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SECURITY IN METRO - AN EXAMPLE FOR SIMULATION OF EVACUATION FROM SUBWAY

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Abstract. *Evacuation presents one of the most important, the most responsible and the most complex tasks related to human safety in facilities generally. Evacuation from facilities or certain places is needed for different reasons: fire, explosion, flood, earthquake, etc. This is especially important for special-purpose facilities such as subway (metro). Such facilities are characterized by heavy traffic and frequent transit of people and vehicles; therefore, the possibilities and probability for accidents or disasters are great. This is always open and actual problem, which was confirmed great number of people who couldn't be evacuated and were killed by disasters. Possibilities for evacuation in subway are smaller due to much rapid spread of fire and smoke than in open space, as well as the length of tunnels. This paper has been written to show the possible evacuation situation and calculate minimum time needed for evacuation in case of 3600 m long metro with emergency exits at every 1200 m.*

Key words: *evacuation, simulation, metro*

1. INTRODUCTION

Building evacuation presents one of the most important and most complex tasks in designing. It is very difficult to predict every possible situation that leads to safe and secure leaving the facility. The evacuation as a term is very complex, but, generally, it presents the safest, shortest and fastest way of moving for people, animals and material properties from endangered object or location to the secure place. The causes for evacuation could be different: fire spreading, earthquake, flood, civil disorders, etc. Each of these causes demands proper strategy of facility or location design that must be realized in order to increase human and material properties safety. The examples for evacuation are presented in Figure 1 (a, b).

Evacuation routes were projected as primary and secondary. Primary evacuation route is, most frequently, route for normal communication in object. For example, these routes

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Fig. 1 Examples for evacuation under fire (a) and under earthquake (b)
(picture sources: www.china.org.cn (a), www.independent.co.uk (b)).

could be stairs, hallways, corridors and other surfaces used for communication in facility or in separate floor. There are different dimensions for every type of facility. These routes are the routes that fire services use in case of fire. The secondary routes depend on building's purpose. These routes could involve windows, roofs etc. Both types of evacuation routes must satisfy many standard and demands, depending on the number of people, type and purpose of facility, speed of people moving, time necessary for evacuation, etc. The evacuation routes must be clearly visible at the evacuation plan. However, it is very important to note that some facilities, due to their specific nature, could have only one ore two possible evacuation routes which could endanger people evacuation. Very often, it is not possible to realize the evacuation until the accident is over, although the evacuation demands momentary reaction, examples for that cases are earthquake, flood or similar. Very often, occupants in the state of panic and stress try to leave the building and the location in disorderly manner and cause tragedy. There were lots of similar cases with tragic epilogue. The occupant's behavior, knowledge and education, physical and psychic condition (occupant speed, panic and stress influence, moral and human qualities) should be studied in details in order to improve evacuation possibilities [6, 7].

Particularly interested aspect according to object or location evacuation is how panic and stress affect the occupants. In panic and stress situations, occupants move faster but in a chaotic manner. That implies creating many unexpected situations in buildings or at some location. Evacuation routes in facilities have their own maximum occupant flow. That is especially important for stairs, elevators, hallways, corridors, narrow tunnels, bridges, transitions, etc. [3].

Huge transit also called metro, subway or underground, presents a type of high-capacity public transport generally used in urban areas. Unlike buses or trams, rapid transit systems are electric railways that operate on an exclusive right-of-way, which cannot be accessed by pedestrians or other vehicles of any sort, and which is often grade separated in tunnels or on elevated railways.

Modern services on rapid transit systems are provided on designated lines between stations typically using electric multiple units on rail tracks, although some systems use guided rubber tires, magnetic levitation, or mono rail. The stations typically have high platforms, without steps inside the trains, requiring custom-made trains in order to avoid gaps. They are typically integrated with other public transport and often operated by the same public transport authorities. However, some rapid transit systems have at-grade intersections between a rapid transit line and a road or between two rapid transit lines. It is unchallenged in its ability to transport large numbers of people quickly over short distances with little use of land. Variations of rapid transit include people movers, small-scale light metro, and the commuter rail hybrid S-Bahn.

