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EVACUATION SCENARIOS AND REPEATED RUNS FOR EVACUATION SIMULATIONS

Abstract

The aim of the present study is to show what evacuation scenarios need to be examined during the evacuation calculations and according to which aspects they should be developed. I examined international regulations, recommendations, and literature data and compared them with domestic expectations and practices. Using an approach and examples, I show how usage patterns, geometric features, person characteristics and starting positions can influence the number and nature of evacuation scenarios. In addition, I show the extent of repeated runs due to the statistical settings of the input parameters and how it is worth evaluating the obtained results.

Keywords: evacuation, evacuation simulation, evacuation scenario, repeated runs, statistics

KIÜRÍTÉSI VÁLTOZATOK ÉS ISMÉTLÉSEK A KIÜRÍTÉS SZIMULÁCIÓKBAN

Absztrakt

Jelen tanulmány célja bemutatni, hogy a kiürítés ellenőrzése során milyen kiürítési változatok vizsgálata szükséges és azok milyen szempontok szerint alakítandóak ki. Ennek érdekében megvizsgáltam a nemzetközi szabályozásokat, ajánlásokat és irodalmi adatokat és összehasonlítottam azokat a hazai elvárásokkal és gyakorlattal. Megközelítési móddal és példákkal mutatom be, hogy a használati módok, a geometriai adottságok és a személyek jellemzői és kiindulási helyük hogyan befolyásolhatják a kiürítési változatok számát és jellegét. Emellett bemutatom, hogy a bemeneti paraméterek statisztikai beállításai miatt milyen mértékű ismételt futtatásokra van szükség és hogyan érdemes kapott eredményeket kiértékelni.

Kulcsszavak: kiürítés, kiürítés szimuláció, kiürítési változatok, ismétlések, statisztikai eredmények

1. INTRODUCTION

Computer evacuation simulation is playing an increasingly important role in the preparation of the decision in our environment. In a 2019 survey of modeling programs, a total of 272 respondents identified more than 72 types of programs, of which 35% of respondents use the Pathfinder program, which is the most prevalent in Hungary as well. [1]

In simulation, reality needs to be simplified during model building and an important decision is what and how much we simplify. When evaluating the model, it is important to know how the simplifications affected the results, so it is necessary to evaluate them together. [2]

A simplification of reality is the creation of evacuation variants during a modeling task. In another international study conducted in 2020 [3], several modeling habits and assumptions were assessed at an international level with a population of 60 participants. This revealed that 86.8% of users make multiple evacuation variants, typically due to the exclusion of the smoke-induced route, different demographic distributions, or different pre-evacuation time periods. In addition, it was found that 36% of modelers always use the default settings of programs (even if they do not know the professional reason or source), which draws attention to the responsibility of developers of modeling programs. Reruns of evacuation variants are performed by 86.9% of respondents in their studies if they apply the settings based on probability calculations.

According to the European Guideline [4], the characteristics of persons need to be specified in order to estimate the evacuation process: number of people, location in the building, whether they are asleep or awake, special function, physical characteristics, local knowledge factors, physical and mental state. The guideline also provides a recommendation for evacuation scenarios and other parameters, which I will explain in detail later.

According to the German modeling recommendation [5]: "The scenario is defined by a geometry, an initial distribution of persons, a route distribution and the statistical composition of the population." Accordingly, a change in any of these parameters means a new evacuation scenario, however, it does not define the extent of the change and in my own experience it is important to pay this issue more attention. The proposal also states that the possibility of multiple uses must be considered, and appropriate versions must be created. The choice of scenarios to be analyzed must take account of the population that applies to the property in question, the choice of escape routes and, where applicable, the effect of environmental factors.

According to the Fire Safety Technical Guideline on Evacuation [6], the scenario of the evacuation is “a description of the evacuation process and a schedule set up during the examination of the evacuability of the building or free area, during which the existence of certain conditions influencing evacuation is ensured”. This definition is very broad, and the directive does not provide further guidance on the conditions at a later stage.

