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OPTIMIZATION OF THE EVACUATION OF THE MUSIC FESTIVAL GROUNDS USING A NUMERICAL MODEL

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ABSTRACT

Every summer, countless cultural events and open-air music festivals take place around the world. Festivals are often held in places that were not primarily designed for this purpose (meadows, former airport areas, former industrial areas with existing buildings).

These are places with a large concentration of people - in the order of several thousand to tens of thousands of visitors and very often with a low degree of protection (the so-called "soft target"). These types of places become potentially easy targets for a terrorist attack (bomb, gunner) or crowd disaster. For places with a high concentration of people, the crisis situations mentioned are a great danger in the form of crowd evacuation, which can lead to numerous injuries or even death. The process of organizing and planning evacuation from music festival grounds is not only one of the key components of the emergency response strategy, but also an emphasis on public safety, which is a very sensitive topic in the domestic and foreign environment.

The paper analyzes the evacuation process and the impact on its performance during the crisis situation of the festival grounds in the Czech Republic. It is a part of the former production area with the existing development. The complex has only two emergency exits and its total area is over 25,000 m2. The evacuation process is simulated using Pathfinder software, in these variants of scenarios - normal operation, simple evacuation and evacuation in a crisis situation (waiting, blocking the exit). Scenarios are simulated with different occupancy of the area. The geometry is created according to the existing operational solution of the area, which is, thanks to the knowledge from repeated simulations, optimized into a safer form and supplemented with new evacuation exits. The outputs of selected variants were statistically evaluated and compared against each other.

INTRODUCTION

Festivals are events that bring together from thousands to tens of thousands of people, taking place all around the world. Also, the festivals are a place with a large number of people and a very small level of security. Such places are considered as so-called soft targets. These types of places become potentially easy targets for a terrorist attack (bomb, gunner) or there is a higher probability of a crowd disaster created by a mass of people trying to evacuate. In the event of such a crisis situation, it may be impossible for people to escape in any of the considered directions.

Festivals are often held in the open air (on a green field) or in various, existing, industrial areas, which are often used for the rest of the year for common purposes, such as warehouses, production areas, breweries, etc. The above-mentioned production areas were built for a different purpose with different operational requirements. Examples are through security, warehouses and operations, which often have their premises fenced with non-detachable, high fences with barbed wire (they make it impossible to dismantle the fence and create emergency exits). The areas are primarily dimensioned for the movement of cars or other equipment (for transporting, loading, production) and the movement of people is considered only to a limited extent of tens to hundreds (in the sense of individuals, not as a crowd) according to the size of traffic, which are completely different conditions compared to crowded festival.

In the event of an emergency and subsequent emergency evacuation, open-air festivals may not be as dangerous as those held in closed industrial areas, where there are many obstacles and existing structures, which increases with increasing density the risk of death - suffocation or crushing an obstacle.

RELATED EVENTS

For places with a high concentration of people, such as festivals, combined with alcohol and drug use, the above-mentioned crisis situations at these events are a great danger in the form of crowd evacuation, which can lead to numerous injuries or even death as we can see in historical events. Dozens of tragic events with loss of life have taken place at music festivals in the past. The most common causes of these incidents are non-compliance with the capacity of the complex in terms of number of people [1] - ticket sales above the permitted limits, poor crowd organization [2], insufficient marking or interpretation of information, or poor arrangement of evacuation corridors in combination with a small number of escape routes / low permeability.

A few selected examples of festival-related incidents are, for example, the Roskilde festival, during which 8 people died in 2000 from trampling which was caused by the crowd trying to get closer to the stage [3]. In 2009, during the Mawazine Festival in Morocco, the crowd, thanks to the overcrowding of festival premises, caused the collapse of the dividing fence structures, which claimed 11 human lives [4]. Another example is the German Love Parade Festival in 2010, where massively overloaded the entrance ramp combined with poor crowd organization resulted in 341 people injured and 21 deaths [5][6]. There are a number of historically tragic mass events, not only at festivals, but also incidents at sports matches [7][8][9], concerts [10] and religious or cultural parades [2][11], which is why the issue of the crowd and crowd situations is covered by a number of research groups around the world. This leads, among other things, to the development and use of numerical models of movement of people in the planning of mass events or their retrospective analysis. According to G. Still, their use lies primarily in the complex characteristics of interactions between people in time and space. Their application took place, for example, in the design of the Jamarat Bridge in the Mina Valley, where a numerical model analysed the movement of several million people across different directions and patterns of behaviour. As another example, the use of a numerical model in 2011 in organizing a royal wedding in Great Britain, or planning the Olympics in London in 2012 [12]. Hundreds of thousands of people took part in these events, but the above-mentioned tragic incidents show that there is a need to analyse the dynamics of the crowd even in events with a lower turnout.

