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MEASURES TO IMPROVE EVACUATION SAFETY IN DURA AUTOMOTIVE CZ LP

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Abstract

The article aims to explore and tackle safety issues, including emergency evacuation schemes in the DURA Automotive CZ LP, using the Pathfinder simulation program by Thunderhead Company. We ran twelve simulations, where six tested the existing conditions and six evaluated the implemented remedial measures. The simulation input data involved two parameters, including full occupancy, morning and afternoon (night) shifts. The first simulation profile observes ČSN 73 0804 [4], while the second implementation complied with Kady et al. [9] profiles. Each survey determines different average speeds on a flat surface and staircase to identify and remove impediments in the evacuation scheme, including a critical number of people on the first floor and using the only emergency exit within the fire escape. The suggested remedial measures must observe the necessary evacuation time before and after introducing the preventive action, the essential parameter for evaluating the effectiveness of evacuation procedures.

Keywords: automotive; safety; simulation; evacuation

1. Introduction

In times of continuous innovation, all top companies seek top occupational safety, including optimizing evacuation schemes for employees during emergencies. They stretch from natural disasters to fires within the premises.

In the automotive manufacturing industry, various hazards pose significant risks to workers' safety and well-being. These hazards encompass a spectrum of potential dangers, including the risk of injury or fatality due to accidents involving heavy machinery and moving vehicles within the production environment. Additionally, exposure to hazardous chemicals during the manufacturing process presents a serious health threat, necessitating stringent safety

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protocols and protective measures. Furthermore, the pervasive presence of noise and vibrations generated by industrial machinery and manufacturing processes can lead to long-term health issues such as hearing loss and musculoskeletal disorders [1, 13].

Moreover, the intricate interplay between humans and automated systems, including internal transportation equipment and industrial robots, introduces the potential for entrapment or collision accidents, emphasizing the critical importance of robust safety mechanisms and employee training initiatives. Overall, the multifaceted nature of hazards within automotive manufacturing underscores the imperative for comprehensive risk assessment strategies and proactive mitigation measures to safeguard the well-being of workers and promote a culture of workplace safety.

Article [8] deals with evacuations during emergencies, optimizing the evacuation zone in case of disturbance of a part of the transport network during the onset of the emergency. Study [18] focuses on fire safety and emergency evacuation guidelines. Building Fire Safety and Evacuation Interaction is a topic of the article [26]. The analysis [6] explores the application of a rescue cushion, an airbag system for reducing the threat when people have to jump from heights. Studies [12, 17] examine safety and security systems, while article [10] deals with train evacuation.

Our article explores the effectiveness of evacuation schemes in a selected automotive enterprise, assessing the threat and suggesting appropriate safety measures for smooth evacuation.

A sound evacuation plan involves an accurate assessment of the current state. The efficiency of training evacuation procedures will inform us of the staff's alertness and attitude towards the current scheme. ČSN 73 0804 [4] governs the safety requirements for the fire safety of facilities and persons, regulating the size of emergency exits or outer limits for evacuating the last occupant of the object afflicted by the emergency.

Since regulations cannot do the whole job, we must consider individual psychology as a critical factor in human decision-making. Understanding psychological aspects will help tailor the schemes and training courses to the human mindset during emergencies.

Many studies have analysed evacuation schemes using simulation software, providing our article with valuable data. Article [2] applies the Gama simulation software. Study [14] employs the AnyLogic program for a simulated evacuation. Article [5] dealt with new simulation software for improving evacuation plans during disasters. Publication [3] deals with the Unity program for simulating an emergency evacuation of elderly citizens. Paper [24] explores a new evacuation model within a new application program. Study [20] developed FDS fire simulation software for devising a new evacuation scheme. Article [23] focuses on improving fire safety using evacuation simulation software. Paper [19] uses EXODUS computer software

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to simulate emergency evacuation, while publication [7] explores the development of a new mathematical program.

Today's digital world offers many simulation programs for modelling emergencies and evacuation plans. The Pathfinder software by Thunderhead Engineering Company provides a user-friendly interface and DWG file compatibility, enabling excellent models for simulated evacuations.

Some articles use the Pathfinder software for developing evacuation schemes in buildings [15, 21, 22], dormitories [11, 25] and a metro station [16].