At the beginning of the Fire Safety Technical Guideline [7] on evacuation simulation, it is stated that the test should be performed on the basis of a predefined evacuation scenario. But this directive does not provide - for the time being - any further guidance on how these scenarios should be set up.

Based on the above described, it can be stated that the explanation of the evacuation scenarios to be examined in several places in the international regulations is completely missing from the Hungarian regulations. Probably this is the reason why many professionals don’t see clearly, that these issues should be dealt with as early as possible in the design, because during later modifications of functions and of use, the desired operating conditions can typically be achieved only with expensive modifications.

2. EVACUATION SCENARIOS

In order to develop evacuation scenarios, the methods of use and evacuation strategies of the building must always be reviewed. In the case of an existing building, this can be more easily determined based on previous operator experience and operational objectives. In the case of planned buildings, the prospective operator is often not yet known in the design phase, so proposals can be made based on the design program, customer needs, the experience of the architect and fire designers.

Each evacuation scenario includes the built geometry, the characteristics of the people, and their location [5]. The change of these implies the possibility of a new version, but after examining the extent of the change, it is recommended to decide on this during the examination, if necessary, after official consultation. Different sccenarios may be caused by different modes of use, consideration of smoke propagation (i.e. geometric design), characteristics of accommodated persons, presence of persons with reduced mobility, starting position of accommodated persons. Some parameters can change continuously during operation, so it is necessary to design and examine the typical evacuation variants by considering the following aspects.

2.1. Modes of usage

Different modes of operation can be found in different buildings. On the one hand, they are typical of buildings that perform multiple functions, and on the other hand, they can occur in almost any building in individual cases. In this case, it is recommended to check all expected modes of operation.

It is probably not possible to prepare for each expected event during the planning phase; therefore, it is recommended to form “groups” with almost the same number of people, almost the same evacuation conditions and the same routes. Based on this, one such arrangement can be examined and then, subject to compliance with the conditions, the actual type of event is uninteresting from the point of view of evacuation.

Starting from the domestic building stock, here are some examples of these:

• In the case of a sports function, there are almost always other uses for the sustainability of the building: individual or group events, concerts, family events, political or religious gatherings, village days, etc. This is true for existing rural sports halls, which are typically the largest buildings in the settlements. Also, in the case of new sports facilities, there is a need to ensure sustainability from the outset.

In the case of a sports hall, if there are spectators in the entire stands fleeing upwards, it essentially does not matter what (sports) event takes place. However, if they can also escape down to the arena, it is necessary to examine whether these directions are blocked in the case of different types of sports or other equipment and, if so, whether this has an effect on evacuation (for example, the fixed backboard in hockey).

- In the case of multi-purpose places, it is worth examining all possible layout patterns. But if we assume a stage in the front or in the middle, it doesn't matter if there's a concert or a speaker on it.
- In an event hall, it does matter in terms of evacuation whether there are seated spectators or standing spectators, because quite different numbers and obstacles are expected.
- Halls and gyms are typically used in school buildings to host larger events, balls, school year openings, so these should be checked as well.

Of course, there are buildings where the design allows for practically 1 use and in that case it is not necessary to design several evacuation scenarios due to different uses, but this requires careful consideration in each case.

2.2. Characteristics of persons

The characteristics of individuals typically include their size, speed of movement, ability to escape, and other properties of movement. These parameters can be specified with fixed values or based on statistical distributions.

Modeling programs make a default recommendation for people's properties, making everyone in the model "the same". In the research of Kinsey et al. [3] it is found that 36% of modelers always use the default settings of programs (even if they do not know the professional reason or source), which draws attention to the responsibility of developers of modeling programs. However, from a professional point of view, it is recommended to use different personal settings and the corresponding literature data, because this is expected to bring the representation more realistically closer, although this is not currently expected during the application in Hungary.

