EVACUATION STRATEGY PLANNING

SPECIAL REQUIREMENTS FOR HOSPITAL DEPARTMENTS

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ABSTRACT

In this study, I determined what parameters were suggested to be considered when evacuating a hospital and how these could be translated into the language of evacuation simulation. For this reason, I investigated the evacuation of a unit in more variations using Thunderhead Pathfinder. The aim of the case study was to look at how the model can be built and how a change of parameters causes changes in the evacuation time.
Based on the case study, I managed to set up a modeling method, which can be clarified in the further explored directions in my further research. In the present case study, I also proved that even changing only 1 parameter can cause a significant change in the evacuation time, so it is worth examining several variants. An obvious option for this is the use of computer-based simulations.

KEYWORDS

hospital evacuation, simulation, case study, Pathfinder

In health care institutes, evacuation processes are quite complex and complicated, and to do them efficiently, a well-defined strategy is required. The reason for this is that users of hospital facilities are characteristically patients unable to make an unaided egress. Therefore, healthcare staff should be trained and be ready to ensure patient's egress and rescue.

Current domestic (Hungarian) regulations and the rules of evacuation presume that individuals egress unaided and regulations focus on the provision of the conditions of such unaided egress [1]. There is no other guide to plan this special strategy for hospitals. In Fire Safety Technical Guideline - Evacuation [2] is only this recommendation: "For the evacuation of rooms used by persons unable to egress unaided, the general computation method applies, however, during the computations, disabled persons' reduced speed, the equipment available during the evacuation and persons capable to help with the evacuation shall also be considered". However, the method and further details of such considerations are not provided.

A computer-based evacuation modeling allows for the analysis of different scenarios. It looks like to be an easier, faster solution of decision-making progresses thus does not cause practical and ethical issues. But how to use this possibility?

In this paper, I set up a hospital evacuation model, testing the setting options of evacuation scenarios in the Thunderhead Pathfinder software. [3]. I would like to present what special strategic issues need to be decided in the case of a hospital unit evacuation.

ESTABLISHMENT OF A CASE STUDY

In this study, I model a surgery unit, as in such units, patients needing assistance are characteristic, but, depending on the recovery phase, they may be able to egress unaided or to be evacuated while laying. In line with the domestic professional minimum regulation [5], the minimum capacity of a surgical unit is 5-15 beds depending on the progressivity level, therefore I assume 19 beds. For a 5-30-bed unit, a total of 11 nurses are required, but they are working in 2-3 shifts, therefore, their number is distributed. In this paper, I'm only considering two types of persons: healthcare staff and patients.

Based on my experiences, in hospital units, the worst patient-staff ratio arises during nightshift, therefore, this is the worst scenario that can be examined. So, in this study, I assume two versions:

- In the hospital unit, evacuation becomes necessary during the day, when 4-4 nurses are working in the area (each unit);
- The other version, evacuation becomes necessary during the night, when 2-2 nurses are working at each unit, and for the evacuation, further 1-1 nurses from units with the same layout, but one level lower and higher assist the evacuation.

In the set layout, there are 2 identical hospital units, in a mirrored layout, with 1 joint-use corridor block. The area is divided into 3 fire compartments: the two units and the corridor block [4]. The unit hosts single bed rooms, except for the 3-bed ward (for patients in the worst condition). The structure of the building entails a 2-corridor system (2.00 m wide), with the patient rooms to the facade, and with the supply rooms in the middle (storage, reporting room, nurse standby room and nurse working room). The doors of the patient rooms are asymmetric and two-leaved, opening outwards, with a net width of 130 cm. The fire doors in the corridor are net 180 cm wide, two-leaved and self-closing.