ČSN 73 0804 [4] governed the requirements for emergency exits, outer limits for the evacuation, estimated evacuation time and the time of the smoke penetration of fire exits. Using the software, we convert the object to a 3D model and alternately fill it with occupants at periodic intervals. The results allow us to evaluate the current evacuation plan and suggest changes to improve occupational safety in the building.

2. Materials and Methods

We performed the simulation in the Pathfinder program from the Thunderhead Company. After finalizing the model and spreading employees through the premises, we can simulate the evacuation and find out the time necessary for abandoning the building, the longest trajectories, maximum densities and occupancy of areas. The first simulation profile observes ČSN 73 0804 [4]. The second reflects Kady et al. [9], indicating different speeds on a flat surface and staircases than ČSN 73 0804 [4]. Three simulations within both profiles concerns three building occupancy types:
- maximum occupancy,
- morning shift,
- afternoon/night shift.

2.1. Maximum Building Occupancy in Automotive Enterprise (ČSN 73 0804)

The building accommodates maximum occupancy during shift changing. The employees coming on the shift are in the hall while the workers going off are in changing rooms on the first floor, which is a rare situation. We launch the simulation with people rushing towards the nearest emergency exit. Most workers within the hall premises are comfortably escaping through side exits. The last worker left the main assembly hall within 107.2 s. Office workers gather on staircases and leave through the main entrance. The simulation suggested that the fastest evacuee left the building in 10.5 s, whereas the last person fled the premises within 157.5 s. The highest floor sends the last evacuee to safety in 70 seconds, while the first floor in 102.3 seconds. Figure 1 suggests the simulated evacuation and trajectories of evacuees.

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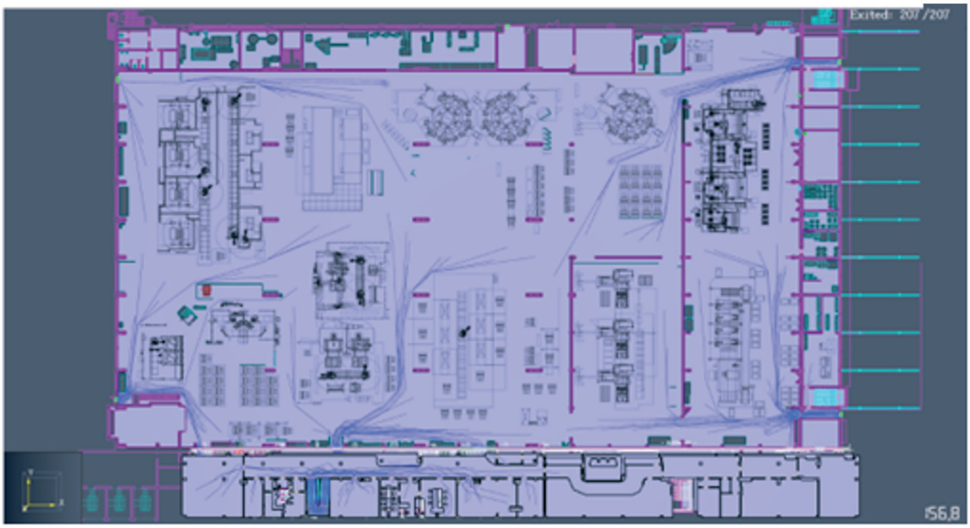

Fig. 1. Maximum occupancy trajectories. Source: authors

The figure illustrates that evacuees from the main assembly hall escaped through side entrances, preventing congestion at the main entrance. The staircase on the first floor indicated the highest density, accommodating operatives leaving their changing rooms and office workers abandoning the second floor (Figure 2).

Fig. 2. Staff's density on the stairs. Source: authors

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2.2. Morning Shift Simulation in Automotive Enterprise (ČSN 73 0804)

The morning shift contains fewer people on the first floor, as afternoon shift workers are still home. The simulation also involves office employees. The operatives' trajectories mimic the maximum occupancy from the previous simulation, witnessing the first evacuee leaving the building in 10.5 seconds and the last in 135.7 seconds, indicating a faster evacuation by 21.7 seconds than in the previous case. The highest floor was empty within 70 seconds, and the last evacuee left the assembly hall within 107.2 seconds, the same time as in the earlier situation. This simulation shows a lower maximum density on the staircase and at the main entrance (Figure 3). We can filter the contours of the maximum density on the right side of the simulation called density (maximum).