The social distribution is typically the same for each run in an evacuation scenario. In modeling, individuals should be mobile on their own, so there is no need to consider the social dimension of group relationships, even if the program would otherwise provide an opportunity. It is important to note that if the result of a simulation does not match, the demographic data should not be modified for compliance! [5]

The main characteristics of persons are generally defined and grouped by age and gender in the literature. If the distribution of users (by age and / or gender) is known in the building under study, it is recommended to use it. In the case of an existing institution, this can be examined by measuring the number of employees, using usage data, in case of planning, determined based on the target groups defined in the planning program. Sometimes other external controllers (e.g. standard, sports regulation, operational safety regulation, etc.) provide the information you are looking for, which can also be used in modeling.

If no other data are available to construct the model, it may be appropriate to use a generally accepted population distribution. Of course, it is recommended to consider whether this may actually occur in the type of building under study, but it may be applicable to general cases (e.g. shopping mall). In Germany [5], this distribution is 50-50% women and men, with an average age of 50 years (standard deviation 20 years, between 10 and 85 years). A similar one could be developed in Hungary in the future based on the census data of the Hungarian Central Statistical Office.

The characteristics of the persons should be set according to the mode of operation and, if expected in the given function, the variants considered “extreme” should be checked in at least one mode as a sensitivity test. For example, in the case of a concert, one extreme could be the masses of teenage girls, while the other extreme could be older, classical music program students. If, based on the sensitivity test, the building behaves almost identically in these, it is no longer necessary to deal with the difference between persons, an average distribution or fixed values can be used. According to the SFPE guidelines on evacuation behavior [8], in the case of a well-defined, robust model, a small change in the characteristics of individuals should not cause a major difference in the result.

2.3. Presence of disabled persons

In evacuation simulations, it is expected that if persons with limited ability to escape may be present in the building, they should also be included. As public buildings in Hungary are mandatory to be accessible, it is typical to include into the modeling a person who is always limited in his / her expected movement speed, and most often this limitation includes using a wheelchair. In other cases, it is an issue of operation or a feature of the function (for example, as a hospital nurse, there will certainly not be a person in a wheelchair).

Annex E of the FPTG on Evacuation [6] contains the proportion and type in which it is necessary to consider persons with reduced mobility during the design, and this should also be applied to simulations. Temporary protected spaces shall be sized for the maximum number of occupants and shall be tested in at least one evacuation scenario.

However, there may be a design in which the evacuation process is not affected by, for example, the number of wheelchair users, and this can be supported by a sensitivity test. In this case it is not necessary to apply the maximum number of evacuations in all evacuation scenarios.

2.4. Location, starting position

As the location of persons is a constantly changing parameter in time and space during the operating of the building, it is recommended to develop typical scenarios for them. This must be considered individually for each building type in the knowledge of the operation processes.

Some examples from my own experience:

1. For a stand, one extreme value of operation is when everyone is sitting in the stand, while the other is when no one is there but instead everybody is in the aisleways. In the case of a longer event, almost any division between the two is conceivable due to the constant crawling in and out, the use of washbasins and purchases in the buffet. In this case, the examination of the two extremes may be typical, which may show different loads in the use of aisleways.

2. In an office building, the theoretical maximum occupancy is when everyone is sitting in place and even external guests are in the meeting rooms. It is recommended to consider whether

the company has such internal rules of operation, or whether external persons can only be present in "external" negotiating areas.

3. In offices or in industrial buildings, it is possible to consider how the meals are solved: with a central canteen, which operates at a fixed time with high occupancy (but then workers are not in place, so they may use other evacuation routes) or tea kitchens on each level, more informal time distribution, which is not expected to substantially affect level evacuation.

4. In an industrial buildings, consideration should be given to the system followed during shift changes, whether they are in the locker room or in shifted time zones at the same time.

The number of employees and the starting point are basically determined by the planning program or the FPTG on Evacuation [6], this is recommended to be checked as a basic version. If a reserve appears in the building compared to this, it is worth determining the maximum capacity by simulation and creating a separate version for this.