In his work, G. Still [12] distinguishes 3 basic areas that need to be addressed to ensure the security of mass events - design, information and crowd management. The task of evacuation models is then to reveal safety risks and provide a basis for the functionality and effectiveness of the three areas [12]. His paper also further introduces the methodology of modelling large-scale events summarized in the following points:

1. Defining model goals.
2. Analysis of input data.
3. Compilation of scenarios and simulations.
4. Presentation of output to supervisory bodies (police, firefighters, …).
5. Design phase.
6. Design testing.
7. Project operation manual.
8. Model revision.

The following case study focuses on points 1 to 6 as part of the above-mentioned mass event security planning process.

CASE STUDY

For the purposes of this paper, dealing with the analysis of the evacuation process, a case study of a selected festival complex in the Czech Republic is created. Complex is used throughout the season for a number of music open-air festivals, which enjoy high attendance.

Festival area

The festival takes place every year in the production area, which has a total area of over 25, 000 m2, of which about 40 % of the area is built up with existing buildings of the liqueur operation (about 11,050 m2 is freely accessible to visitors). Complex is located in the industrial part on the outskirts of the city. It is lined on the north side by a train track and on the south side by a road. The complex consists of two main areas, with a height difference of 1.7 m, which connects in the southern part of the staircase 2.25 m wide and in the northern part a ramp 6.0 m wide. The whole complex is fenced with high inseparable fencing. The complex has two entrances (entrance A - width 6.4 m and entrance B - width 3.5 m). In the event of a crisis situation, these are currently the only emergency exits.

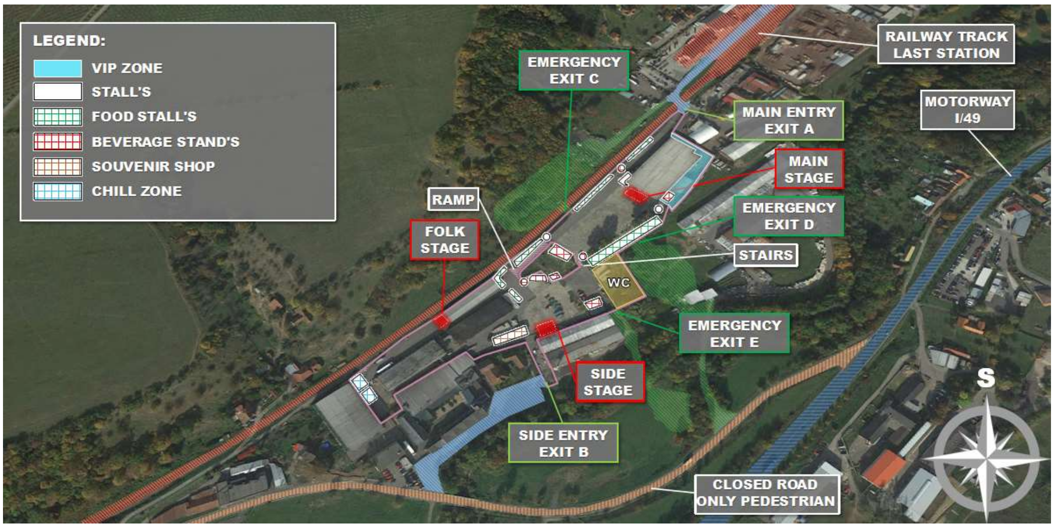

Figure 1: 3D diagram - shows an aerial view of the area with an indication of the basic elements and equipment of the area.

There are three stages in the festival area - the main stage (on the right in the main area), the side stage (in the middle part) and a small folk stage (on the left at the end of the area). Furthermore, there are a number of accompanying attractions and equipment of the area, such as stalls with refreshments and beverages, festival bars, chill zones, stalls with souvenirs, sanitary facilities with mobile toilets, etc. (illustrated in **Chyba! Nenalezen zdroj odkazů.**).

Figure 1: Photographs depicting the situation on the main screen in peak times (during major concerts) [1] [2].

Visitors are free to move around the entire area of the festival grounds. The largest crowd is usually in front of the main stage at peak times, when the main music groups perform. Therefore, even for the purposes of the model, the crowd in front of the stage is modelled according to the experience gained during field observation of the crowd during the concert and back analysis of video recordings (=> with distance from the stage, the density of the crowd decreases, Figure 2). Other patterns of visitor behaviour (where people go, where the queues are formed, where the waiting areas are created, etc.) and the distribution of people around the area is done in the model with emphasis on the acquired knowledge of field research, information provided by the organizers and from the testimonies of festival participants.