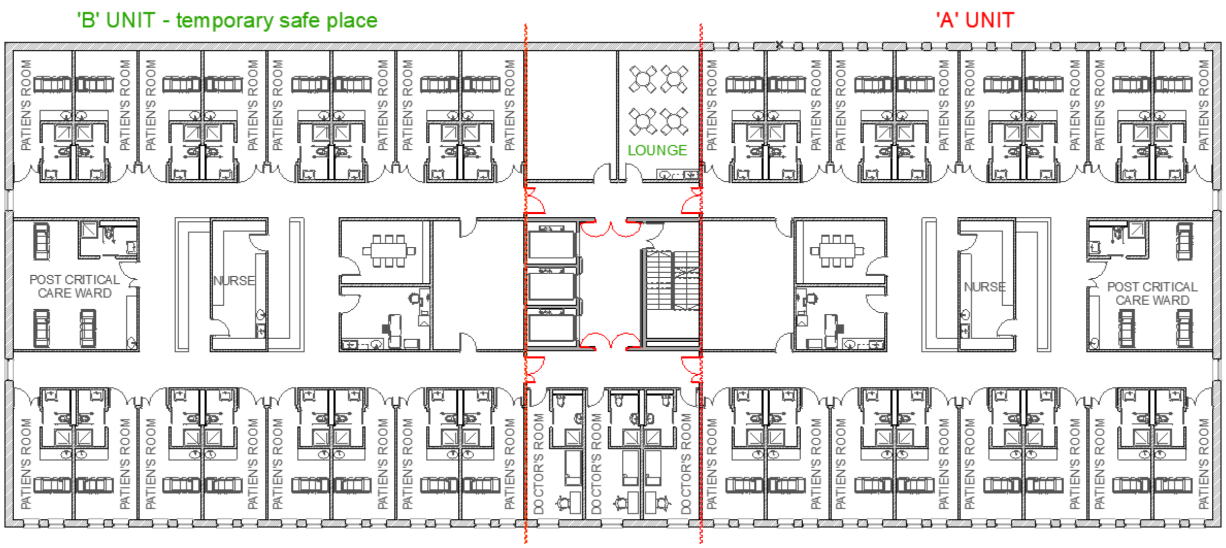


Figure 1: Floor plan (The green title indicates the safe unit, while the red title indicated the unit to be evacuated)

In the subject layout, on the floor of the hospital unit, another unit with the same size and layout is also available, where patients will be relocated (it is in a different fire compartment). In this paper, I assume that the fire does not jeopardize the evacuation and both emergency doors are available. **The goal of the evacuation is to relocate persons from A unit to the other B unit, and to establish the expected duration thereof.**

THE MODEL AREA

I prepared the floor plan in Fig. 1 in the model area, as per Fig. 2. Elements of the model area characteristically have the default settings: rooms, doors, stairs. Larger pieces of furniture are depicted as holes (built-in counters, patient beds). The unit to be evacuated is on the right side of the figure, and on the left side is the safe area defined as the target area of the evacuation.

For the self-closing fire doors on the corridor (blue rectangle), I set a delay to consider navigation on the door. Based on Boyce's 1999 measurement [6], the values of this are the following: average: 3.6 s, spread: 1.3 s, min.: 1.6 s, max.: 10.2 s.

In the B unit and in the interim fire compartment, I established temporary protected areas. The lounge is used for persons egressing without assistance (blue), the ward is for patients with more serious conditions (red), and the ends of the corridor are for wheelchair users (green). In the model they are set as 'refuge rooms'.

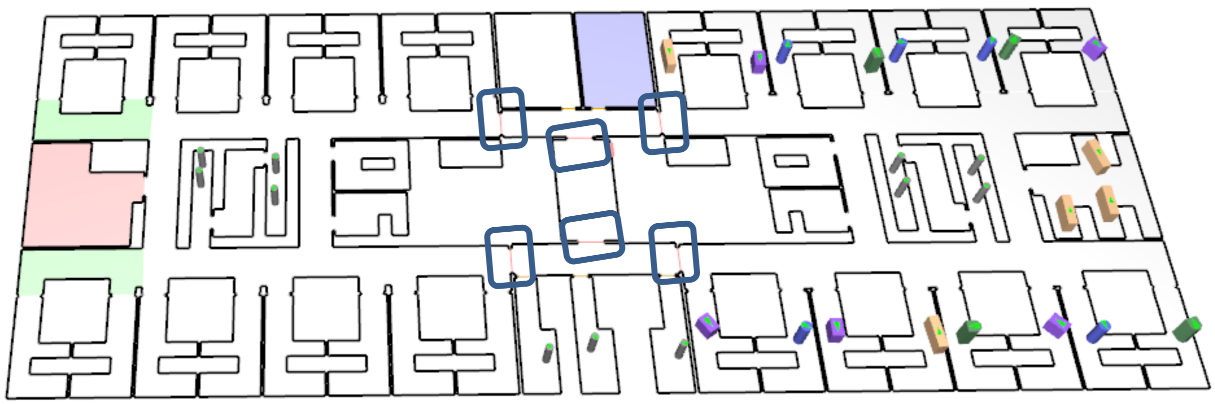


Fig. 2 – Model area version 1

In the first version, this was the only level in the model, while in version 2 (Fig. 3), I created identical levels 3.6 m below and above the subject level, potentially sending helpers to unit A.