The world's first rapid-transit system was the partially underground Metropolitan Railway which opened as a conventional railway in 1863, and now forms part of the London Underground. In 1868, New York opened the elevated West Side and Yonkers Patent Railway, initially a cable-hauled line using static steam engines.

The world's largest rapid transit network is the Greater Tokyo rail system with more than 40 million daily passengers and 882 stations within the metropolis. The world's largest single rapid transit service provider by both length of track (842 miles (1,355 km), including non-revenue track) and number of stations (469 stations in total) is the New York City Subway. By length of passenger route, the world's longest single-operator rapid transit system is the Shanghai Metro. The busiest rapid transit systems in the world by annual rider ship are the Tokyo subway system, the Seoul Metropolitan Subway, the Moscow Metro, the Beijing Subway, and the Shanghai Metro [4]. Some of the longest subways in the world are presented in table 1.

Table 1 The longest subways in the world

Name of the tunnel	System	Stations	Length (km)	Year completed
Line 3	Guangzhou Metro	Airport South - Panyu Square	60.4 (the longest branch)	2005-2010
Line 10	Beijing Subway	Xiju - Shoujingmao	57.1	2008-2012
Seoul Subway Line 5	Seoul Metropolitan Rapid Transit Corporation	Banghwa - Macheon	47.6 (the longest branch)	1995-1996
Serpukhovsko-Timiryazevskaya Line	Moscow Metro	Altufyevo - Bulvar Dmitriya Donskogo	41.5	1983–2002
Metro Madrid L-12: (Metro Sur)	Madrid Metro, Spain	circle route	40.96	2003
Toei Oedo Line	TMBT Subway, Ja pan	Hikarigaoka - Shiodome - Tocho-mae	40.7	1991–2000
Kaluzhsko-Rizhskaya Line	Moscow Metro	Medvedkovo - Novoyasenevskaya	37.8	1958–1990
Circle MRT Line	Mass Rapid Transit (Singapore)	Dhoby Ghaut - HarbourFront	35.7	2009–2011
Seoul Subway Line 6	Seoul Metropolitan Rapid Transit Corporation	Eungam Loop - Bonghwasan	35.1	2000-2001
Seoul Subway Line 7	Seoul Metropolitan Rapid Transit Corporation	Cheongdam - Bupyeong-gu Office	35.1 (the longest branch)	2000-2012
Line 7	Shanghai Metro	Meilan Lake - Huamu Road	34.4	2010
Metro Madrid L-7	Madrid Metro, Spain	Hospital del Henares - Pitis	32.9	1974–2007
Line 3 (Southern leg)	Guangzhou Metro	Tianhe Coach Terminal-Panyu Square	32.767	2005–2006

It is obvious that such way of passenger transport implies very strict safety precautions related to build strategy, used trains types, ventilation systems, emergency exits and lot of other important parameters. Although all parameters are checking permanently, there are always some unpredictable factors, by human or no human nature that could cause accidents and in those cases, the fastest evacuation is the most crucial thing that should be done. Because the evacuation, as it was noted above, present very complex groups of tasks that should be realized, it is very important to somehow, as much as it is possible, predict each potential aspect. One of the most successful, safe, economic, correct and most frequently used ways for potential occupant evacuation prediction in different accidents scenarios is the usage of the simulation software designed for that purposes, such as Pathfinder. In this paper, the Pathfinder 2012 version was used.