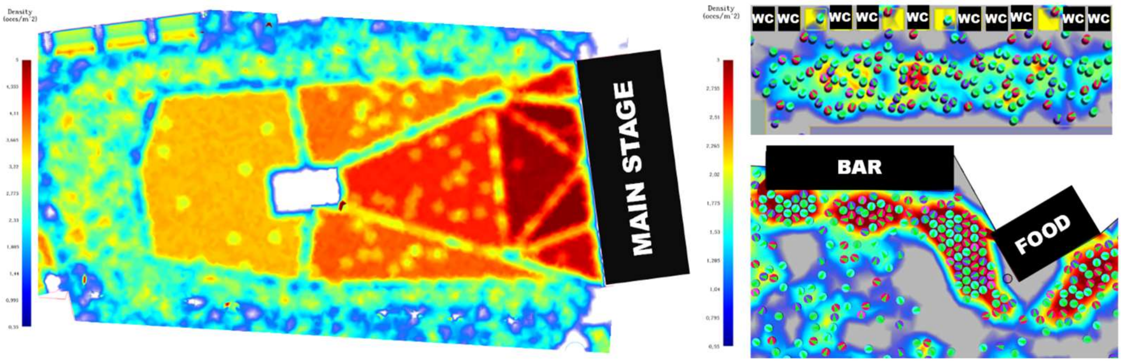

Figure 2: Example of uneven distribution of people in the model during normal operation based on field research and testimonials of participants.

Composition and occupancy of the area

For the purposes of case study simulations, the maximum occupancy of the complex is chosen - 20,000 people. The gender composition of festival visitors was chosen on the basis of data provided by the organizers of the event from 2019, when the festival was visited by about 15,000 people, of which 47 % were men, 38 % women and 16 % teenagers (for more details see Table 1). Age distribution in Table 1 was determined on the basis of a combination of data from the demographic curve of the Czech Republic [15] and the statistical survey NMS Market Research [16], which deals with the attendance of festivals in the Czech Republic. This survey also shows that the most numerous age groups of visitors to Czech festivals are groups of people aged 16-29 and 30-49.

Table 1 Age and gender composition of the population [15][16].

Persons	Representation [%]	Persons	Representation [%]
Women (< 30 years)	25,80	Men (<30 years)	30,20
Women (30-50 years)	14,70	Men (30-50 years)	17,30
Women (> 50 years)	5,50	Men (> 50 years)	6,50

It should be noted that the representation of gender and age groups may vary considerably for other music festivals (with regard to the type of event, performing musicians, etc.) and should not be uniformly extended to all sporting events. Handicapped people are not considered in the model through poor barrier-free conditions of the entire complex.

AGENT-BASED MODEL OF FESTIVAL

The basic geometry model of the existing operational solution was created in cooperation with the organizers of the event on the basis of the drawing documentation of the festival area and was supplemented by findings from field research. To simulate the scenarios, a model with a continuous network based on agent technologies - Pathfinder, produced by Thunderhead engineering, was created.

Scenarios

The first scenario, which was simulated – S1 – Normal operation, was the basic model of the functioning of the entire festival area. It was compiled in order to verify and eliminate the emergence of critical points during the festival (crowd events). Based on its results, changes in the geometry of the layout of the area are proposed. Furthermore, the model was simulated in five variants of evacuation scenarios: S2A - Simple evacuation (non-optimized), S2b - Simple evacuation (optimized), S3 - Barrier exit A, S4 - Addition of new emergency exits C, D, S5 - Addition of new emergency exits C, D and E, in which an emergency situation (fire, bomb, etc.) is expected in the auditorium in front of the main stage with the subsequent complete evacuation of all persons from the complex. A specific description of all scenario variants is detaily described in Table 2. and schematically shown in Figure 3.

Table 2: an overview of modelled scenarios for the festival grounds.

Scenario		Description
S1	Normal operation	It shows the normal functioning of the festival and the flow of people. There are about 190 combinations of patterns of behaviour (e.g. arrival, visit to the stands, waiting in queues, visit to the toilet, participation in the auditorium, etc.), occupancy of 20,000 people.
S2a	Simple evacuation (non-optimized)	It shows the emergency evacuation from the area in the current state (without removing critical points of operation), with the availability of both exits, occupancy of 20,000 people.
S2b	Simple evacuation (optimized)	It shows the emergency evacuation from the area in an optimized state (with critical points of operation removed), with the availability of both exits, occupancy of 20,000 people.
S3	Barrier exit A	It shows the emergency evacuation from the area in an optimized state (with critical points of operation removed), during which exit A is blocked, occupancy of 20,000 people.
S4	Addition of new emergency exits C, D	It shows emergency evacuation from the site in an optimized state (with critical points of operation removed) with the addition of two new exits C and D with a width of 4.1 m at the central area, occupancy of 20,000 people.
S5	Addition of new emergency exits C, D (at the central area) and E (in the bottom part of the area).	It shows emergency evacuation from the site in an optimized state (with critical points of operation removed) with the addition of three new exits C and D 4.1 m wide at the central area and one exit E at the bottom of the site, occupancy 20,000 people.