2.5. Geometric properties

With the basic, classical approach, all exits are safe and accessible and are known and used by individuals [5]. This approach also coincides with the design principles of the OTSZ [9], but also assumes that the other parameters related to evacuation are designed in accordance with the law: escape direction signs, safety lighting, trained personnel who are present. However, this basic approach does not consider that the building may have not only people with local knowledge or that there might be people who will not take into account the exit signs.

Therefore, in a building, the evacuation concept developed and the flexibility of evacuation routes can be checked with other recorded scenarios. It can be examined whether the building can be safely left even in the case of closing, temporarily closing and weighted use of an exit direction. This is suggested by several international standards:

1. In the US regulation [10], for example, evacuation must be justified for certain functions so that 2/3 of the users can leave the main entrance and in general at least half of the users.

2. In English regulations [11], if there are several exits from an area, it must meet the requirement even with the largest closure. A similar requirement applies to stairwells: one shall be considered unusable and still comply with the requirements, unless the staircase can be

approached through a protected passageway at all levels or is designed as a pressurized smoke-free staircase.

3. In the European Evacuation Guideline [4], when considering safe evacuation, it is recommended to consider scenarios of fire events that are difficult to control or close to the exit. In addition, 2 basic variants are detailed, during which the largest exit must be disregarded.

According to the current Hungarian regulations, the performance of such tests is only expected if the simulation test is carried out together with the fire- and smokespread simulation and, based on the results, one direction is physically limited by the effect of smoke. In the case of other evacuation verification methods, this does not need to be addressed at all during the planning process.

2.6. Change of the pre-movement time

According to the current Hungarian guideline [7], the pre-movement period is used in the modeling only if the evacuation is to be studied together with fire- and smokespread simulation [12]. In addition, however, all professional participants are aware that this period is a significant part of the evacuation process, which can often be more decisive than the time of the movement itself.

There are more and more pre-movement time results in the international literature [13], which is also aided by the spread of CCTV systems. These typically refer to a specific function, for which they can also be used in studies. However, there is no data available for many functions for which categories can be formed based on building and user characteristics. In the European Guideline [4], these categories are: users are asleep or awake, they are acquainted with the place or they are not, and how complex the building is and what the fire alarm system is like. Based on these, very different values are recommended starting from 0.5 minutes to> 30 minutes.

During the complex assessment of the suitability of the building, it is recommended to check the traffic areas and crowding with several settings, but the aim of the test is not to check the compliance with the evacuation times specified in the OTSZ [9]! To do this, it is recommended to use the following 3 settings and evaluate the occurrence of possible overcrowding:

• immediate evacuation - the pre-movement time is 0 s for each person

• fast evacuation - the pre-movement time is 0-60 s, given by the even distribution function

• slow evacuation - the pre-movement time is given in an even distribution, selected based on the characteristics of the building and of the users.

3. EVACUATION RUNS

The total evacuation time predicted by the models and the actual evacuation time are also influenced by a lot of parameters, which is due to the statistical nature of the evacuation process. [5] Evacuation simulation programs allow for a variety of settings for configurable numerical data: constant values or a statistical distribution. At the moment, in Hungary it is not a requirement to check the probability of the set parameters of the evacuation scenario by running the program multiple occasions.

3.1. Need for multiple runs

When using statistical distributions, the modeler needs to consider the extent to which changes in those values affect the results. If significant, it is important to run the different evacuation scenarios several times and to recalibrate the set parameters randomly for each run (demographic characteristics, time before evacuation, possibly starting point). By evaluating the results and partial results of these runs, it is possible to realistically evaluate the evacuation of the examined area on a statistical basis. Of course, based on everyday practice, this means extra work to the model maker, but program developers try to facilitate this by developing appropriate automations.

There may be a variable setting of values that, based on the observation, does not cause a significant change in the result, but it is recommended to examine this option as well, which can also be done using multiple evacuation scenarios. Such is the case with a delayed departure for a relatively small number of staff in a high-capacity building, which can always be realistically different, but is not expected to cause significant fluctuations in the end result compared to the large whole.