2. Simulation Model

One of the most frequently used simulation software for evacuation generally is Pathfinder. Pathfinder presents an agent based on egress and human movement simulator. There are several different versions of this program. This program for evacuation provides a graphical user interface for simulation design and execution as well as 2D and 3D visualization tools for results analysis. The movement environment is a 3D triangulated mesh designed to match the real dimensions of a building model, what is very important. This movement mesh can be entered manually or automatically based on imported data. Walls and other impassable areas are represented as gaps in the navigation mesh. The construction of curved walls could be realized as construction of several straight wall segments and for more complicated objects, in geometry sense, could be an obstacle. These objects are not actually passed along to the simulator, but are represented implicitly because occupants cannot move in places where no navigation mesh has been created. Doors are represented as special navigation mesh edges. Every door has its own length. In all simulations, doors provide a mechanism for joining rooms and tracking occupant flow. Depending on the specific selection of simulation options, doors may also be used to explicitly control occupant flow. Stairways are also represented as special navigation mesh edges and triangles. Stairways can connect different floors and levels. Occupant movement speed is reduced to a factor of their level travel speed based on the incline of the stairway. Occupant speed could be defined for different evacuation scenarios. Each stairway implicitly defines two doors. These doors function just like any other door in the simulator but are controlled via the stairway editor in the user interface to ensure that no geometric errors result from a mismatch between stairways and the connecting doors.

Occupants are modeled as upright cylinders on the movement mesh and travel using an agent-based technique called inverse steering. Each occupant calculates movements independently and can be given a unique set of parameters (maximum speed, exit choice, 3D model, etc.). Pathfinder supports two movement simulation models: "Steering" mode and SFPE mode. The example of occupant's movement over the platform to the exits, after 101,6 seconds from the start of the simulation in one of the paper scenario, is presented in Figure 2.

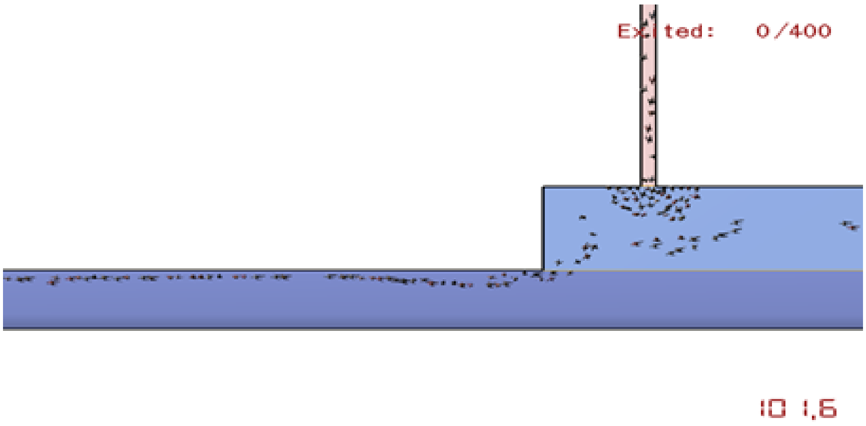

Fig. 2 Modeled occupants on the metro simulation model after 101,6 seconds from the start of the simulation in Pathfinder

One particularly appropriate software possibility is importing files created in 3D CAD, FDS and PyroSim. These files have its own geometry which can be used in Pathfinder and significantly save time needed to complete the whole evacuation and fire project. The imported geometry is sent as-is to 3D Results, resulting in a clean and fast graphical representation of the data. The used version of Pathfinder for paper results was 2012 version. [12].

3. Simulation

The first step is to create the simulation model of the desire object, in this case, the metro tunnel and train with the specific dimensions. The simulation model of the tunnel was constructed as pipe with 3500 m length, 6 m width and 5 m height. The simulation model was constructed with emergency exits at every 1200 m. For both scenarios, there were five different cases, for the occupant's speeds of 1.25 m/s, 1.75 m/s, 2.5 m/s, 3.5 m/s and 5 m/s. The position of the whole train composition was at the middle of the tunnel. For the first scenario, there were no accidents in the metro tunnel while the second scenario implied an accident in the metro tunnel where the wagon in the middle of the train jumped out from railway tracks. The train had maximum passengers load, which meant that the passengers number was 400 (8 wagons with 50 passengers per wagon). The simulation models of the train in metro tunnel for the first and for the second scenario are presented in Figures 3 and 4.