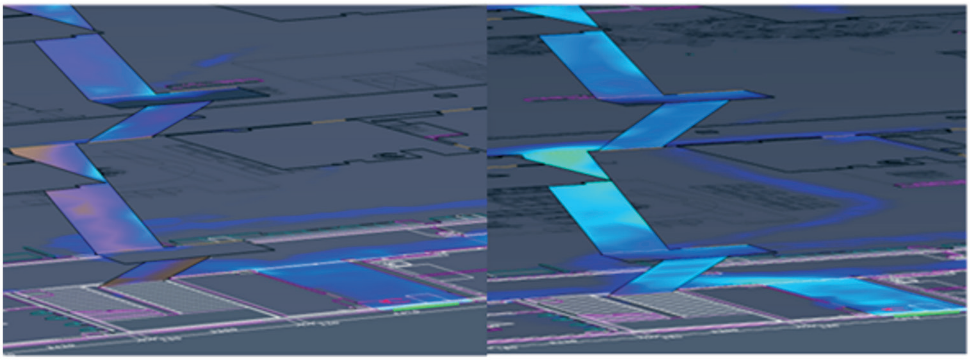

Fig. 3. Comparison of density. Source: authors

2.3. Afternoon/night Shift Simulation in Automotive Enterprise (ČSN 73 0804)

The afternoon/night shift involves minimum occupancy, including only operatives and supervisors. The hall's ground floor accommodates 80 workers, leaving the staircase and offices empty. Figure 4 suggests a smooth evacuation process using all available emergency exits. The evacuees abandoned the building within 108.1 seconds, indicating the fastest evacuation. The north part of the hall and the main door saw increased congestion of 25 and 28 evacuees respectively, totalling 66.25% of the evacuated people. The text document suggests that the first evacuee left the premises within 10.5 seconds, the same as in the previous case.

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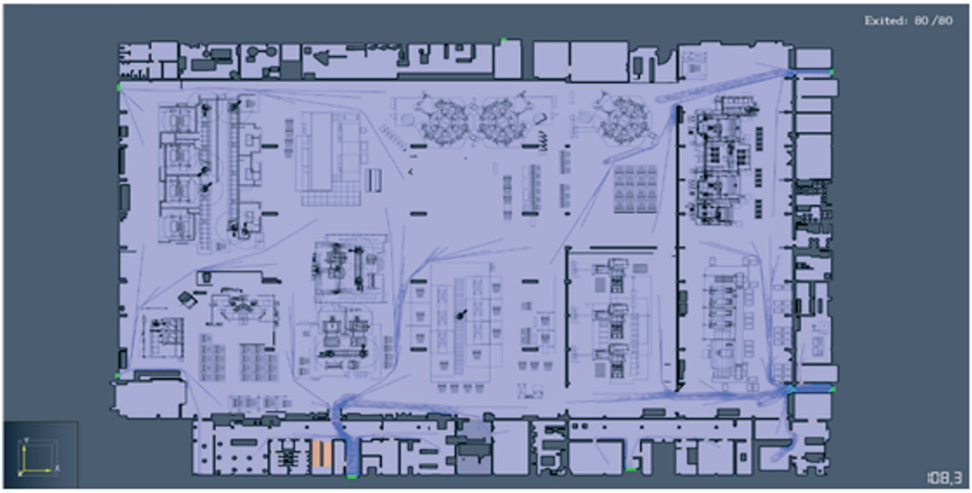

Fig. 4. Simulated trajectories. Source: authors

The subsequent occupancy simulations involved Kady et al. [9], and changes in speed profiles of workers according to ČSN 73 0804 [4]. The trajectories mimic the previous profile.

2.4. Maximum Building Occupancy in Automotive Enterprise (Kady et al.)

Maximum occupancy (Figure 5) under ČSN 73 0804 [4] varies only in the evacuation time when the last person left the highest first floor within 32 seconds and 50 seconds respectively, indicating the half-time of the previous profile. The crowd density copies the earlier analyses where the largest crowds assembled on the staircase and the main exit. The first and last workers abandoned the hall premises in 48 seconds and 97.3 seconds, respectively. Most people, i.e. 119 (57.48%), escaped through door No. 8, i.e. the main entrance, accommodating the biggest crowd of evacuees.

