 pm to 7.00 pm, rocketing the maximum number of occupants in the ward up to 116 people.

During night time, the number of staff and the total number of people in the ward reaches its minimum, because no visitor is allowed into the ward and there are just 4 nurses attending a maximum of 37 patients. The characteristics of patients are shown in *Table 3*

| patients | |
|---|---|
| total number | 37 |
| n° men | 19 |
| n° women | 18 |
| men's age range | 19 – 91 |
| women's age range | 22 – 99 |
| bed-bound | 10 |
| disabled | 6 |
| **dysfunctions**: breathing difficulties, cardiac disease, late cronic disfunction, low weight syndrome, late acute disfunction, lower urinary tract symptoms, prostatitis etc. | |

*Table 3 patient's characteristics*

Each occupant has been defined by a profile and a behavior (e.g. wait in the room until the fire alarm rings, go to a patient's room, go to an exit). *Table 4* reports the profile for a geriatric bed-bound patient, for instance. There were up to twenty different profiles: geriatric patient (able to move without assistance , bed-bound or needing assistance), plastic surgery patient (able to move without assistance , bed-bound or needing assistance), ear-nose and throat patient (able to move without assistance or needing assistance), urology patient (able to move without assistance or needing assistance), nurse, nurse student, doctor, medicine student, paramedic, maintenance staff, waitress, fire fighter, visitor.

| **geriatric_patient_2** (mobilise with bed) | |
|---|---|
| speed [m/s] | 0.25 – 0.40 |
| shoulder width [cm] | 77 |
| current door preference [%] | 100 |
| reduction factor | 1 |
| comfort distance [m] | 1.73 |

*Table 4 geriatric bed-bound patient's profiles*

Even through each profile can be described by many parameter, we decided to use only five of them, leaving the others (such as acceleration time, slow factor etc.) at their default value, because we didn't find enough data in bibliography (egress of inpatients from hospitals is a subject that has not being studied enough).

As for the *speed parameter*, we found values for disable and elderly people in literature [2], [4], [7]. The value for people to be mobilized with bed has been determined with testing the real egress of a bed (with a patient lying in it) in an empty ward, finding out its average speed.

We set *shoulder width* parameter at 40-48 cm for women and 45-50 cm for men.

Beds are of course larger than a person and we approximated the width of a bed as a cylinder having the maximum allowable shoulder width (77 cm) and a comfort distance of 1.73 m, so that the overall length is 220 cm, as shown in *Figure 2*; however this larger comfort distance is not well-rendered in the simulation, because bed-bound patients stay close to other patients.

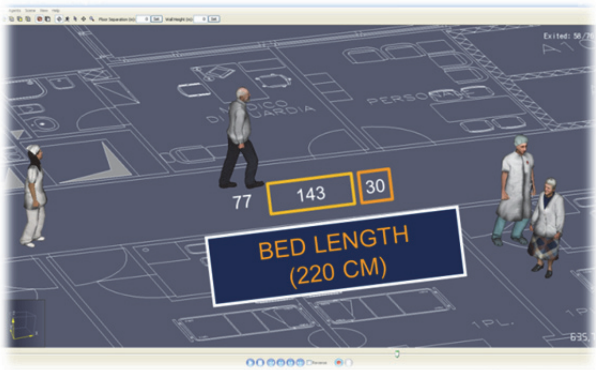


*Figure 2 bed length*

To take into account a bed that moves through a door, the door's state has been set as open or closed for a certain amount of time (*Figure 3*).

