Logistics Principles for the Emergency Evacuation of People

Logistički principi za hitne evakuacije ljudi

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Summary

This contribution focuses on the issue of the evacuation of people during emergency situations. The study of the logistics processes for a selected object were based on the layout of the administration building, namely that of the Institute of Technology and Business in České Budějovice. The evacuation model, PathFinder, was utilized for the calculation and preparation of the logistics processes for the evacuation of people.

KEY WORDS

logistics process, evacuation of people, emergency situations, schools

Sažetak

Ovaj prilog se fokusira na pitanje evakuacije ljudi za vrijeme hitnih situacija. Studija procesa logistike za odabrani objekt temeljena je na nacrtu administrativne zgrade, naime Instituta tehnologiju i poduzetništvo u gradu Českе Budejovice. Model evakuacije PathFInder korišten je za izračun pripreme logističkog procesa za evakuaciju ljudi.

KLJUČNE RIJEČI

logistički process, evakuacija ljudi, hitne situacije, škole

1. INTRODUCTION

In recent times, there have numerous emergency events (EE), accidents or terrorist attacks that have threatened people, their health, animals, property etc. People should be prepared for such situations and should be able to respond adequately and quickly to a particular event. Every one of us is confronted with such adverse situations on a daily basis. In order to adequately face this reality in the 21st century it is essential that the potential participants in such situations are aware of what they must do. This is particularly true from the viewpoint of the principles of behaviour during such an occurrence and for the elimination of the adverse impacts thereof. In fact, participants in such EEs are usually not sufficiently instructed, informed, or practically equipped. This only increases the risk of the possible negative impacts. Unfortunately, as is evident from news events from around the world, no school, at whatever level, is truly safe against such situations. It is not just children and students that should be regularly instructed in these topics, but also school employees. With regards to the risks that threaten schools (fire, flood, terrorist attack, seismic events, etc.) it is necessary for all to know what such risks bring and how to respond to them.

2. LITERATURE REVIEW

a) Historic origins of the topic

Folwarczny, Pokorný [1] state that the origin of the first significant research into the evacuation of people in relation to an occurred EE dates back to 1935. Significant success was achieved in Japan in 1955, when an equation was formulated and published for calculating the time necessary for people to escape a situation. During the period 1972-1982 the majority of the research in the field of evacuation was performed in Canada, where the behaviour of people on construction sites was monitored due to the massive accumulation and consequent concentration of people. As a result, the term EE was born and defined. Martínek and Linhart [2] present the following types of emergency situations (including sub-divisions thereof): *natural disaster* (flood, earthquake, huge landslide, volcano eruption, hurricane, tornado, extreme cold and heat, meteorite impact and large forest fire); *accident* (chemical operation, radiation accident, oil accident, road accident and building collapse); *other events* (terrorist act, sabotage and arson). According to Zeman and Mika [3] there are two basic types of emergency events, namely *natural* (natural and biological) and *civilization* (anthropogenic disaster, accident).

b) Methodology of evacuation

According to Kratochvílová [4] the term evacuation can be classified from different points of view e.g. in terms of *the size of the measure* (site and general), or in terms of *the duration (short-term and long-term evacuation)*. Kratochvílová and Smetana [5] classify evacuation in terms of *the size of the area* (site and general), in terms of *the selection of people* (general and selective), in terms of *evacuation duration* (leading out,

short-term, long-term), and in terms of *the evacuation level* (spontaneous, controlled). Baštecká [6] classifies evacuation according to the same factors as Kratochvílová, but adds parameters such as *threat* (direct evacuation – without hiding, and evacuation with hiding). Baštecká [7], Kyselák [8], who tackle the issue of evacuation by foot, which they divide into planned and unplanned, present a similar classification to the aforementioned authors.