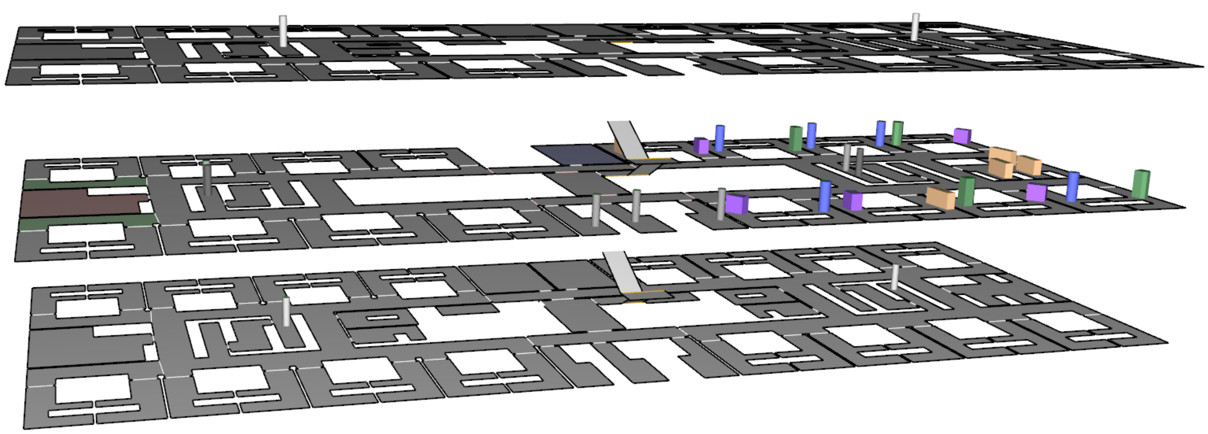


Fig. 3 – Model area version 2

In the model, only the persons necessary for the sessions were placed. In the unit to be evacuated, patients are staying in the rooms, and the staff in the nurse counters, doctors are staying in the doctor's offices. In the rest of the units, no patients are set in the model, only the nurses in the nurse counters.

CHARACTERISTICS OF PERSONS

Healthcare personnel

Healthcare personnel (nurses and doctors) assist the evacuation. Their speed varies throughout the process: when they are alone, with a speed of their own, with that of a healthy persons, while during evacuation, with the speed defined by the evacuation equipment. I based the exact values on data in the references, entering a normal distribution in the software.

Patients

I classified patients in four groups, each with different characteristics.

- Patient type A is able to egress unaided, however, they use a cane, are able to move independently, but slower than healthy individuals. During evacuation, they don't require assistants.
- Patient type B is able to egress unaided, however, they use a walking frame, are able to move independently, but slower than healthy individuals. During evacuation, they don't require assistants.
- Patient type C is not able to egress unaided, they need wheelchairs and assistants. To help them in the wheelchair and to push it, presumably 1 assisting person is required.
- Patient type D is not able to egress unaided, they need a bed-type evacuation equipment. Such equipment used in the simulations are delivery bed, to which I allocated 2 helpers.

1. Table – Persons' settings in the model

Persons		Staff	Patient type A	Patient type B	Patient type C	Patient type D
type			cane user	walking frame user	wheelchair user	patients to be evacuated on delivery bed
shape		roll	roll	cuboid	cuboid	cuboid
appearance in the modeled area		gray	blue	green	violet	orange
dimensions (m)	average	46.5 [7]	66 [8]	70/80 [8]	110/70	176/56 [8]
speed (m/s)	minimum	0.65	0.15	0.11	0.84	-
	average	1.35 [9]	0.56 [10]	0.34 [10]	1.3 [11]	1.04 [12]
	maximum	2.05	1.18	1.04	1.98	-
	SD	0.25	0.22	0.20	0.34	-

Patient rate and layout

In these simulations, persons are located in identical positions in all sessions, and the proportion of their types is also the same. Consequently, the models feature 11 staff and 19 patients. Patient type proportions are the following: 4 type A patients, 5-5 type B, C, and D patients.
For repeated runs, only the settings of the individuals change with the program's randomize command to estimate the change due to the input values specified by the normal distribution.