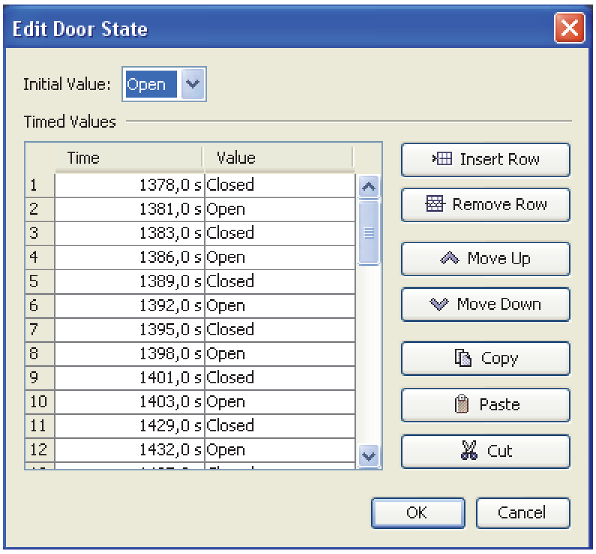


*Figure 3 door state*

Nurses are supposed to move beds across the ward; this action (two persons walking together) is not available in Pathfinder so we supposed that the nurse arrives in the patient rooms and she waits there until bed-bound patient exits the ward.

*Current door* parameter says if the occupant can freely switch the door exit (0%) or is forced toward a certain exit (100%, especially for bed-bound patients). We assigned a wide range of values to this parameter, from 10% assigned to visitors who are able to egress from whatever exit they choose, to 100% assigned to bound-bed patient, who can only egress from the exit toward the next ward or toward the hallway (minimum route).

The *reduction factor* specifies how well an occupant may squeeze past others in tight corridors. In an hospital ward nurses help inpatients and visitors to safely reach the exits, so we set a value of 0 for visitors and patients, and 1 for nurses and staff, supposing that they can squeeze themselves in order to go back and assist someone else.

The *comfort distance* parameter specifies the desired distance one occupant will try to maintain with others nearby. We chose a different range of values for this parameter, as shown in *Table 5*. For a bed-bound patient, for instance, we set it equal to 1.73 in order to simulate the bed's length, while we considered that nurses and doctors needed a lower value (0.15-0.20).

While the profile is the same for every scenario, the behavior changes, due to the sequence of actions that a person should perform.

For instance, *Table 5* shows the behavior of a nurse in the fire in the electrical room scenario.

| **nurse_1** | |
|---|---|
| initial delay [s] | 110 |
| exit | F30 |
| actions order | A+C+B+C+B+C+B+C+B+C |
| behavior | nurse_1 smells burnt, alerts another nurse and tryies to extinguish the fire, while nurse_2 alerts the control room |
| n° of person with same behavior | 1 |

*Table 5 behavior of nurse_1 in the fire in electrical room scenario*

The actions allowed by the software are:

A = *go to a place*
B = *go to a room*
C = *wait*
D = *use elevator*

The action D has not being considered in either of our simulations because all the egress is related to the same floor.

Initial delay time is a very important datum: it specifies an initial delay that makes the occupant wait at its starting position before moving to the next action. Many papers can be found discussing the value that should be assigned to this variable. In both our scenarios, the initial delay is the time needed to the nurse to reach the patient's room, for patient's behavior. For visitor's behavior, who are emotionally linked to patients, delay time correspond to the time needed to the patient to leave the room.

The **first** supposed **scenario** is a fire in the electrical room (*Figure 4*).

In this scenario, fire exits A and B are not available because they're too close to the fire.

Visitors are forced to use exits M and N and reach the basement of the building while patients enter the next ward through the exit F18. In fact available exits are F4, F18 and F19.

The area near exit F18 separates one ward from the other, its structures are fire/smoke/heath resistant for 120 minutes and it is designed so that smoke can't spread from one ward to the other, having vents on the top or being forced ventilated.