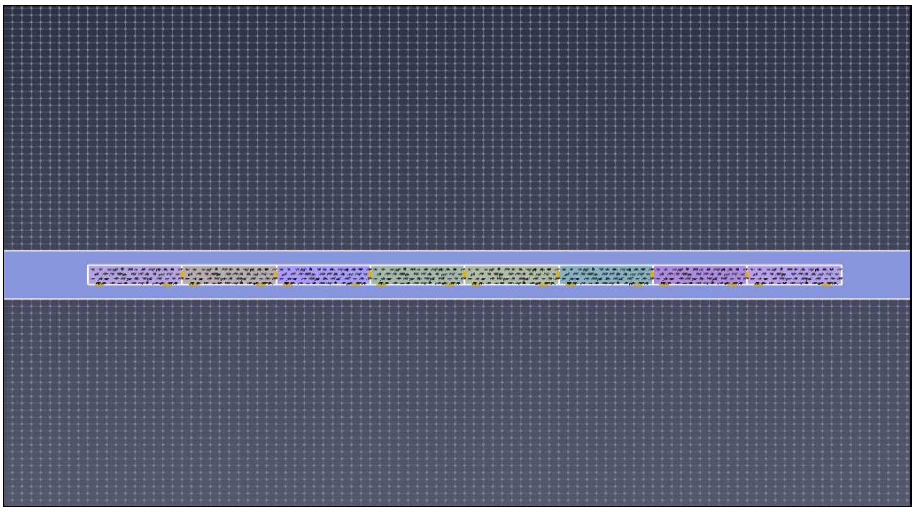

Fig. 3 The simulation model of train in metro tunnel for the first scenario

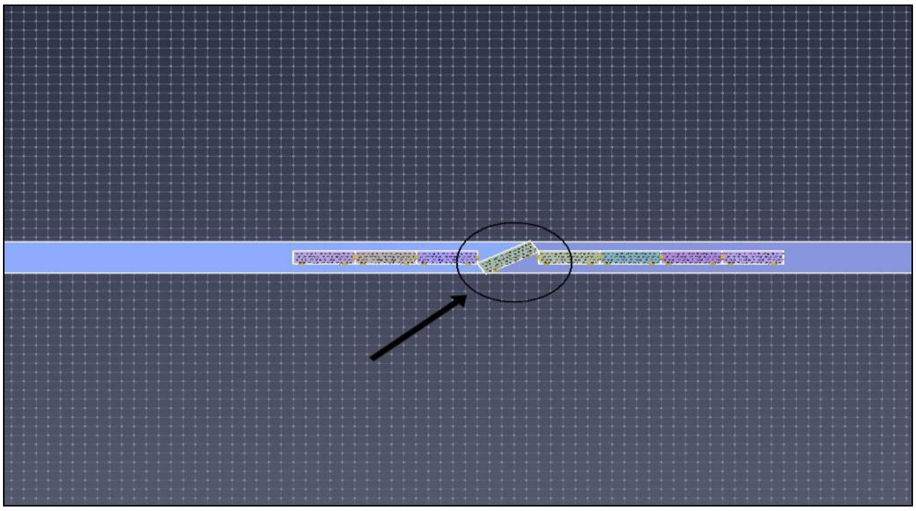

Fig. 4 The simulation model of train in metro tunnel for the second scenario with marked wagon that was jumped out from railway tracks

The train was simulated according to its real dimensions, with 8 passengers' wagons. The wagon's dimensions were 16500mm x 2500 mm. According to the valid literature, there are different metro trains, related to theirs dimensions, in usage. The height of the wagons was 3500mm. Every wagon has two doors with length of 1 m. The platform length was 150 m [2, 13]. The length of the stairs to the surface exits were 250 m, while the stairs angle was 25 degrees.