PRE-EVACUATION TIME

Every evacuation process is preceded by pre-evacuation time, during which persons recognize and understand the fire alarm, interrupt their actual activities and prepare for evacuation [13]. In the case of hospitals, following more time periods are added:

- The leader of the evacuation must establish the sequence of evacuation in a special, triage-type system. [14].
- Staff must get to the area to be evacuated (if necessary, redirected from other units) and to the persons to be evacuated. The person in charge of the evacuation must instruct them, detailing their exact tasks during evacuation.
- If necessary, the person to be evacuated must be medically prepared for evacuation and must be helped (sat or laid) in the evacuation equipment.
- If evacuation of further persons is necessary, they need to return to the unit with the evacuation equipment.

Designated personnel and evacuation sequence [14]

An evacuation process for the entire healthcare facility is part of the emergency response plan of each hospital. There should be a command center and an evacuation coordinator for the hospital. Generally, a personnel must be designated for each area, who will make the responsible decisions in emergencies, being aware of the number, types and location of patients. In this study, I assume that 1 nurse of each unit remains in the nurse counter, who will lead the process of evacuation and stays in the unit on standby.

In line with the emergency response plans of the actual hospital, a triage-type classification will be effected, facilitating the evacuation of the largest possible number of patients in emergencies. In such situations, the default priorities are assumed:
1. Persons exposed to direct dangers
2. Persons egressing unaided or with assistance, but without an evacuation equipment
3. Persons egressing unaided and with a transportation equipment
4. Persons evacuated with assistance and with an evacuation equipment
5. Persons requiring medical preparation and evacuated with a transportation or evacuation equipment

In this paper, the classification system was used only partially in the model, as due to the simplification of the testing, assistant groups are allocated to a given patient type. Prioritization of such patients is not based on a pre-set priority sequence, but solely on distance.

Arrival and Movement of Staff

In the model, in both versions, part of the staff is staying in the given unit, while the others are borrowed from elsewhere. In the area between the two units, next to the staircase, I assume 3 doctor's offices, where I assume 3 persons who are setting out to evacuate.

In version 1, only 3 persons from the 4-person staff of the B unit arrive to help with the evacuation, while 1 person remains there to control the B unit and manage the persons evacuated to there. In version 2, assistants arrive from multiple locations (another floors also), units from the levels above and below send 1-1 assistant each, while 1 staff remains in the respective units to oversee those.

Prior to the actual commencement of the evacuation, everyone must go to the nurse counter of the subject unit, and they have to wait 10s, assuming that they will coordinate everyone's tasks. After this, they are going to the persons to be evacuated and they execute the relocation.

Preparation Period

In this study, assuming that in a normal unit, presence of patients needing intensive care is not characteristic, I did not consider that patients may also need medical preparation. Therefore, in the settings, I only applied the time necessary for the use of equipment units type C and D, i.e., until after all members of the assistant team, patients are helped onto the evacuation equipment. The period set for patient type A and B covers getting up from the bed and preparation, while the time period set for staff covers completion of previous actions.

2. Table - The applied time periods before evacuation is shown in the following table:

Type of persons	Applied delay (s)			
	min	average	max	SD
staff [9]	30	71	246	60
Patient type A [15]	30	60	90	20
Patient type B [15]	30	60	90	20
Patient type C [6]	32	41	52	8
Patient type D [6]	60	78	120	19