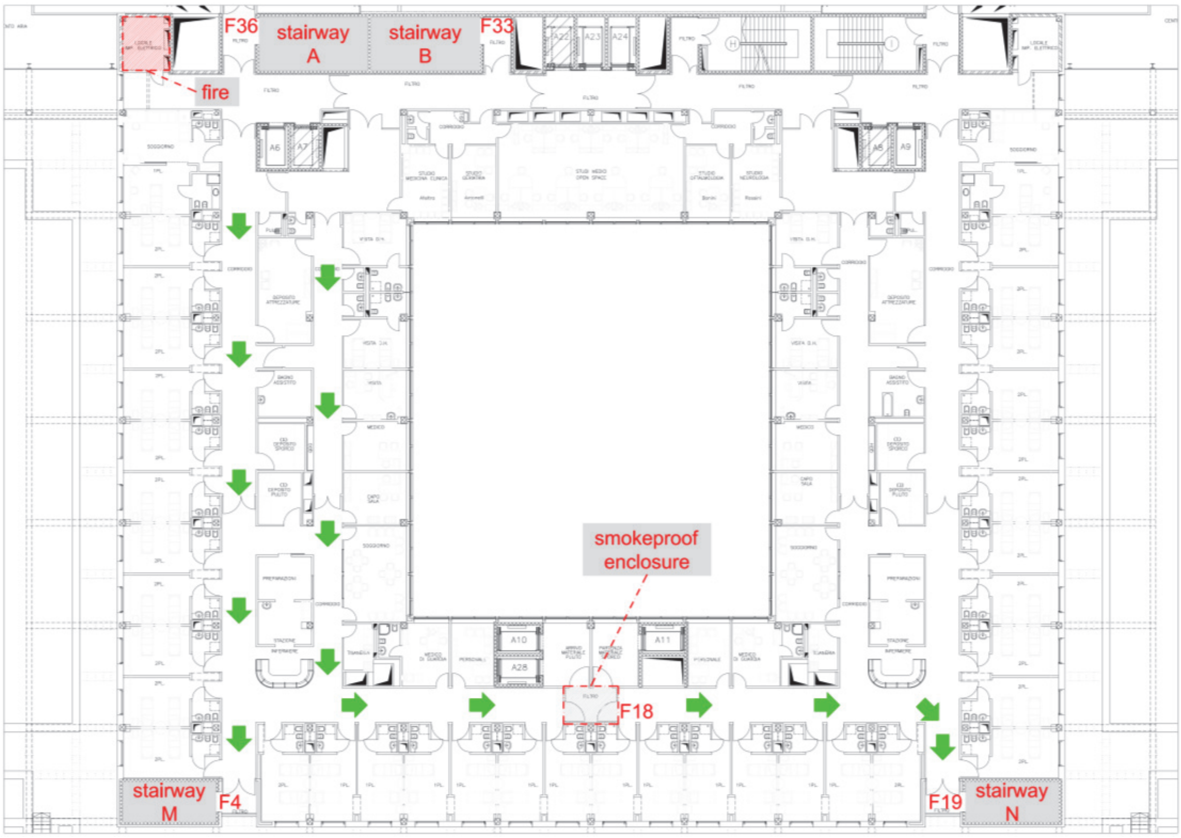


*Figure 4 fire in the electrical room scenario*

Unfortunately, egress can occur both ways, from one ward to the other and back. That's why one door opens facilitating the egress and the other preventing it.
This is according to Italian fire protection laws, but actually not particularly appropriate because it generates a bottleneck, perfectly visible from the software simulation.
Moreover, there are some nurses that still need to enter the threatened ward to move patient to the safe one, and they further prevent the egress.
The situation in the area after 1551 seconds after the beginning is showed in *Figure 5*.

*Figure 5 bottleneck in the smoke proof enclosure*

The **second** supposed **scenario** is a fire in the local kitchen (*Figure 6*).
The local kitchen is located in the middle of the ward, so in this case the smoke is supposed to spread in the corridor so that some exit areas are no longer available after a certain length of time.
Since the most dangerous zone is in the middle of the ward, the egress will start from the rooms closest to the fire, whether or not patients need assistance to move.
Exits F4 and F18 can be used for few minutes only and just by the nearby rooms (orange pathway), while all other patient should use exits F36 and F33 and bed-bound patients can reach the next ward using exit F30.
The **third** supposed **scenario** is a fire in the patient's room (*Figure 7*). This scenario has been used to perform a simulation which was exactly the same as the real drill (identical number of person, identical sequence of actions, identical available exits).