c) Evacuation plan

The rules and methods for the evacuation of a site are defined in an evacuation plan (EP). An EP is drawn up for buildings and premises where the conditions for intervening are complicated or where activities with a high risk are performed. The framework for an EP is laid down in fire prevention documents that are formulated on the basis of the specific fire safety conditions with regards to these activities, including performed activities with a higher than level 1 fire risk. In addition to an EP, some companies must also draw up specific internal emergency plans with specified evacuation principles [9,10]. Baštecká [6] states that an evacuation plan is a set of selected information and prepared procedures that sets out the principles for the evacuation of occupants. Kočí, Stiebitz, Kopecká [11] suggest that for premises and areas where activities with a high fire risk are performed, or where the conditions for intervening are complicated, a fire evacuation plan for the quick and effective evacuation of people, animals and materials from areas threatened by fire (natural disaster) is formulated. According to Baštecká [7] an emergency plan is a document that needs to be in place where level three or special emergency events are, or can be, anticipated. The responsibility for drawing up such an emergency plan lies with the regional fire brigade, the units that make up the Integrated Rescue Service, the regional office, and other relevant administrative bodies, and is based on an analysis of the occurrence of emergency events and subsequent threats in a specified area.

d) Evacuation of people

Folwarczny, Pokorný [1] state that the evacuation of people is the short-term abandonment of an area potentially endangered by the side effects of a fire (e.g. lack of oxygen, fumes, heat) without the assistance of the emergency services. In terms of evacuation time, this can range from tens of seconds to a maximum of several minutes. According to Martínek and Linhart [12], an evacuation is one of the most effective and widespread measures used for the protection of occupants/inhabitants from the possible consequences of emergency events or the threat thereof [13]. An evacuation is performed on the basis of the assumption of the long-term or substantial aggravation of life conditions as a consequence of a natural disaster or an industrial accident (radiation, chemical). Evacuation measures are frequently applied when there is still only the threat of an emergency situation, or when an emergency situation is in its initial stages. Neugebauer [14] states that there are numerous reasons for instigating an evacuation – fire, flood, terrorist attack, technical failure, as a consequence of an emergency event that happened to another legal entity, etc. The term evacuation is often confusingly understood to mean only the evacuation of inhabitants. Its definition is however much wider, and in principle involves the movement of people, animals, objects of cultural value, technical equipment, but also machines and materials necessary for maintaining essential production, and dangerous substances from the places endangered by an emergency event [8]. Kofránková [15] claims that one´s own safety has to be kept in mind during such events. A rescuer is exposed to various kinds of danger e.g. burial, explosion, flames, toxic gases, etc.

3. MATERIALS AND METHODS

The premises of the Institute of Technology and Business in České Budějovice, specifically Block D, the main administration building of the institute, was chosen as the test object. The building was designed and constructed in the 1960s. It has 6 storeys and its bearing structure is a reinforced-concrete skeleton. The cladding is also prefabricated – reinforced-concrete blocks, inter window fillers and windows. The building has been altered on several occasions. Each floor is divided into two fire sections, with a Type B protected escape route (PER). This PER involves a lift, but one that does not meet the requirements for an emergency lift. The ground floor consists of an entrance hall, reception area, offices and toilets. The first to fifth floors are home to a combination of offices and classrooms. The sixth floor consists of a dormitory and some additional offices. The building has three entrances – from the east through the front entrance into the reception area, from the south through a side entrance into the reception area, and from the west through a rear entrance. Alterations during recent reconstruction work focused on the enlargement of the Type B PER space and the installation of an evacuation lift. The existing lift also forms part of the PER.

The PathFinder evacuation model was used for the calculations. It is an analytical tool, which when connected with an external model of a fire, can simulate the evacuation of people for risk assessment purposes. PathFinder is particularly useful for determining where evacuation barriers may occur and where queues may form, and therefore for safe evacuation design. PathFinder is not designed with a particular type of building in mind, it therefore offers users a range of versatile applications. The model works with the individual movement of people and enables us to obtain information on the position of each individual escaping during the simulation, and where they are moving to (usually towards the exits). It provides an overall overview of the concentrations of people throughout the whole structure being studied. The model enables researchers to establish the places where accumulations and queues of people are likely to occur during an emergency evacuation. This makes it possible to determine the optimum widths of escape routes and exits. The model divides the space into nods, through which the individual people move. A system of interconnected nods forms a two dimensional network which represents the structure through which the people pass. PathFinder uses a geometrical model within which a so-called navigation mesh consisting of continuous 2D triangular areas is defined. The movement of people follows this navigation mesh. The navigation mesh has an irregular one-sided surface consisting of adjacent triangles. Example navigation mesh is shown in the figure below (Figure 1).