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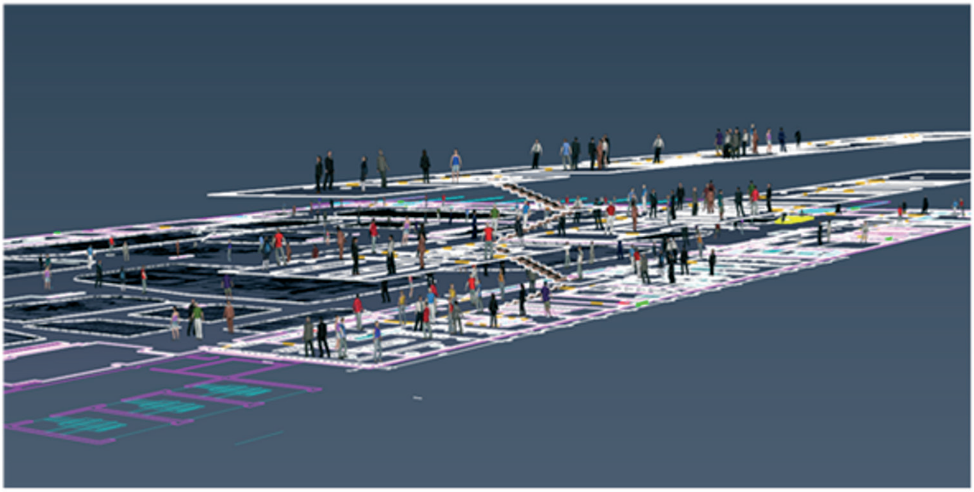

Fig. 5. Occupancy. Source: authors

2.5. Morning Shift Simulation in Automotive Enterprise (Kady et al.)

Kady et al. [9], simulation provides the same results on proportional densities, congestion and evacuation times as the previous profile ČSN 73 0804 [4], again indicating the largest crowds gathering on the staircase and main exit.

2.6. Afternoon/night Shift Simulation in Automotive Enterprise (Kady et al.)

The simulation mimics the previous afternoon/night reproduction under ČSN 73 0804 [4], indicating smooth evacuation without high densities and congestion using both main exits. The maximum and minimum evacuation time was 48.2 seconds and 5 seconds, like in earlier cases. There was no need for evacuating office workers, as all employees occupied the ground-floor assembly hall. The following Table 1 illustrates the parameters of individual simulations.

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Tab. 1. Simulation times. Source: authors

Profile	ČSN 73 0804			Kady et al.		
Occupancy	Morning	Afternoon/ night	Max.	Morning	Afternoon/ night	Max.
People total	127	80	207	127	80	207
Total evacuation time (s)	135.7	108.1	157.5	63.5	48.2	97.3
Average evacuation time (s)	62.5	55.5	72.3	28.5	25.2	33.4
The first evacuee (s)	10.5	10.5	10.5	5.0	5.0	5.0
Highest density (os/m^2)	2.539	1.845	2.356	2.539	1.52	2.356
Most used door (os)	52 (no.8)	28 (no.8)	119 (no.8)	52 (no.8)	28 (no.8)	119 (no.8)
Evacuation time of the 1st floor (s)	105.0	0.0	102.3	43.9	0.0	49.7
Evacuation time of the 2nd floor (s)	70.0	0.0	70.0	29.1	0.0	33.0
Average trajectory length (m)	34.3	31.4	36.7	34.6	31.4	36.7
The longest trajectory (m)	72.3	62.5	83.3	74.8	62.6	83.3

The bar chart in Figure 6. compares the times of various evacuation schemes, indicating the evacuation drill time approaches the outer limit of the evacuation time under ČSN 73 0804 [4]. The evacuation drill took place under a standard occupancy during the morning shift.