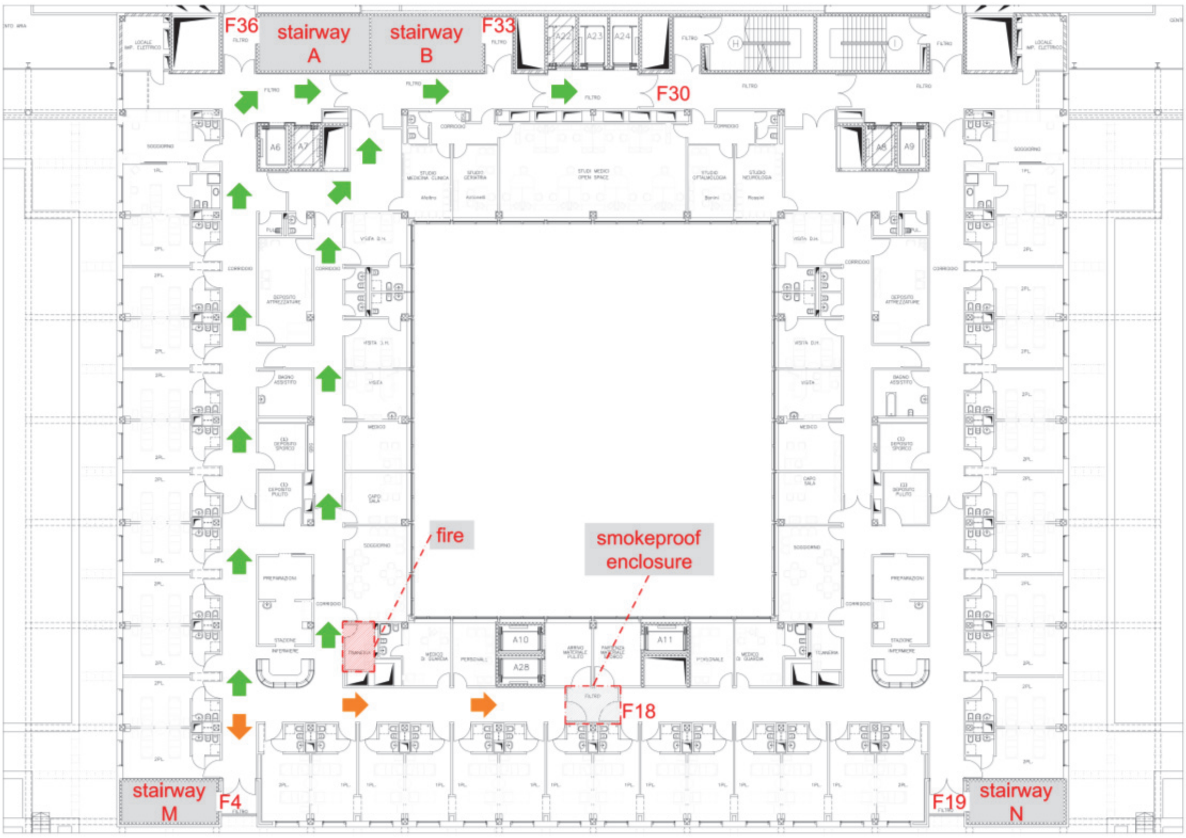


*Figure 6 fire in the local kitchen scenario*

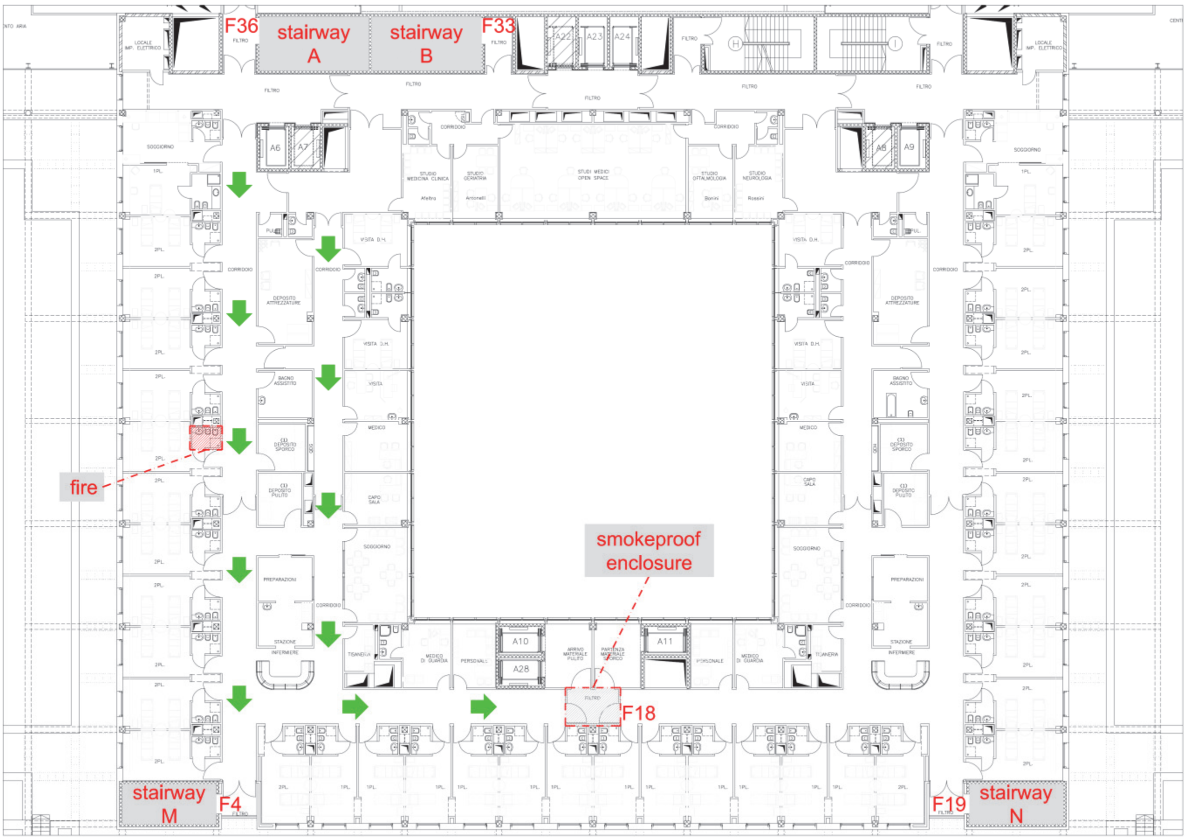


*Figure 7 fire in the patient's room scenario*

The *Table 6* sums up the differences between the three supposed scenarios:

| scenario | n°of person | available exits |
|---|---|---|
| **fire in the electrical room** | 116 | F18, F4, F19 |
| **fire in the local kitchen** | 116 | F4, F18 (just for few minutes) F36, F33 |
| **fire in the patient's room** | 76 | F18, F19 |

*Table 6 different scenarios*

## RESULTS AND DISCUSSIONS

Egress time is the first datum that easily comes out from the modelization with software, even though influenced by the hypoteses and accuracy of the user.
Results were almost the same for two scenarios: it took 1800 seconds to empty the ward if the fire was in the electrical room (*Figure 8*) and 1370 seconds if the fire was in the local kitchen (*Figure 9*).