4. Simulation Model and Simulation Results

The simulations were realized on laptop Fujitsu Siemens Esprimo Mobile V5535, with Intel Celeron 1733 MHz (13x133), 2GB of RAM and SiS Mirge 3 Graphics (256 MB). Pathfinder simulation software and similar simulation software demand very strong hardware configuration because the duration of simulations could be from several hours to several days, even weeks, in dependence of the simulation's model complexity. For objects created in another program, such as, for example, some version of Auto Cad, it is often necessary to reformat some parts of the facility, exits and similar elements. Creation disability of some complex objects, for example, creation of curved edges or curved elements in Pathfinder are the most common cases for importing from some other program. In these cases, both simulation models were created in Pathfinder and average durations of simulations were about 45 minutes.

Realized simulations provided to calculate minimal times for complete tunnel evacuation for both noted scenarios and directions of occupant's evacuation related to theirs positions and given scenario. In order to limited size of paper, only some scenes from the first scenario are presented on pictures from 5 to 9 as examples. Complete simulation results for both scenarios are presented in Figures 10 and 11.

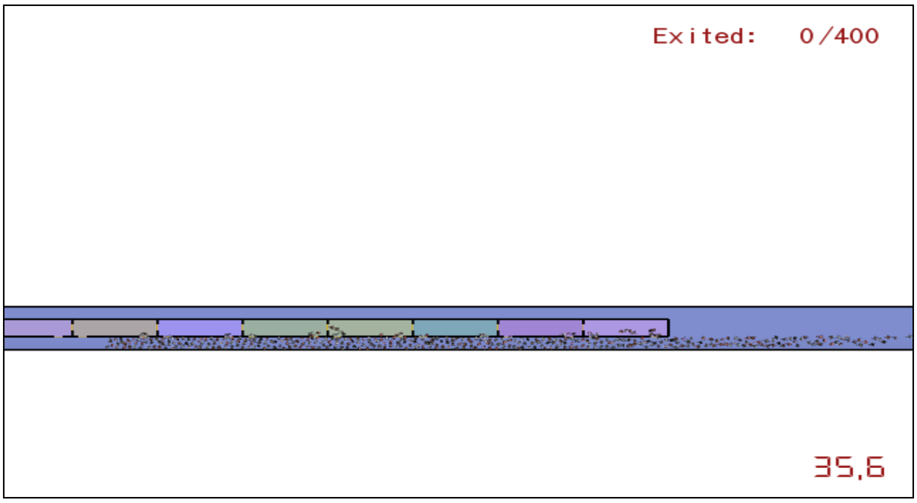

Fig. 5 Simulation example for the first scenario after 35.6 seconds from the start of the simulation

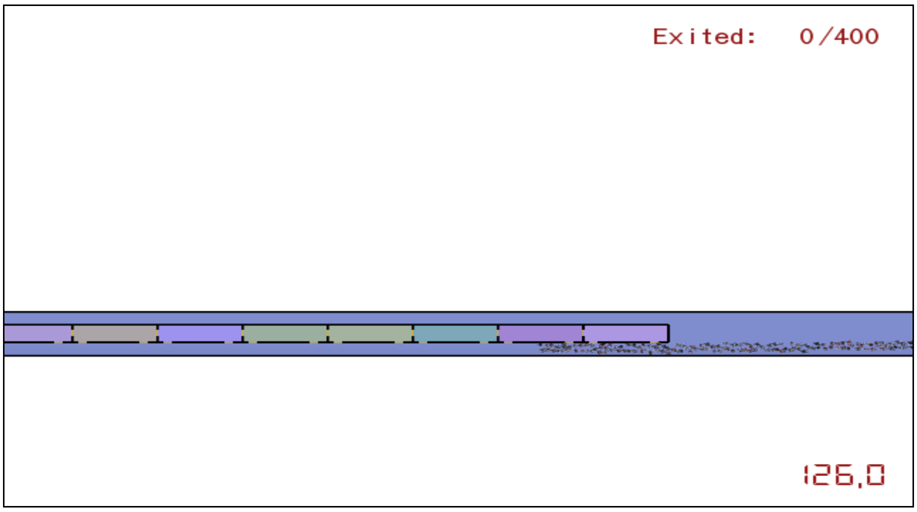

Fig. 6 Simulation example for the first scenario after 126 seconds from the start of the simulation