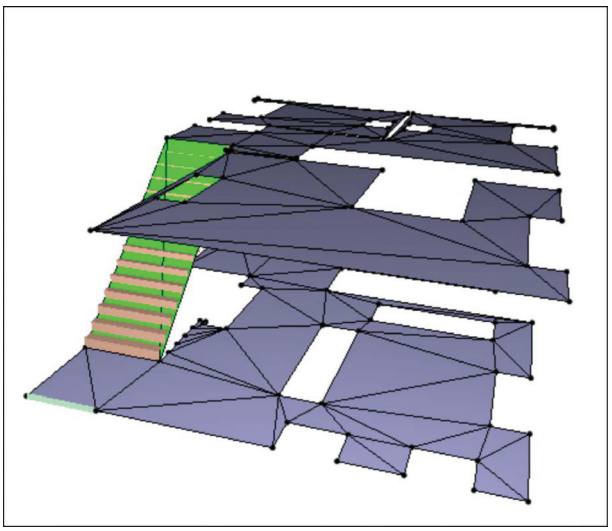


Figure 1 Example of a navigation mesh [16]

Basic outputs:

- the number of people that used the monitored exit,
- the minimum, maximum and average time necessary to leave a particular room,
- the time required to empty the stairwell or floor,
- the total evacuation time,
- the average or current evacuation speed, etc.

a) daytime operation

- expected occupation of the building (bedrooms only used occasionally, so not taken into account),	offices and classrooms
- time delay,	5 seconds
- total number of people in the building.	811

b) night time operation

- expected occupation of the building (offices/classrooms only used occasionally, so not taken into account),	bedrooms, reception
- time delay,	2 minutes
- total number of people in the building.	117 (3 of which at reception)

4. RESULTS AND DISCUSSION

Calculations were carried out for six daytime evacuation plans and two night time evacuation plans[1]. Only the most effective methods are presented due to the limitations set on the size of this article.

a) Daytime operation

Alternative 1 **–** evacuation time *14 minutes 5 seconds*, the evacuation time is acceptable.

Type B PER, the evacuation lift is not (very unlikely) used.

Alternative 2 **–** evacuation time *13 minutes 31 seconds,* the evacuation time is acceptable.

Type B PER and escape by the evacuation lift, approx. 10% of the people on the 5th and 6th floors, then escape through the main or side exit.

Alternative 3 **–** evacuation time *13 minutes 20 seconds,* the evacuation time is acceptable.

Type B PER and escape by the evacuation lift, approx. 20% of the people on the 5th and 6th floors, then escape through the main or side exit.

Alternative 4 **–** evacuation time *14 minutes 14 seconds,* the evacuation time is acceptable.

Type B PER and escape partly through the main or side exit, the evacuation lift is not used.

Alternative 5 **–** evacuation time *13 minutes 58 seconds,* the evacuation time is acceptable.

Type B PER and escape partly through the main or side exit, the evacuation lift is used by 10% of the people on the 5th and 6th floors.

Alternative 6 **–** evacuation time *13 minutes 42 seconds,* the evacuation time is acceptable.

Type B PER and escape partly through the main or side exit, the evacuation lift is used by 20% of the people on the 5th and 6th floors.

A further in-depth analysis follows for *Alternative 6* for daytime operation.

Alternative 6

Ground floor	escape partly through the main (front), side and rear exits (87 people)
1st - 4th floor	escape through the Type B PER and partly through the ground floor, ratio 70:30 (377+161 people)
5th - 6th floor	escape through the Type B PER and partly through the ground floor and approx. 20% of people by the evacuation – approx. 60:20:20 (110+38+38 people)

→ evacuation time *822 seconds (13 minutes 42 seconds)*

A further in-depth analysis follows for *Alternative 8* for night time operation.