In order to get an overview of the impact of optimization changes on the evacuation process, scenarios S2a and S2b are created, in which the evacuation under current conditions (S2a) is compared with the evacuation from the site after removing the problem of critical points (S2b). Evacuation scenarios are simulated in order to predict the development of the situation during the evacuation of a fully occupied festival area, both under current conditions and when blocking one of the exits (S3), or when adding new emergency exits (S4, S5).

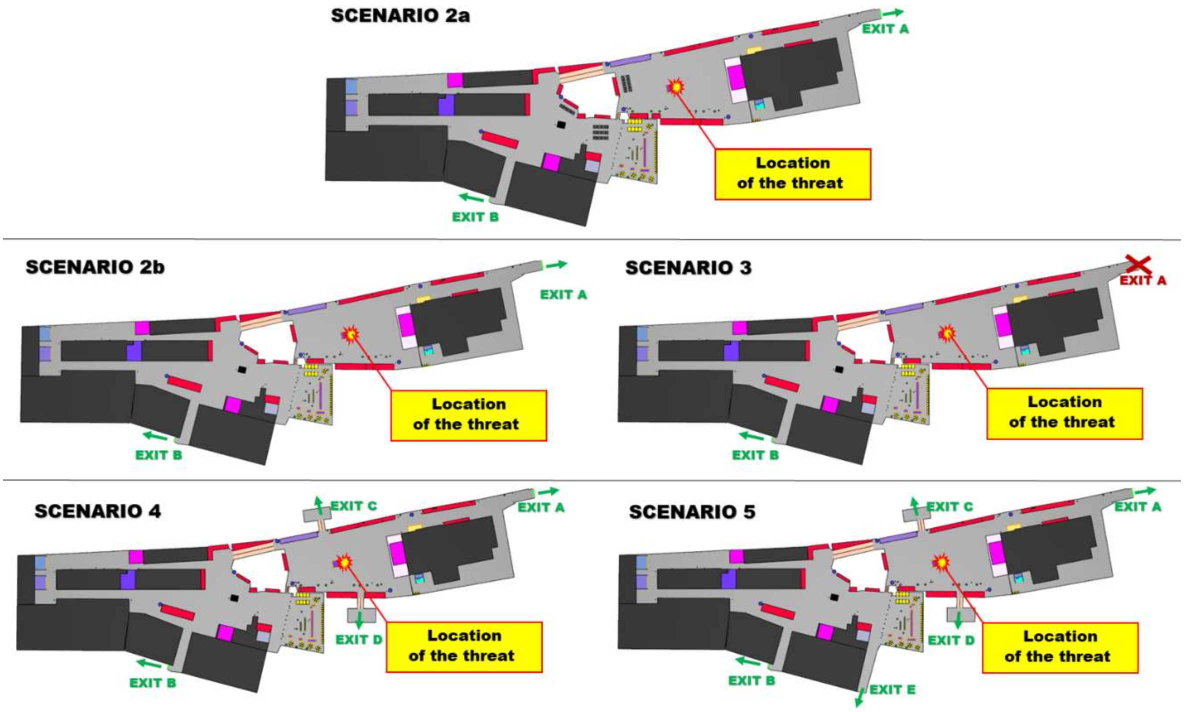

Figure 3: Scheme of the area with individual variants of scenarios (grey area - flat for free movement of visitors, red and purple - equipment of the area, pink - stages and black - existing building).

<u>Input data</u>

Characteristics of population

Within the input data of the model, all persons are assigned selected parameters according to individual divisions, especially the parameters like body space, walking speed and Pre-evacuation time. To define the body space of individuals divided into groups according to Table 3, the knowledge from the work of S. Pheasant is used [17].

Table 3: Gender composition of the model population.

Years	Gender	5% percentile	Mean μ	St. Dev σ	95% percentile
19 - 25	Women	35,5	39,5	24	43,5
	Men	41,5	46,5	29	51,0
19 - 45	Women	35,5	39,5	24	43,5
	Men	42,0	46,5	28	51,0
45 - 65	Women	35,0	39,0	24	43,0
	Men	41,5	46,0	27	50,5

The physical abilities of festival visitors are represented through the distribution of walking speed (see Table 4). The used speeds of persons are distributed into six groups according to gender and age, in the range from 0.391 - 1,610 m.s^{-1} (according to the direction and type of terrain). The primary source for the speed of walking of people on the plane was the findings of U. Weidmann [18] and J. Fruin for the movement of stairs [19][20]. The assigned speeds represent the maximum speeds of the individual persons who can move around the terrain. These speeds may vary during the simulation depending on the current situation and the density of the crowd.