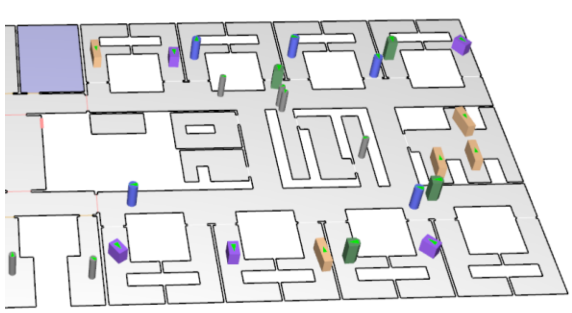
Considering the Hungarian conditions and regulations [5], only 1-2 rescue devices are available in 1 unit: 1 wheeled stretcher, 2 wheelchairs, possibly 1 hand stretcher. Thus, the devices need to be used multiple times to transport a patient of 15-30 people.
So I had to model that in a refuge area, the patient must be transferred from the rescue device to a piece of furniture there so that the rescue device can be used again. That I didn't find any Pathfinder setting options that during assisted evacuation, when the rescued person is "released", how to set a delay time. Therefore, this parameter was omitted from this study.

RESULTS OF SIMULATIONS

As the most settings contained normal distribution, to produce useable results, several sessions are required. In this paper, I did 20-20 sessions, with random person settings (but their position and type remain the same in every session!). This is a strong simplification of reality, but I would like to exclude other variables from the result.

Version 1 – Daytime evacuation

In this scenario, assuming staff numbers usually present during the day, 4 staff members are present in the unit, while staff members assisting in the evacuation are coming from the same floor. Roughly, by the end of the 2nd minute, they start evacuating the persons moving with assistance, while the helpers arrive from the other units. This results in a gradually improving patient/assistant ratio, which speeds up the evacuation.



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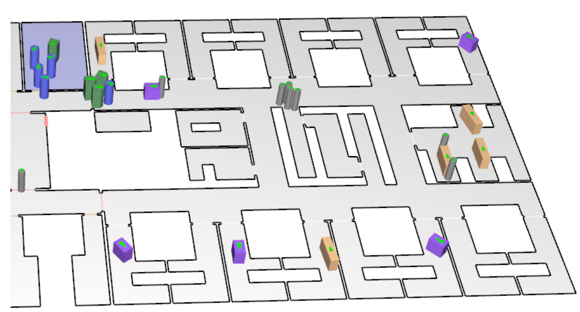

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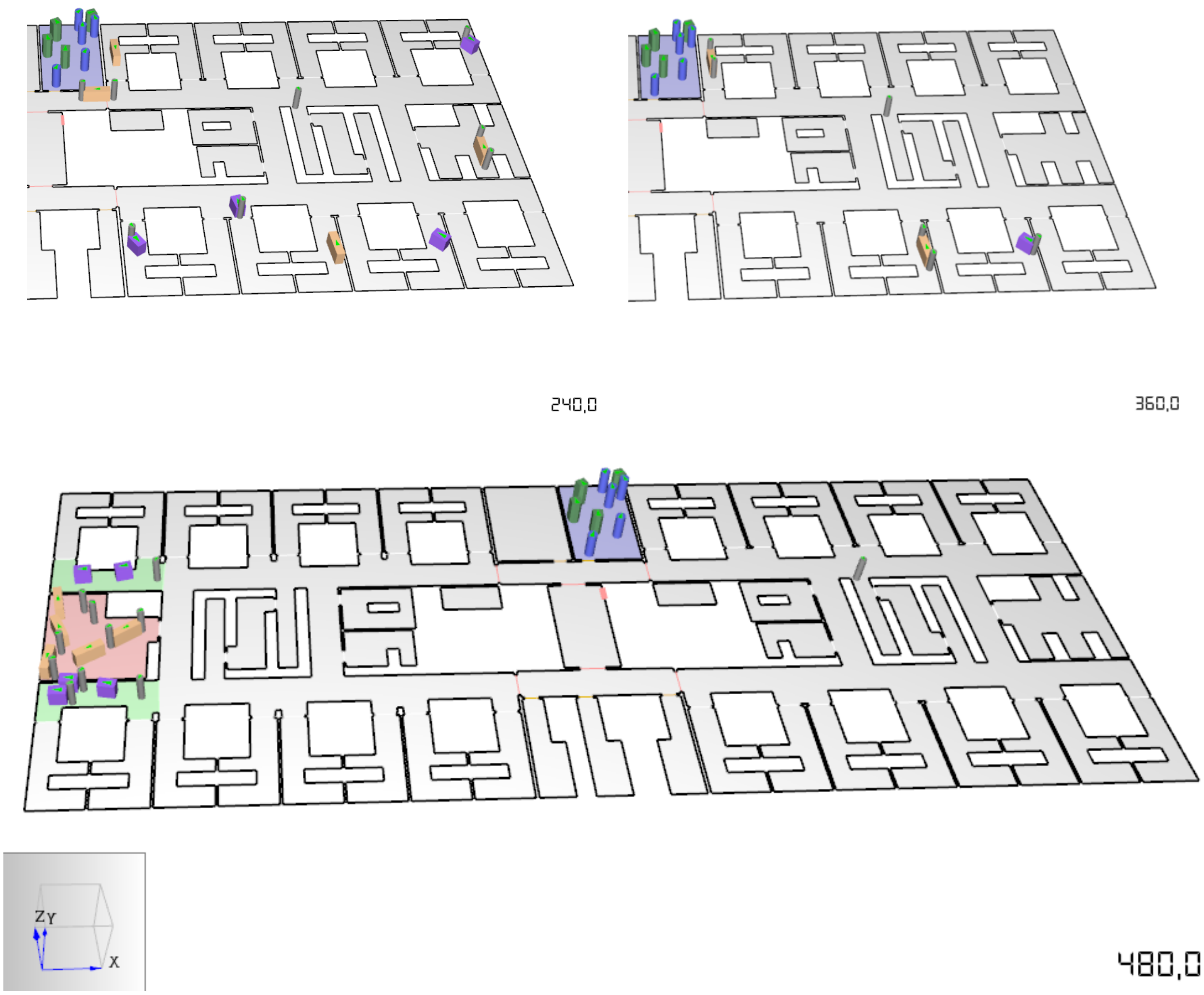