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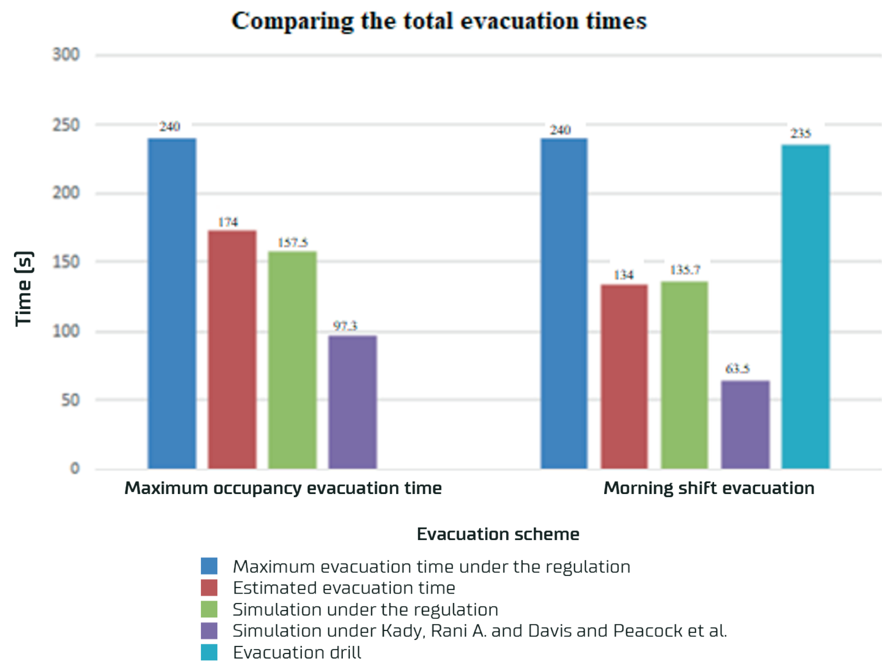

Fig. 6. The comparison of evacuation times. Source: authors

Our simulation aimed to identify potential pitfalls within the evacuation scheme, testing a critical mass of people on the first floor and using the only fire exit in the office premises. The evacuation times abide by the evacuation limits prescribed by ČSN 73 0804 Regulation [4]. Both computer simulation profiles allow a much faster evacuation, preventing slow reactions of employees during evacuation drills, a lack of urgency, or not taking the evacuation drill seriously.

3. Results

Based on our results, we suggested the following measures to make the evacuation schemes more effective:

- smoke detectors (Hall 64), including sirens and laser smoke sensors, common smoke sensors (offices), emergency switches (all premises except for Hall 57),
- new and wider door,
- operatives should evacuate through side emergency exits,
- administration building overhaul,
- a new system informing on current building occupancy.

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3.1. Adjusting the Entrance

Most workers evacuate through the 800 mm first wing of the main entrance. The opening of the second wing is subject to a fire watch, who may be in the middle of the crowd, unable to open the extension. A door with one wing of 1100 mm and a second of the width of the current exit will allow more people to pass through when changing shifts and during meetings.

All four side emergency exits with only a standard fireproof door set (a handle on the inside and a doorknob on the outside) also need refurbishment. As these ways out are always open, we suggest buying smart locks connected to sensors installed at the entrance and syncing to the device at the main entrance.

3.2. Operatives to Use Side Exits

Emergencies requiring immediate evacuation may also occur when office premises hold more people than usual. The company may use the conference chamber to accommodate workers when office capacities are full. In an emergency, people would overload the main entrance unless the automotive enterprise decides to adjust the 800 mm entrance door.

Despite the instructions to escape through the nearest exit, the operatives tend to use the main building entrance. Our computer simulation showed the most extensive use of the main door in two of three cases. The evacuation drill indicated that operatives headed straight to the meeting point rather than using the nearest exit, resulting in a critical mass of people flooding the emergency exits.

We suggest instructing the operatives to use side emergency exits and specifically instruct workers in the assembly hall premises to escape through side exits.

If the company decided to swap the side doors with the same automatic door system as in the main entrance, automatically opening from the inside and requiring an access card from the outside, no congestion would occur, and the safety system would undergo a welcome radical overhaul.

3.3. Constructing Fire Escapes

The company uses many of its premises as warehouses or locks them empty. This unused space includes a large conference chamber in the eastern part of the second floor and logistics offices in the adjacent building shared with the PLASMAN Company.

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The company should invest in renovating the second staircase as a fire exit from the office premises, allowing the accommodation of more people within the fire escape and reducing the evacuation time. The files could go into the empty northern part.

The company could change the emergency exits into fire escapes using sophisticated ventilation systems involving stairwell pressurization or a smart ventilation system. Despite its complexity, costliness and elaborateness requiring an expert's analysis, this measure would improve occupational safety.

3.4. Installing AI Counting People Cameras

We must always ensure that all people are outside the building premises. The company has not yet implemented a method of counting employees at the meeting place, unable to decide whether all workers left the building. Logistics experts who do not have a permanent workplace on the premises might still be inside. The simulation only observed workers on the shift, using a screen photo in the entrance hall displaying assembly workers.