Alternative 8

Ground floor	escape through the main (front) or side exits (3 people)
5th - 6th floor	escape through the Type B PER only (102 people); escape by the evacuation lift by approx. 20% of the people on the 5th and 6th floors (23 people) then escape through the main (front) or side exits

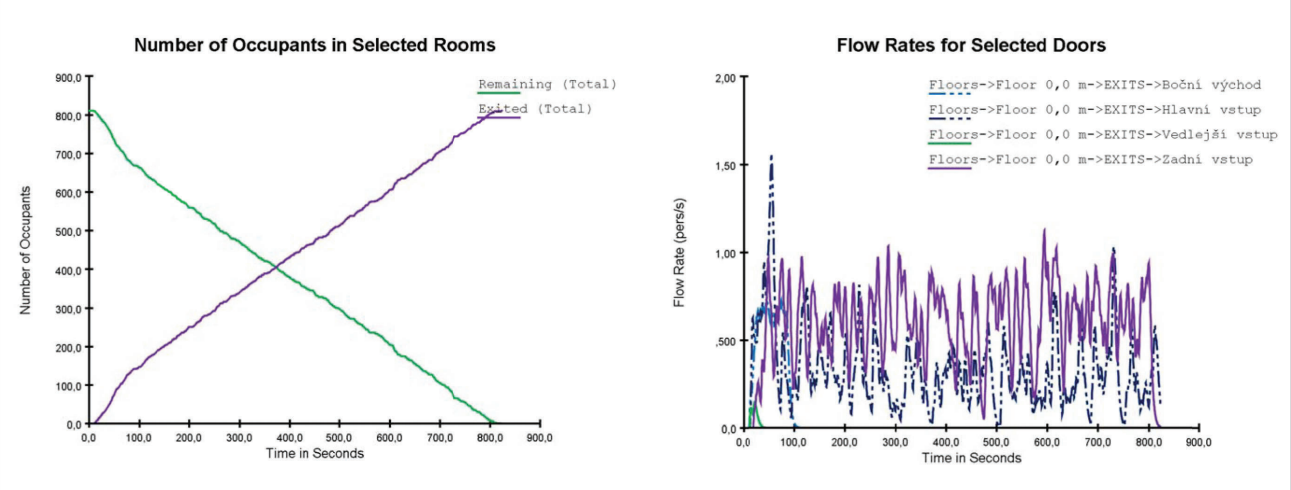
→ evacuation time *383 seconds (6 minutes 23 seconds)*

5. CONCLUSION

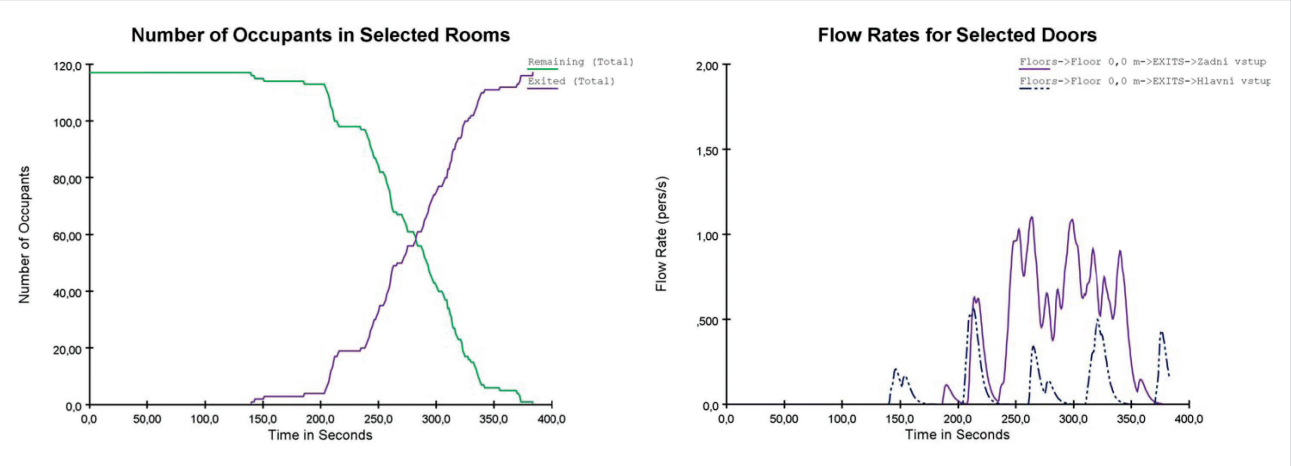
The calculation was based on the following assumptions:

- The number of people was determined on the basis of the purpose of the rooms and the requirements under the standard ČSN 73 0818 *Fire protection of buildings - People/ surface area in buildings*. The number of people determined on this basis exceeded that of the number of people the building was designed for as well as the usual numbers of people in the building. The number of people is therefore within safety limits.
- Evacuation of people with lower movability: 4% of all the people during daytime operation, 1% of all the people during night time operation.

[1] The conclusions of the study *Evacuation of building D at the premises of the Institute of Technology and Business in České Budějovice* by doc. Ing. Petr Kučera, Ph.D. and Ing. Isabela Bradáčová, CSc. from the Fire Protection Department of the Mining University Ostrava (2014) were used for the calculation.



Graph 1 Evacuation of people – Alternative 6 [16]



Graph 2 Evacuation of people – Alternative 8 [16]

- The calculation distinguishes between daytime and night time operation. The occupation of the bedrooms is substantially lower than the occupation of offices and classrooms. The utilization of the bedrooms during the daytime was not taken into consideration because they are only used occasionally during this time. During night time operation the bedrooms are fully occupied, with three additional people being present at reception. During daytime operation, the classrooms, offices, conference room and reception area were considered to be fully occupied.
- The threshold evacuation time was set at 15 minutes - in compliance with the operability of the Type B PER.
- For all the alternatives, the ground floor was evacuated through the main (front) and side exit of the reception area and the rear exit.
- The protected escape route (Type B PER – the exit from the landing between the ground floor and the first floor – the flow from the 1st to 6th floors does not cross the flow from the ground floor).

For the aforementioned alternatives, the adherence to the determined time parameters is conditioned by the principles listed below. These principles can be generalized and applied to other schools too.

Rules for those people being evacuated:

- to keep calm and not to get nervous
- to avoid useless discussions or arguments with other people
- to follow the instructions of the evacuation leader
- to stay at the gathering point after leaving the affected area so that it can be established how many people have been evacuated and how many are still in the affected area
- teachers who are in classrooms when an alarm is announced should lead their groups to the gathering point, check the presence of the students and report their number to the evacuation leader.

Proposed evacuation procedure of the school building:

- Teachers lead their individual groups of students away in the order set by the evacuation leader
- Teachers appoint other students in their group to assist those in a poorly condition
- Students should leave their bags in the classroom
- Teachers are expected to maintain order and prevent panic among the students e.g. to prevent a person jumping out of the window
- Teachers are obliged to check that all windows are closed to prevent draft
- Teachers are at all times the last to leave the classroom
- If a school group (class) is without a teacher another teacher must take care of them.
- Teachers must check that nobody is behind in the toilets or in any other side room