Figures 4-8. The process of evacuation, version 1 (60, 120, 240, 360, 480 s)

Staff needs to return to the area several times to evacuate everyone. Usually, the last patient is one of the delivery bed user patients of the ward, therefore, based on the distances, the theoretical evacuation sequence was also established.

Table 3 – Results of version 1

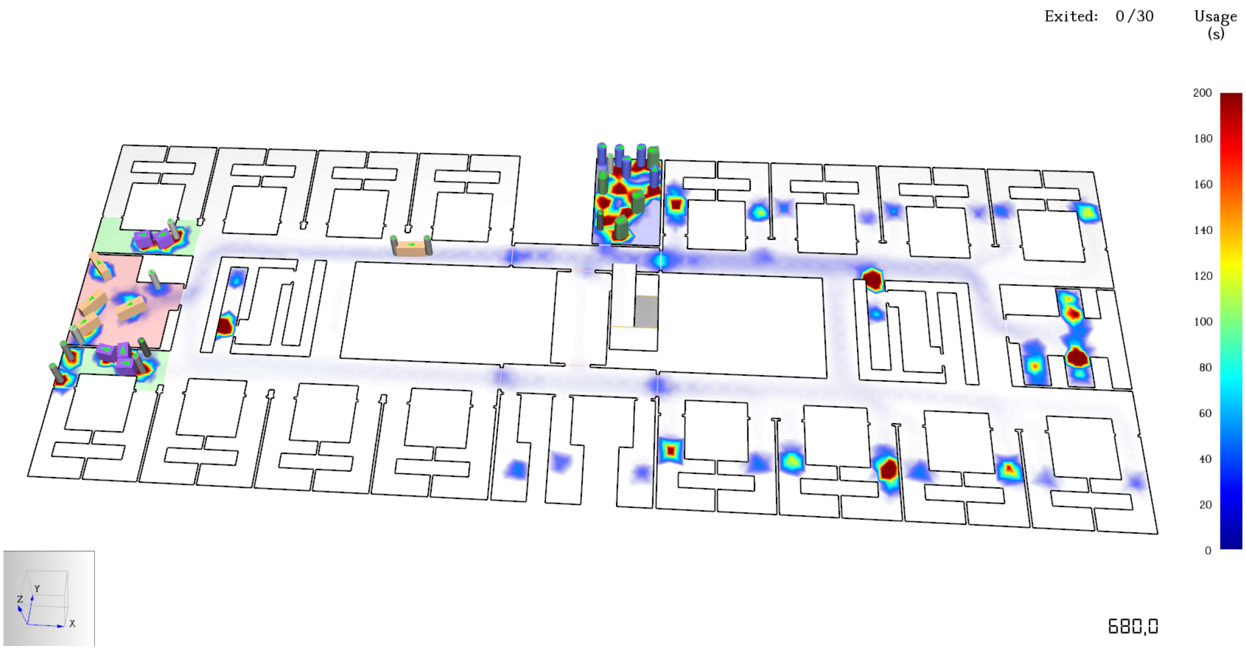
Evacuation version	session	staff		patient			everyone arrives to the designated area
		arrival of first staff	arrival of last staff	first patient leaves the unit	last patient arrives to lounge	last patient leaves the unit	
Version 1 – Daytime evacuation	1	47	193	70	150	440	502
	2	87	224	62	325	512	554
	3	83	185	66	278	477	521
	4	93	205	74	227	497	546
	5	61	177	81	221	460	501
	6	76	193	83	270	477	522
	7	63	154	58	172	478	522
	8	66	170	83	186	480	523