The company uses a simple access card system to pass through the main entrance. Since this is not the only doorway to enter the building and workers come in groups, counting incoming individuals is impossible. The evacuation list of workers on the shift cannot serve the purpose either, as the building also houses people without a fixed workplace. The list would provide us only with a rough number of occupants.

To accurately determine the total number of people in the building, we suggest installing high-tech AI cameras for counting people inside the premises.

The following schematic depiction proposes the possible camera positions, considering a potential reconstruction of the second wing of the office premises. The camera systems stretch over all entrances (Figure 7).

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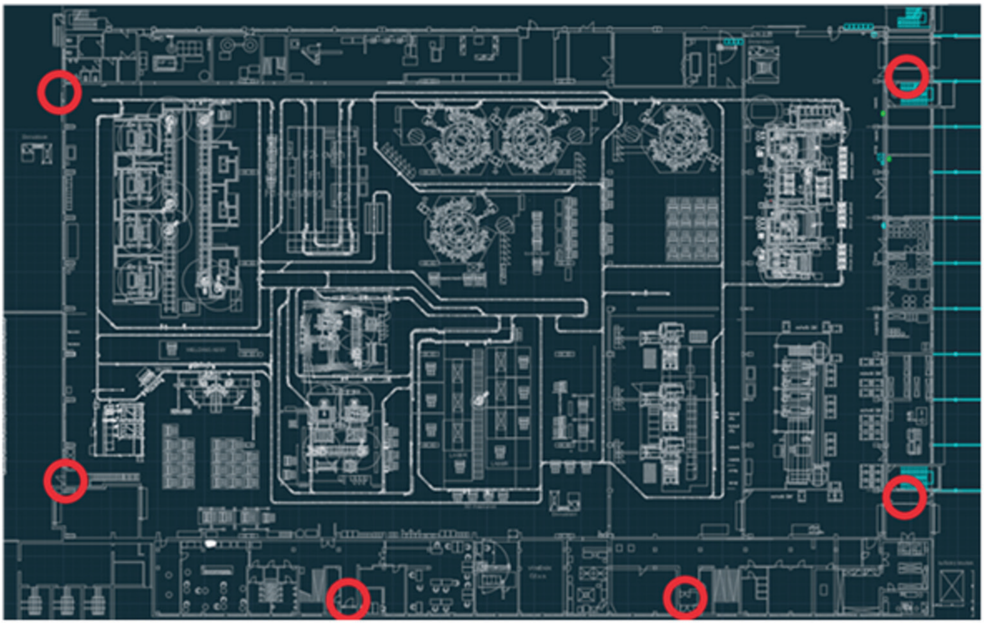

Fig. 7. Camera positions. Source: authors

4. Evaluation

Our study aimed to propose measures for a more effective evacuation, including safety, prompt and automated information on the emergency, and efficient counting of people in the building.

We used simulation software to create a building model with the implemented safety measures, involving training operatives to leave through side exits and installing a wide entrance door. Although the other measures do not directly reflect the simulation, they can speed up the whole process and ensure everybody has abandoned the building.

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Fig. 8. Modified simulation. Source: authors

The first simulation profile monitors the morning shift under ČSN 73 0804 [4]. Figure 8 illustrates systematic changes in the trajectories, relying more on side exits and spreading the load among more escape routes. Although the total evacuation time remains the same (the last evacuee leaves the building always within the same time – 135.7 seconds), the evacuation procedure is safer and smoother without overcrowding the main entrance.

We also dealt with an oversized scenario containing 207 occupants under Kady et al. [9]. This simulation reflects the average human speed more faithfully, showing a draconian decrease in the evacuation time and population density per metre. The total time fell from 97.3 seconds to 75 seconds (a 22.3 seconds difference), indicating a considerable reduction. The density at the main entrance was lower than in the previous analysis, where the highest density rose to +3 persons per square metre.

Our proposal lowers the density values to the trough of 2.7. The main entrance now holds 88 people compared to the previous 119. The suggested scheme would improve the safety of evacuees during disasters when smart sensor and detector systems would clearly and promptly inform of an emergency. Figure 9 illustrates a big difference in the distribution of occupants strictly regulated by the proposed measures.