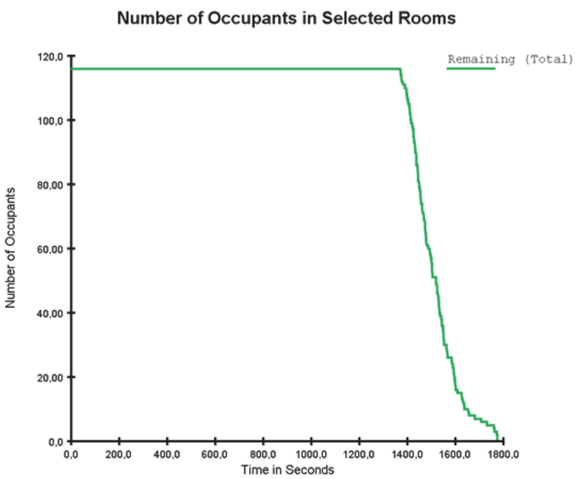


*Figure 8 fire in electrical room*

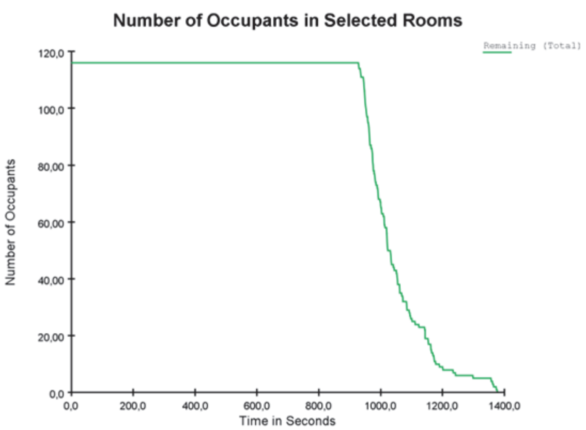


*Figure 9 fire in the local kitchen*

Both graphs (*Figure 8* and *Figure 9*) show that for the first period (1360 seconds and 970 seconds) nobody exits the ward. It takes a certain lenght of time for people to move, because the fire needs to be detected and notified, the fire alarm needs to be propagated and the staff needs to organize patient's evacuation. This "pre-evacuation time" decreases if people are aware of what they're supposed to do in case of fire (if more fire drills are conducted in the ward, for instance), if the firefighting system and the fire alarm system are efficient and are working well.
The total time for evacuation considers the detection and notification time, the pre-movement time (including response and recognition time), the movement time (queuing time and travel time).
After a peak in the evacuation of the ward, a flat can be found in the graphs of both scenarios, due to the fact that patients with no need of assistance are moved first, while it takes longer to move the last bed-bound patients.
Evacuation time for the third scenario was 957 seconds (*Figure 10*).
In this scenario the total number of persons evacuated was lower (76 instead of 116) and bed-bound patients were 6 instead of 10 (supposed in the other two scenarios).

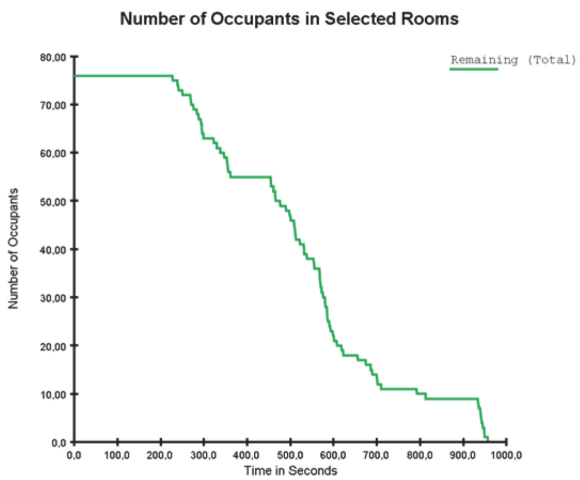


*Figure 10 fire in the patient's room*

As for the first and second scenario (*Figure 11* and *Figure 12*), a high flow rate can be seen through the exit F18, because one of the two doors opens against and beds are obstructing people's exit.