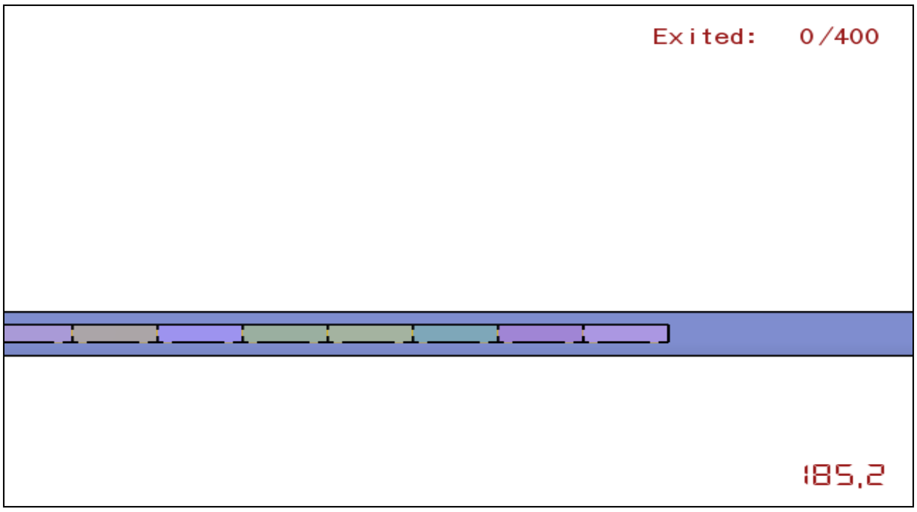

Fig. 7 Simulation example for the first scenario after 185.2 seconds from the start of the simulation

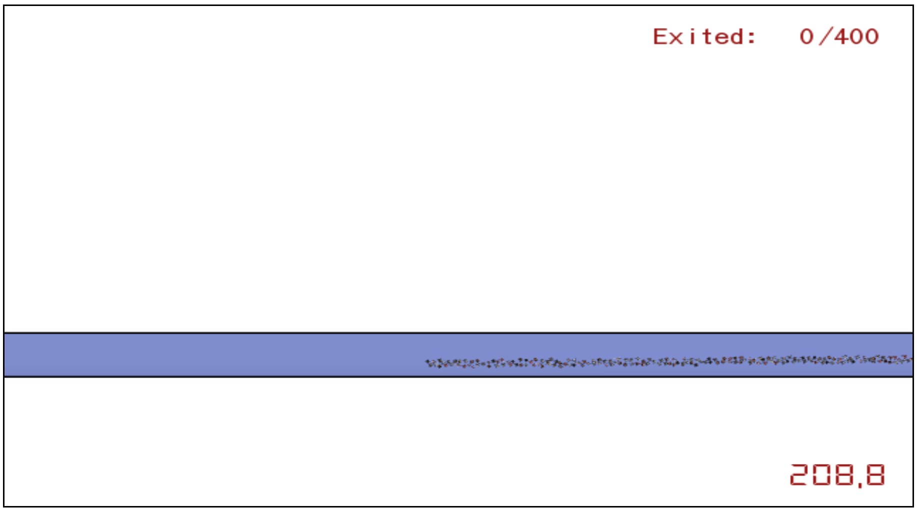

Fig. 8 Simulation example for the first scenario
after 208.8 seconds from the start of the simulation