	9	40	202	74	248	439	503
	10	76	172	63	203	485	529
	11	77	186	64	320	484	528
	12	77	245	81	247	547	592
	13	42	260	84	170	507	551
	14	70	162	75	246	507	550
	15	59	171	72	282	451	497
	16	51	168	98	198	507	554
	17	82	191	99	170	532	577
	18	62	190	99	255	460	502
	19	82	172	72	280	480	523
	20	93	195	96	181	511	553
simulation value	min	40	154	58	150	439	497
	average	**70**	**191**	**78**	**232**	**487**	**533**
	max	93	260	99	325	547	592
	SD	16	27	13	52	29	26
interval estimation	lower limit	**62**	**179**	**72**	**209**	**474**	**521**
	upper limit	**76**	**203**	**83**	**255**	**499**	**544**

The results of the different reruns are summarized in Table 3, and I calculated the average values thereof. Based on statistical calculations the results show normal distribution [10], so from the 20 reruns I can calculate statistical values and interval estimations. The established time to reach the lounge for disabled persons is between 209 s and 255 s. The established evacuation time of the unit, at daytime shift is between 474 s and 499 s, which significantly exceeds the 420 s time period specified in the Hungarian regulation [16] for evacuation of a fire compartment.

<u>Version 2 – Evacuation at night shift</u>

In this scenario, assuming staff numbers usually present during the night, 2 staff members are present in each unit, while staff members assisting in the evacuation come from the other units (1-1). During the evacuation, the session starts with patients using sticks and walking frames, who characteristically get to the lounge in 4 minutes, which doesn't show significant variations from version 1.



Figures 9-11. The process of evacuation, version 2 (240, 480, 680 s)

Roughly, by the end of the 2nd minute, they start evacuating the persons moving with assistance, while the assistants arrive from the other units between 195-310 s. Persons' progress routes are shown in Fig. 10, which is obviously the most crowded in the area of the corridor door. Additionally, it shows the aggregate using time of the areas, including times spent with waiting. It is also apparent that the time necessary for the evacuation is characteristically affected by the waiting times, and not by the length or layout of the path.

In this case study helpers of type C finished the task sooner and could have helped the helpers of type D afterwards. In further studies I should apply the 'change behavior' command in Pathfinder to avoid this.

Table 4 – Results of evacuation version 2

Evacuation version	session	staff		patient			everyone arrives to the designated area
		arrival of first staff	arrival of last staff	first patient leaves the unit	last patient arrives to lounge	last patient leaves the unit	
Version 2 – Daytime evacuation	1	77	208	74	207	630	673
	2	100	228	86	296	730	773
	3	96	215	109	198	632	677
	4	73	246	87	263	623	665
	5	118	308	86	257	639	681
	6	94	246	78	196	698	742
	7	76	235	73	245	708	751
	8	66	211	85	260	699	745
	9	70	235	89	250	713	755
	10	104	197	65	178	661	703
	11	67	265	84	181	633	675
	12	74	203	93	308	640	682
	13	58	206	86	242	603	652