Table 4: Distribution of rates by gender and age of the group based on [18][19].

Years	Gender	Movement speed [m.s^{-1}]				
		Flat surface	Stairs		Ramps	
		Range	Down	Up	Down	Up
< 30 years	Women	0,516 - 1,433	0,315 - 0,873	0,285 - 0,791	0,415 - 1,153	0,400 - 1,112
	Men	0,580 - 1,610	0,439 - 1,217	0,296 - 0,822	0,509 - 1,414	0,438 - 1,216
30-50 years	Women	1,255 - 1,371	0,486 - 0,530	0,457 - 0,499	0,870 - 0,950	0,856 - 0,935
	Men	1,410 - 1,514	0,666 - 0,716	0,495 - 0,513	1,038 - 1,115	0,952 - 1,023
50 > years	Women	0,605 - 1,255	0,307 - 0,637	0,254 - 0,528	0,456 - 0,946	0,430 - 0,891
	Men	0,671 - 1,392	0,37 - 0,768	0,281 - 0,583	0,520 - 1,080	0,476 - 0,987

The pre-evacuation time parameter includes psychological, environmental, cultural and sociological factors that are otherwise very difficult to describe in evacuation models. Within this time, the effect of alcohol is also taken into account, according to the findings of the study by E. A. Maylor et al. [21] and other works [22][23], which is often consumed at festivals. Documented real crisis incidents and experimental measurements documented so far that pre-evacuation time in most cases follows a log-normal distribution [24].

Based on the log-normal distribution, two random distributions of the reaction time are considered for the case study model, see Figure 4. The first of them - pre-evacuation time for people in front of the main stage, which is defined by the occurrence of an emergency (fire, bomb, lone shooter) and the time of the start of movement (evacuation) of people towards the exit. The second of them - pre-evacuation time for people in more distant positions from the stage, which is defined by the announcement of the evacuation (alarm, voice message, staff warning, danger observation, etc.) and the start time of the movement (evacuation) of people towards the exit.

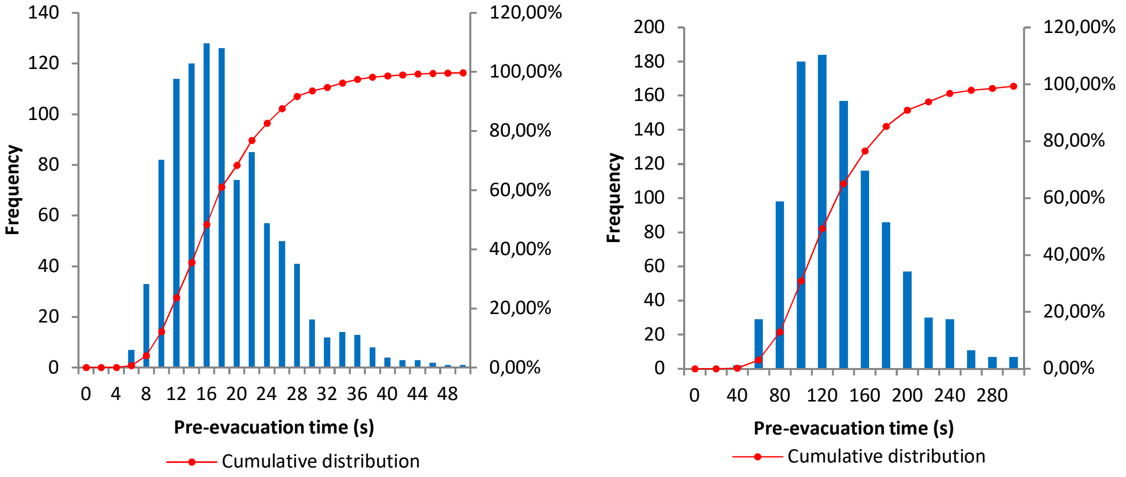

Figure 4: Histogramy log-normal distribution pre-evacuation time determined on a sample of 1000 persons for – persons near the incident before the main stage (left), with parameters μ = 2.8, σ = 0.4, 5th percentile = 8.5 s, 95th percentile = 32 s and persons further away from the main stage (right), μ = 4.8, σ = 0.4, 5th percentile = 63 s, 95th percentile = 237 s.

Results

The basic model of the area geometry was subsequently optimized to a safer arrangement (variant S2b) and supplemented by new evacuation exits (scenario S4) thanks to the findings from repeated simulations of scenario S1 - "Normal operation". Each variant of the scenario was run in several iterations and the outputs of the individual variants were statistically evaluated and compared against each other.