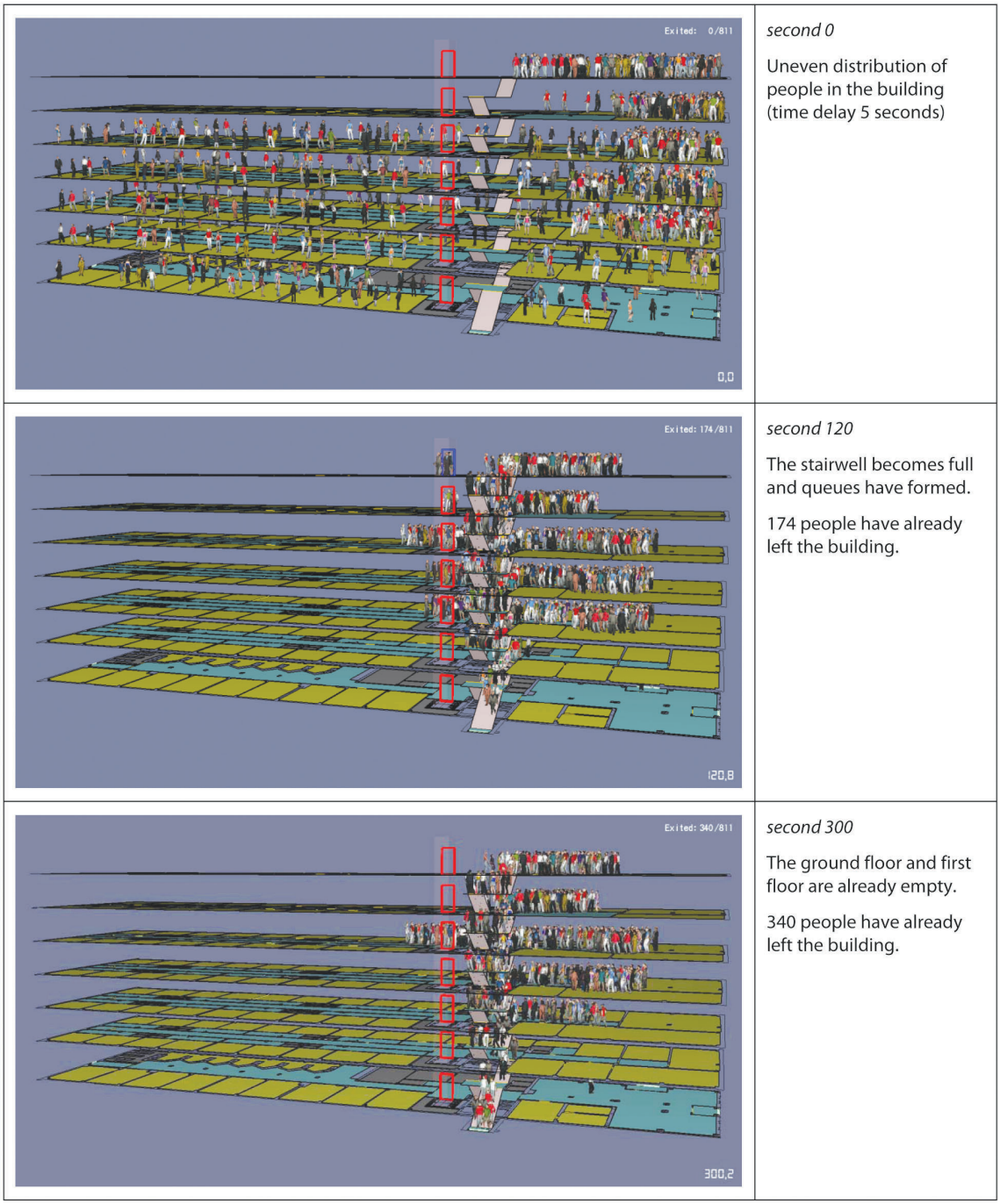


Figure 2 Visualization of the course of Alternative 6 [16]

- If a classroom cannot be evacuated due to dense smoke along the evacuation route, the students and the teachers must stay in the classroom and wait for assistance – in a situation where there is dense smoke all occupants of the space should protect their mouths and noses with a damp handkerchief
- Teachers are obliged to check and know where the official gathering point is
- Teachers and students are obliged to follow the instructions of the rescue services.
- An evacuation gathering point for each class is identified in the evacuation plan.

All the calculated alternatives meet the evacuation time limit. For alternatives 1-6, where the evacuation of the people involves the exits in the reception area, the reception area must be an integral part of the Type B PER (Protected Escape Route). The alternatives that do not foresee the use of the evacuation lift reflect situations whereby people do not use the lift for some reason (fear).