	14	70	197	86	338	678	720
	15	62	225	67	210	702	745
	16	75	252	81	378	643	684
	17	99	212	85	395	650	691
	18	70	220	65	237	724	767
	19	51	219	89	265	640	682
	20	83	220	93	192	699	743
simulation value	min	51	197	65	178	603	652
	average	**79**	**227**	**83**	**255**	**667**	**710**
	max	118	308	109	395	730	773
	SD	17	27	11	62	39	39
interval estimation	lower limit	**72**	**216**	**78**	**228**	**650**	**693**
	upper limit	**87**	**239**	**88**	**282**	**684**	**727**

The results of the different reruns are summarized in Table 4, and I calculated the average values thereof. The established time to reach the lounge for disabled persons is between 228 s and 282 s, wich is a bit largen than version 1. The established evacuation time of the unit, at night shift is between 650 s and 684 s, which, compared to the previous version, shows a ~35% increase.

The only difference in the two simulations was that the same number of helpers arrived to the A unit from different locations. And, though the other settings remained the same, it led to significantly worse results.
During this simulation, it was found that even in a model simplified in many aspects, number and location of helpers translates to a significant difference. This supports the finding that evacuation and rescue of hospital in-patient units should be examined further in future studies and during planning.

SUMMARY

During the setup of this case study, I found that a correct model requires that hospital's emergency response plans also include the rules of evacuation. There should be a command center and an evacuation coordinator. There should be a designated personnel, who can make the triage and who can control other helpers. It is also necessary to know the type and number of transport and evacuation equipment available.

In analyzing a real situation, many variable input parameters are required to build the model. However, they can only be used if there is published data. Thus, the model should always be somewhat simplified compared to reality.

In the preparation of this study, I found that the majority of the parameters and time periods of the strategy can be set in the Thunderhead Pathfinder software:

- The period of pre-evacuation can easily be set as waiting times.
- The time when the instructions are given can be handled as an instruction to go to wait point or room, and waiting times.
- The software also handles different speeds of helpers with respect to when they are alone or actually helping someone.
- The preparation time period can be set in patients behavior
- The time necessary for passing through doors can be set as parameters of the door.

- Though I didn't apply this option in this case study, but the exact sequence of patients' evacuation would also be possible to be set, with the parameters of helper groups.

But there were some parameters which I could not apply correctly in the program:

- When helpers arrive to the protected area with a person, and they still need the evacuation equipment, the patient has to be helped out from the equipment. This relocation time could not be set easily nor at patient's behavior or at helper's behavior.
- There is only two type occupant 3D animation: hospital bed or wheelchair. The user can define as many type of vehicle shape but there won't be animation for sticks, crutches, blind persons, etc.
- For the statistical calculation I needed to do the variations and reruns manually, because 'monte carlo simulation' method makes randomize not only for parameters but for placement also.
- The "wait time of a door" function doesn't take into account that someone might already be waiting at the door, i.e. they are in an open state in reality.

It is also apparent that examination of the evacuation process should include more details, to make more real-life simulations. This study outlines several examination directions for me to continue my research:

1. Regarding to the hospital environment, further evacuation equipment can be available: hospital moving beds, evacuation mattresses, rescue chairs, evacuation chairs, etc. This will increase the number of patient types.
2. Several patient distributions should be simulated to find out the maximum and minimum evacuation times. Since this cannot be fully accomplished for all variations, a frame number must be specified. The distribution can be given thematically or randomly. If the results of the selected runs show a normal distribution, then statistical estimates from it will be generally acceptable.
3. I should use of "change behavior" function to better use of helpers time in the model.
4. I should use of man or women helper because in practical tests it was found that their abilities to carry out evacuation differs in speed and numbers. [9]
5. By modeling a larger area, arrival of helpers to the area to be evacuated can be simulated with a better accuracy, even if they are coming from areas other than the adjacent levels.
   It is necessary to limit this sensibly, because if, for example, they come from another building and only arrive at the end of the process, there is no point in refining the model in this direction.
6. Use of direct sequence of patients allows the triage method usage. But this significantly increases the number of variants to be tested and it may not reflect reality in all cases

You can experiment on your computer, trying out different versions with an improved modeling method, without running into any technical or ethical issues. The result can be used during fire protection planning, for management to develop evacuation protocols or for safety training also. Because of all this, I believe that the use of evacuation simulation programs can be of paramount importance in planning evacuation.

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