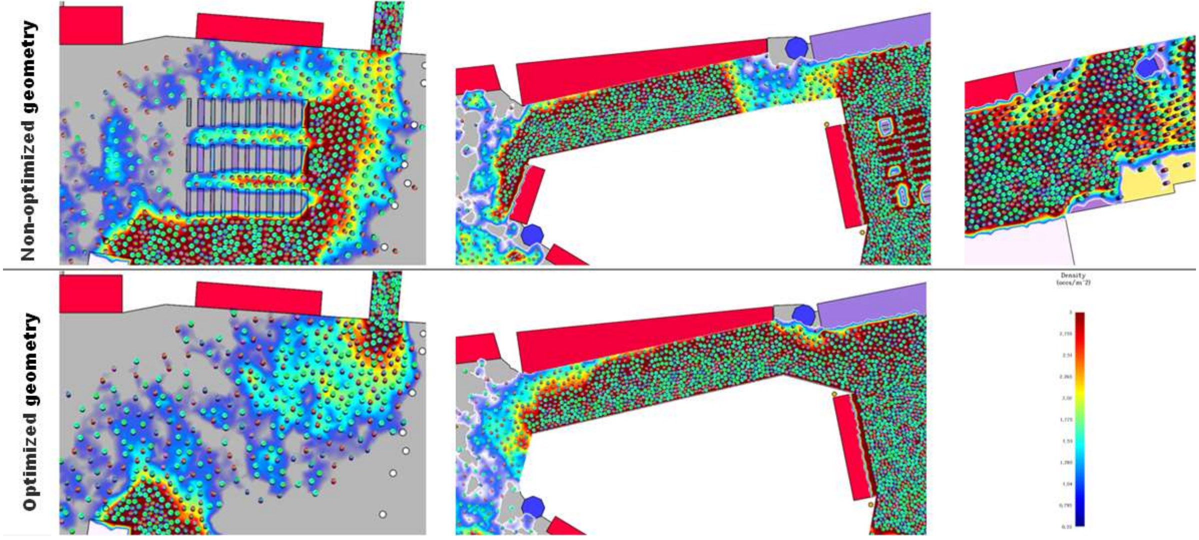

Figure 5: Example of critical points of geometry and their optimization.

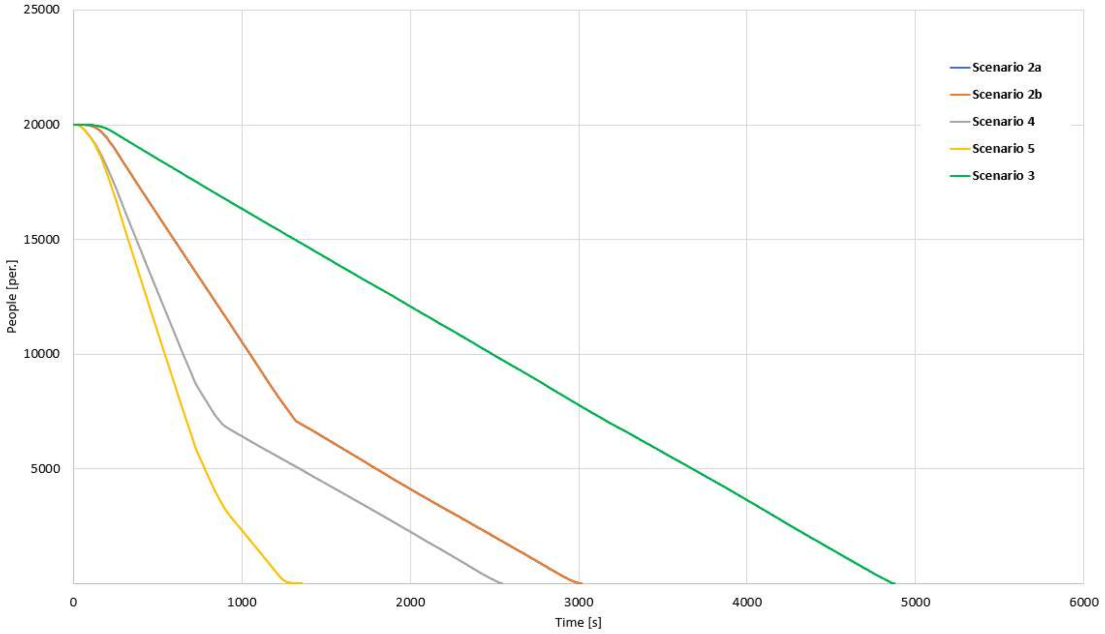

Figure 6: Comparison of the time of evacuation of people from the festival area with regard to the availability and number of evacuation exits - Regular evacuation of the area, availability of exits A and B (S2b) - the resulting curves overlap, Evacuation when blocking exit A (S3), Evacuation with two existing exits A and B and two newly added emergency exits C and D to the central area (S4) and Evacuation by two existing exits A and B and two newly added emergency exits C and D to the central area and one new emergency exit E in the lower part of the complex (S5).