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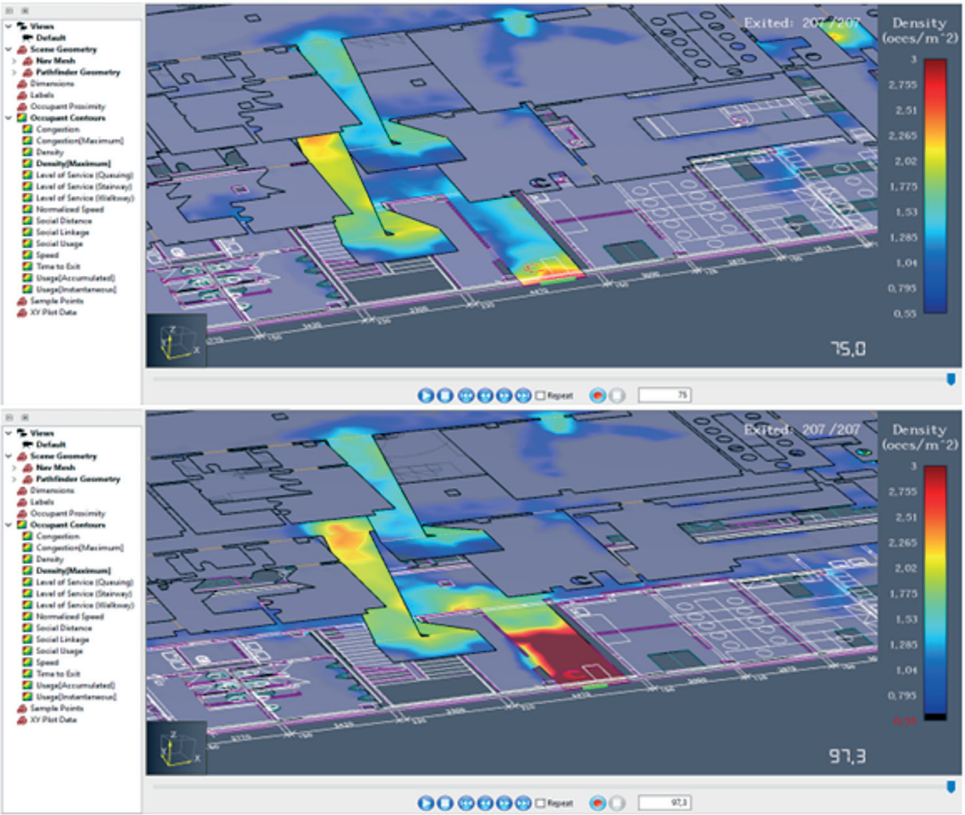

Fig. 9. The comparison of simulations. Source: authors

5. Discussion and Conclusion

The article aimed to analyse the evacuation schemes of a selected company using simulations of various input parameters. These factors determine unforeseen pitfalls, allowing us to suggest safety measures to make the evacuation more effective.

The building lacks smoke detectors, fire alarms, wide doors, camera systems or evacuation plan updates. Our research suggests removing the excessive load from the main entrance and spreading the escaping crowd over other exits.

Our study also evaluated fire exits by extensive calculations governed by ČSN 73 0804 [4] on fire safety of manufacturing objects. The fire exits of the assembly hall are 224 m, complying with the prescribed limits. The estimated evacuation time from the assembly hall

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is 2.28 minutes, and the smoke penetration of the premises is 4.482 minutes. Maximum evacuation time is 6 minutes, observing the regulations. The same applies to fire exits in the office premises where the size of emergency exits and evacuation time limits comply with the safety standards. The following part of the article involves a description of the evacuation drill undergone every year, including the evaluation of its phases and outcomes.

The simulation using the Pathfinder Software by the Thunderhead Company and files provided by DURA Company created 3D building premises occupied by the employees. Three different models tested the evacuation scheme according to the occupancy of afternoon/ night shift (minimum occupancy), morning shift (standard occupancy) and shift changing (maximum occupancy). A computer simulation allowed the exploration of the individual types of the profiles. The first profile observes ČSN 73 0804 [4] governing the average human speed on a flat surface and down the staircase. The second abides by the findings of experts on the movement theory.

The simulated profiles of different occupancies allowed us to formulate a broad concept of the evacuation scheme focused on escaping through the nearest emergency exit. The generated evacuation times contrasted with ČNS 73 0804, and the annual evacuation drill indicated higher density values at the main entrance and staircase.

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