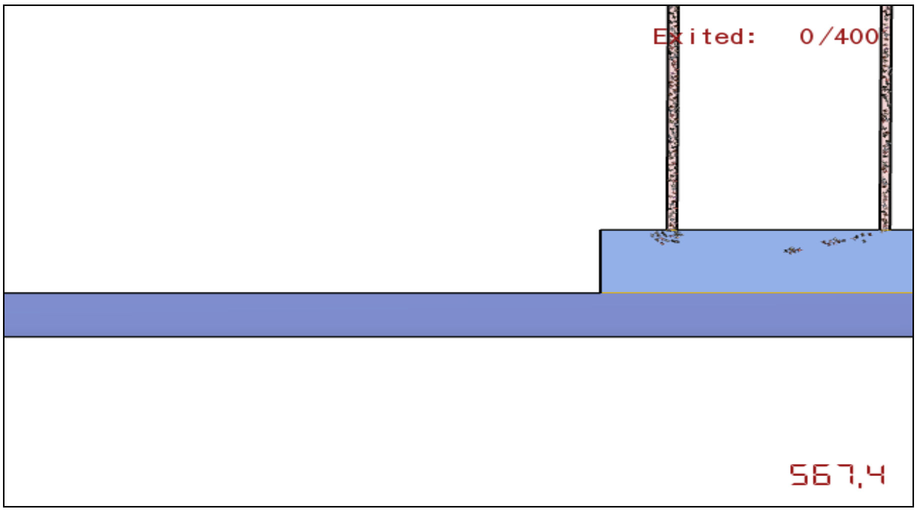

Fig. 9 Simulation example for the first scenario
after 567.4 seconds from the start of the simulation