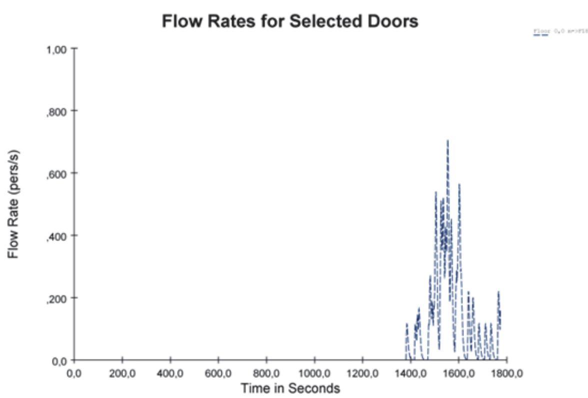


*Figure 11 flow rate through exit F18 in the first scenario*

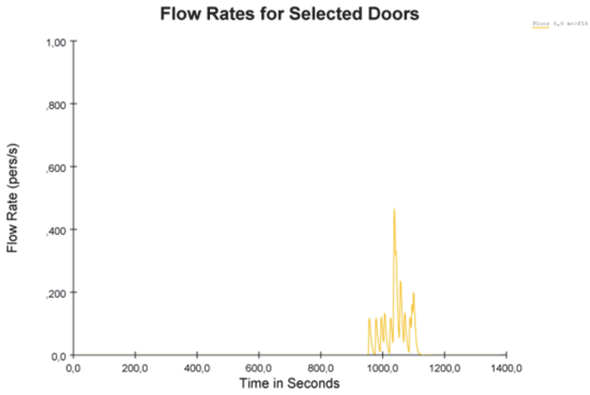


*Figure 12 flow rate through exit F18 in the second scenario*

The third scenario (*Figure 13*) also shows the bottleneck in the smoke proof enclosure, even if the number of bed-bound patients was lower than the previous simulation (just 6 instead of 10).

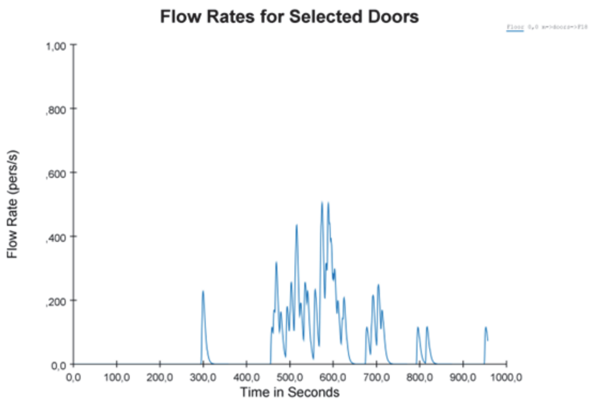


*Figure 13 flow rate through exit F18 in the third scenario*

The graph in *Figure 14* shows the number of persons in the small area in front of exit F18.

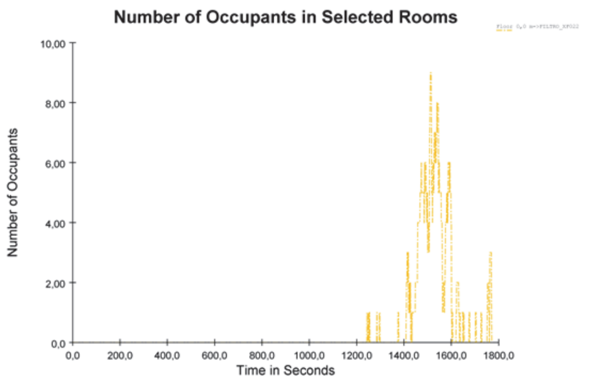


*Figure 14 Number of occupants in the area in front of exit F18 in the first scenario*