Comparison of the evacuation time of the area under the current conditions of the area (S2a) with the variant after geometry modifications - optimization of pedestrian corridors S2b (extension of the northern ramp, removal of benches from evacuation corridors, removal of the bar under the ramp, etc.) does not significantly change the total evacuation time mainly due to the high number of people in the area and massive congestion at exits A and B in the final phase of evacuation (see Figure 6). In variant S2b, due to the changes, the local density decreases at critical points – Figure 5, thanks to which higher user comfort is achieved during normal movement of people and reduced risk of injury in the event of an emergency.

The graph of Figure 6 shows the linearity of the course, while in scenarios 2a, 2b, 3, 4 and 5shows the breaks in the curves. These faults are due to the use of escape routes, when in the initial phase of evacuation (approximately up to 1300 s) relatively free movement of people outwards (dynamic crowd) is presented. When the capacity of free movement is reached and a break of linear relationship occurs. The massive congestions are formed, which prevents the free movement of people (static crowd) and the evacuation time depends only on the permeability of the escape routes themselves. In variant 3, linearity is maintained, which is due to the rapid flooding of a single escape exit.

In variant S4, two new emergency exits C and D are added to the central area, which leads to a significant reduction in the time of evacuation of the central area (a place where an outbreak is expected) and a total evacuation time of approximately 450 s (7 min 30 seconds)). In this variant, a rapid evacuation from the upper central area is ensured, but the total stay of endangered persons in the lower part of the complex is still around 2540 s (42 min, 30 s), due to the flooding of the side exit B, which is only 3.5 m wide.

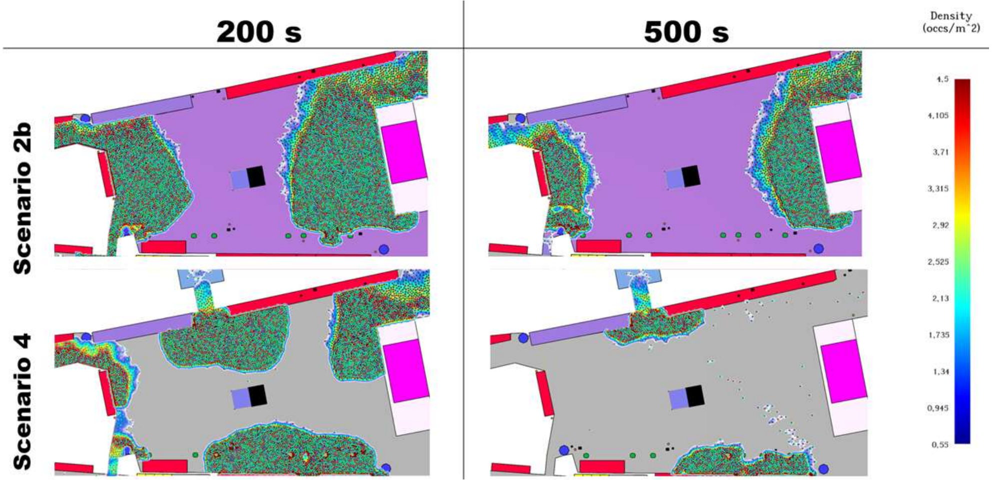

Figure 7: Comparison of central area clearance in 200 s, 500 s - scenario 2b (top) and scenario 4 (bottom).

Based on the results of variant S4, variant S5 is created, for which a new evacuation exit E from the lower part of the complex is added. This change significantly reduces congestion during evacuation in the lower part of the area and reduces the total evacuation time by about 1200 s (20 min) compared to previous variants, mainly due to different redistribution of participants between exits, see Figure 8.