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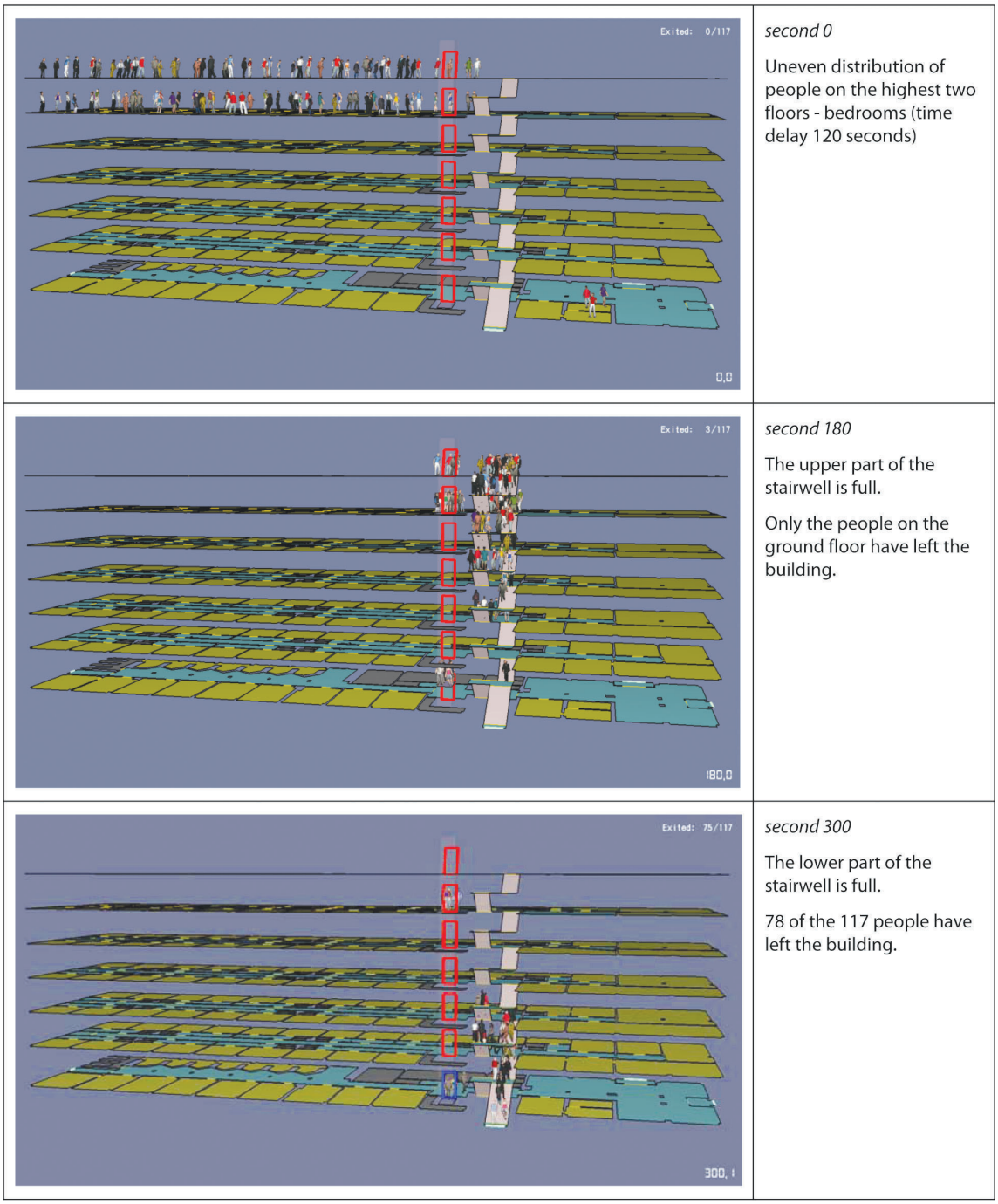

second 0

Uneven distribution of people on the highest two floors - bedrooms (time delay 120 seconds)

second 180

The upper part of the stairwell is full.

Only the people on the ground floor have left the building.

second 300

The lower part of the stairwell is full.

78 of the 117 people have left the building.

Figure 3 Visualization of the course of Alternative 8 [16]

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