In the first scenario, fire in the electrical room (*Figure 14*), a peak of 10 person in 8m$^2$ (the smoke proof enclosure) generates a bottleneck that prevents other patients from exiting the ward.
Actually this overcrowded area, although built according to the Italian fire department regulation and built to prevent the spreading of smoke from the two adjacent wards, is too small to easily hold people and beds (which are 2.20 meters long), allowing the opening of a door too. People are trapped in this space, unless someone else keeps the two doors open, simplifying the movement of beds. But keeping both doors open would neutralize the effect of the smoke proof enclosure because smoke would not be stopped.

## VALIDATION OF THE MODEL

Outputs for journey times and link flows extracted from the simulation were compared with observed counts.
A scheduled evacuation drill of the 4$^{th}$ floor of the University Hospital Campus Bio-Medico di Roma was held on May 7$^{th}$ 2014. The ward was empty and volunteers acted as patients. On the contrary, nurses, doctors and other staff were real.
The drill included a single ward and required the staff to evacuate horizontally, without using the building's stairwells and elevators.
This drill provided the opportunity for us to collect egress data to then be compared with the outputs of the software.
Two methods were used to collect data during the evacuation drill to provide occupancy and flow data:

- video, to disseminate journey times
- manual counts

The survey team was provided with video from internal security cameras. These cameras were placed close to the ceiling in order to capture a top-down view of people as they traversed the stairs thereby allowing the study team to track movements and behaviors. A digital video camera was set up to capture behavior and movements during the evacuation.
Manual counts were taken at the internal exits of the ward. Counters were directed to stand out of the way of those evacuating so as not to interfere with the flows. Each counter took note of the number of people exiting the main door.
The drill was conducted with the hospital working at its full capability and together with the local fire fighters. Therefore, not all exits were available, because in order to prevent accidents, real patients and actors, exiting the ward, had to use different exits and routes.
Each patient received a badge, which reported the disease.
The supposed fire scenario was a fire in a room in the middle of the ward, so it was almost similar to the scenario of fire in the local kitchen.
We are now going to explaining some differences between the real drill and the simulation.
A fog machine has been placed in the room, generating white smoke that gradually spread in the ward, lowering the visibility. This action had not being accounted in the software simulation, that ran under the hypothesis that visibility in the ward remains at less 10mt during the whole egress.
A total of 76 persons were observed evacuating during the drill; 56 used stairway and 16 went in the adjacent ward.
The number of evacuees observed during the evacuation drill consisted of about 65% of the total number of people evacuated in the two scenarios simulated by the software.
Video recorded during the evacuation drill was used to calculate observed flow rates through exit doors and in the

smoke proof enclosure and total egress time, which was then compared to modeled egress time.
The observed evacuation time was 860 seconds (instead of 957 seconds of the simulation). Discrepancies between modeled and observed egress time may be partially explained by the uncertain and therefore inaccurate replication of pre-movement time and by the slight differences in the speed of patients (old in the model, young in the real drill as they were students).
Nevertheless, the authors think that the Pathfinder evacuation model represents a very good correlation to the observed egress data.

## CONCLUSIONS & OUTLOOK

The results from the validation exercises indicate that Pathfinder is a suitable application for egress modeling, producing total evacuation times that are similar to observed total egress times. The real drill took less time, probably because people were aware of the drill and people who took part were younger and faster than modeled geriatric inpatients.
Additionally, agent movements and behaviors through doors corresponded well to observations.
Pathfinder can be used to test egress and evacuation scenarios and make recommendations for safety preparedness improvements. It can be used to teach people what they're supposed to do in case of fire, which exit they can use, which sequence of actions they must follow.
While the model produced positive results regarding Pathfinder ability to simulate egress scenarios, further validation exercises are needed, particularly those involving models of full ward egress scenarios.


## ACKNOWLEDGMENTS

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