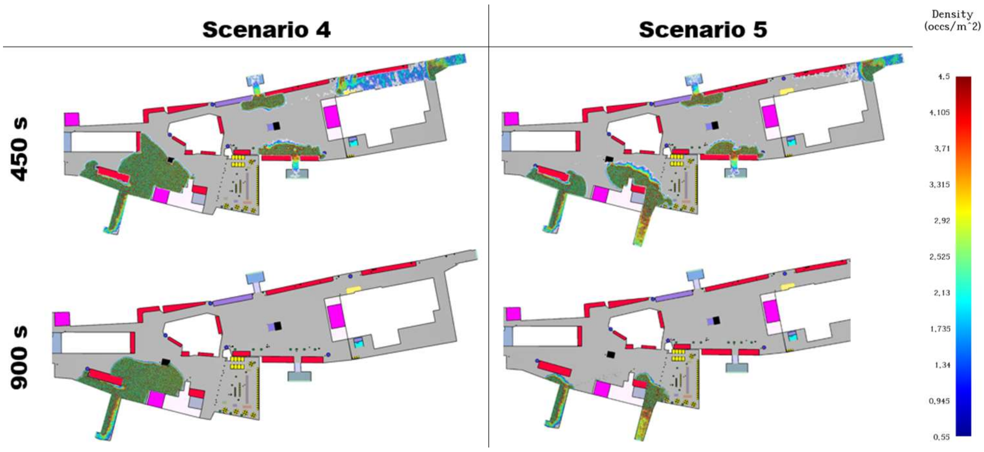

Figure 8: Comparison of clearing the lower part of the area in 450 s, 900s - scenario 4 (left) and scenario 5 (right)

In the occurrence that one of the exits is blocked in the case of an emergency, a scenario S3 considers the obstruction of the larger of the exits, exit A. This creates a situation where only one evacuation exit is available. In this case, the total evacuation time increases up to 4870 s (1 hour 21 minutes), which results in a large delay and retention of persons in the area where the danger may persist. As the time that evacuees have to persist in congestion increases, so does the nervousness of the participants and the pressure of the crowd - which increases the risk of "panic situations", injuries, crowd accidents with the threat of loss of life.

In order to ensure maximal comfort of movement of persons during normal operation, it is possible to use simulations to identify and then remove critical points in the design of the geometry of the assessed area, which can contribute to increasing overall safety during the festival. Minor changes in the geometry of the complex, with the number of 20,000 persons, do not have a significant effect on the total time of evacuation of persons from the complex premises, as demonstrated in the paragraphs above. In the event of an emergency evacuation, it would be appropriate to supplement this area with emergency exits (except for the current exits A and exit B), as in scenario S5, or to create parts within the existing fencing that could be opened in an emergency in the event of an evacuation. In such a case, it would be appropriate to create two places with a detachable fence ("exits") from the central area and two more in the lower part of the area for better redistribution of evacuees - one at exit E and the other at the back behind the folklore stages, towards the train tracks.

DISCUSSION

This study is an example of the use of numerical evacuation models, which are now widely used for large buildings with high occupancy (e.g. transport hubs, stadiums, high-rise buildings, etc.), to verify the safety of existing / planned area for the purposes of the music festival.

Numerical models of movement of people can be considered as a very effective tool for the planning phase of the festival. The application of models helps to find answers to questions about comfort, safety of visitors, creation of time schedules (in case of several stages it is necessary to remember the time needed to move spectators between individual performances) and the selection of a suitable solution. The application of numerical models helps to find possible solutions for the arrangement of festival grounds during the planning phase, verifies the conditions and safety of pedestrians in the event of an evacuation, and in connection with this, individual creation of crisis plans and proposal of security measures is possible. Using numerical models, as proved by presented work, it is possible to effectively analyse the safety of individual designs, their geometry, identify critical points that are insufficient for capacity or other reasons and thus prevent secondary problems (injuries, deaths) during the evacuation of people.

The use of numerical microscopic models allows us to take into account countless different crisis scenarios with a number of variables compared to the usual approach, which can often alert us to possible security flaws. Overall, when designing protection and security measures, it should be borne in mind that it is necessary to focus in particular on limiting the consequences of emergencies and secondary processes such as evacuation, rather than only on preventive security measures against them, as is often the case. Especially in the case of closed areas, which are designed for other uses, it is necessary to check the capacities of individual corridors, the permeability of exits and the elimination of obstacles when planning festivals. It is necessary to consider whether there is no better design variants and whether the arrangement of the geometry and the number of evacuation exits will be satisfactory in the event of an emergency.

CONCLUSION

The subject of this work was to verify the possibility of using microscopic agent technologies depicting the behavioural aspects of the crowd, in order to optimize the geometry of the open-air music festival and to simulate this case study in five modelled evacuation variants of scenarios. Visual analysis of the evacuation process, together with the gradual comparison of the resulting evacuation time curves, made it possible to identify the factors strongly influencing the evacuation and subsequently to propose changes in the area geometry, in this case optimization of the number and location of evacuation exits. A great advantage is the possibility to analyse the proposed variants of the festival area and its subsequent modifications with the possibility of repeated verification. Future research should focus on more detailed collection of data of visitors and their behaviour within individual festivals in order to provide quality input for the creation and calibration of numerical models for this type of event, which could have a significant impact on practice in the form of an effective tool for music festival organizers.

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