3.2. Number of re-runs

The “expected” number of re-runs is not clearly defined in the international literature either. The German expectation [5] suggests at least 10 replicates for each evacuation scenario but mentions that more repeats may be required depending on the results obtained. Elsewhere [3], no specific value appears, but the expected number of iterations is linked to a reduction in the “oscillations” of the results - although this is certainly the case for a sufficiently large number of iterations based on the principles of statistical mathematics. Another approach may be to link the expected number of iterations to a reduction in the standard deviation below a predetermined value. In my opinion, this does not pose a significant safety risk in the results when the standard deviation will be between 0-30 s, but determined in a maximum of 10% of the total evacuation time.

3.3. Evaluation of the results

In a very different way from the Hungarian practice, in international regulations, the results of multiple runs are evaluated with statistical analyses. Processing can also be done by simple mathematical or explicitly statistical processing. During processing, it is important that the results of all simulation runs of all evacuation scenarios are displayed in an understandable way.

Mathematical processing is the simplest way to process results from re-running simulations by determining empirical values: mean, standard deviation, minimum, maximum, percentile values. However, these are only values for a given number of tests, which can be refined by increasing the number of repeats, but do not always clearly characterize the expected value of the test. For example, it cannot be ruled out that in recalibrations, it was not exactly the “worst” parameters that individuals received in that given number of tests, so the results are also “worse”. But in the same way, the reverse of this cannot be ruled out either, i.e. it may be that the “best” results have been verified in that number of studies. It is also recommended to consider the magnitude of the empirical variance that affects the ability to safely evacuate the area. A small standard deviation is conceivable when it is not worth considering this value to evaluate the mean.

During statistical data analysis, it can be verified that the values from re-running the simulations show some kind of a statistical distribution. If so, the expected values can also be estimated using the appropriate equations, at a predetermined level of safety (which is generally 95% in the common statistical practice).

If the empirical values show a normal distribution, the estimated values can be given at the expected safety level: mean, standard deviation, and expected confidence interval. For example, if 20 runs have been made for the total evacuation time of an area, the expected mean value is 100 s and the expected standard deviation is 9 s, then in 95% of cases the evacuation time is expected to be between 96 s and 104 s.

An important question in the evaluation is which of the results we consider to be relevant. According to current perception and practice, if there are no variable parameters when modeling a building, then 1 end value of 1 run should correspond to the expected evacuation time (normative value or ASET). However, if we start using statistical data analysis, it works with probabilities not to give 1 specific value, only to estimate an expected interval (confidence interval estimation). This is more in line with reality but requires a change of approach in domestic practice.

4. SUMMARY

In the present study, I have summarized the role of evacuation alternatives and, in the case of simulation programs, repeated runs in the practice of evacuation planning. Since the actual evacuation processes are different in each case, due to the many objective and subjective factors that affect them, it is not advisable to check a single version when examining the suitability of a building. Modeling is always a simplification of reality, which must be done with due care and the effects of simplifications must also be considered when evaluating the results.

During the development of evacuation simulation studies, the need to design different evacuation alternatives typically appears. The reasons for this may be due to operation, spatial or due to the characteristics and location of the persons. When developing versions, it is always necessary to work closely with the designer / customer / operator, who can provide the most accurate information possible about use and users. It is also important to emphasize that although this attitude appears only in the course of modeling in Hungarian practice, it is also necessary to check for deviations due to use in all manual evacuation checks.

In the study, I also showed that if we do not use constant values in the evacuation alternatives, but input parameters that vary according to some distribution, they typically raise the need for multiple runs. This, of course, adds a lot of extra work to modeling studies, but it is facilitated by program developers. When setting up multiple runs, the variable parameters must always be recalibrated, and the results processed in an understandable form. When evaluating the results, therefore, it is not a specific value that we are accustomed to in Hungarian practice today, but an estimate of a duration or the determination of its expected interval at the accepted safety level. This discrepancy requires a change in attitude in domestic practice, however, due to the statistical nature of the evacuation processes, it would be expected to give a more realistic picture of the expected processes.

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