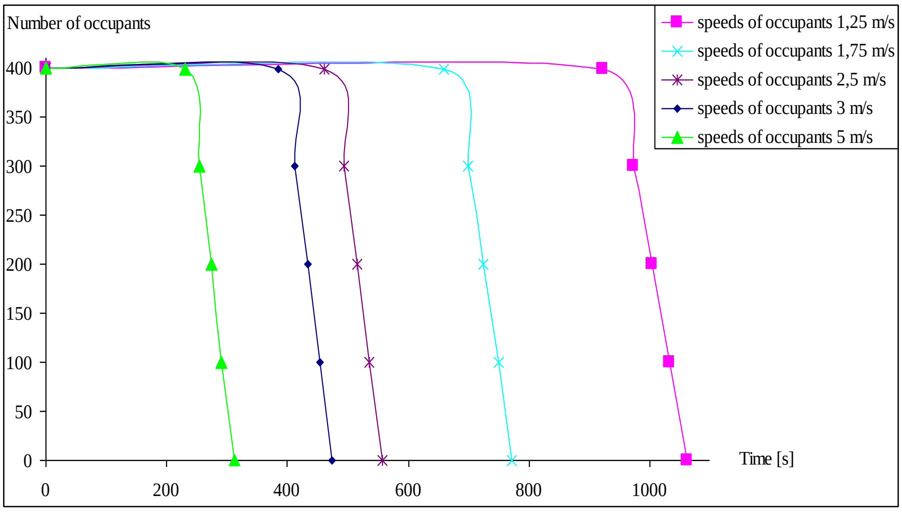

Fig. 10 Simulation results for the first scenario with emergency exits

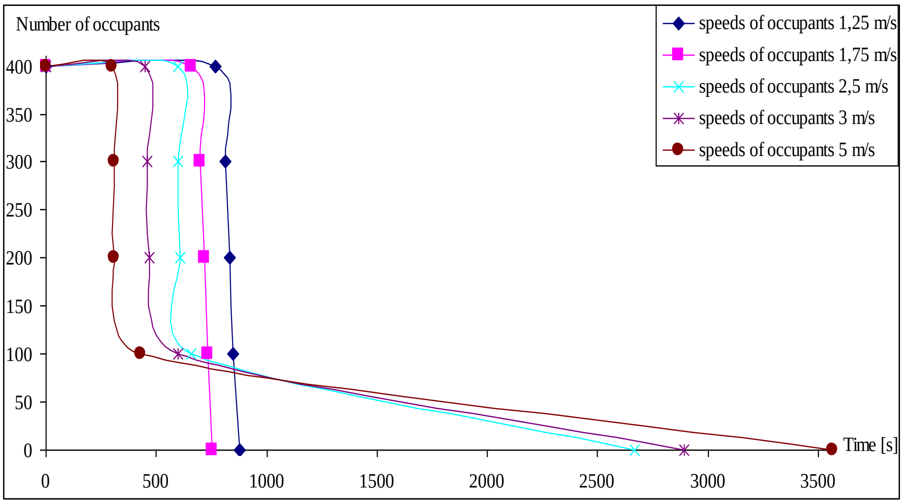

Fig. 11 Simulation results for the second scenario with emergency exits

5. DISSCUSSION

Simulation results mostly showed expected directions, ways and times for complete metro evacuation for the first scenario. For the second scenario, it was obvious that simulated accident would change evacuation routes for some passengers and change evacuation times for different speeds of occupants. For the first scenario, evacuation times were shorter for higher evacuation speeds. For the second scenario, as it could be seen, accident event, presence of fear and panic lead to stuck situations that often result with much longer evacuation time, difficulties and human victims. If we take into account that many metro tunnels could not provide emergency exits on determined distances for many reasons, for example, because of its geography position and location, these facts and results become even more important. It is obvious, according to realized simulation results that bigger speed of occupants could cause occupants to become stuck since they cannot leave the wagon quickly enough. This is even harder if the wagon turned on its side or on the roof. Although some metro tunnels have many emergency exits beside platforms, the complete evacuation could be very and complex. In this case, the platforms would be treated as emergency exits.

This simulation of evacuation examples realizations was not too complex, but, it is very important to note that this and similar software could analyze more complicated situations, such as fire influence on occupant's evacuation, air flow influence on smoke in the tunnel or closed space as well as many other threats where every information is crucial to save human lives and material properties [9, 11].

6. Conclusion

Use of simulation software has a great importance in human lives and material properties protection. It is almost impossible to predict each possible real situation without usage of simulation software. Also, real simulation or exercise of potential disaster could be very dangerous, expensive, and hard for realization and very often with incorrect results and conclusions. Analyzing evacuation times and evacuation routes are very appropriate because it gives a good overview of how available evacuation routes could be used for different accidents (bomb explosion, collision, fire, earthquake, etc.). As well as suggestions of how fast occupants could leave the facility. It is also possible to locate new evacuation routes that could be used in accidents (emergency exits, lower floor exits, lower windows, etc.). Testing these factors for different occupant's speeds and behaviors, on this way, gives a good real presentation of potential evacuation scenario in a given facility and great advantages in designing and installing complete protection systems.

Parallel usage of this software and PyroSim software, a software for fire behavior analysis, could contribute to human and material properties protection. For example, testing one potential scenario in PyroSim could give crucial important information about fire spreading, smoke spreading, air flow influence on fire, temperatures in some facilities, CO_2 and CO presence, flame presence, temperature and smoke detectors positions and lot of other factors that could have great influence on occupant evacuation and their selection of potential evacuation routes. These programs could import created objects between each other and significantly decrease time for projection and increase the importance of realized results [1, 5, 8].

There are many new approaches and algorithms about evacuation and behavior under accident that are constantly improving, the knowledge of which significantly increases the safety level for different evacuation scenarios [10].

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BEZBEDNOST U METROU – PRIMER SIMULACIJE EVAKUACIJE IZ METROA

Evakuacija predstavlja jedan od najvažnijih, najodgovornijih i najkompleksnijih zadataka vezanih za bezbednost ljudi u objektima generalno. Evakuacija iz objekta ili sa nekog mesta je potrebna iz više razloga: požar, eksplozija, poplava, zemljotres... Ovo je posebno važno za objekte sa specijalnim namenama kao što je metro. Ovakvi objekti imaju frekventan promet i saobraćaj ljudi i vozila, tako da, u odnosu na tu činjenicu, mogućnosti i verovatnoće za katastrofe i nesreće su velike. Ovo je uvek aktuelan i otvoren problem, što je i potvrđeno mnogim stradalim ljudima u nesrećama koji nisu mogli biti evakuisani ili gde sama evakuacija nije bila moguća iz nekih razloga. Mogućnosti za evakuaciju u metroima značajno smanjuju mnogo jača širenja požara i dima nego na otvorenom prostoru, dužina tunela kao i mnogo drugih razloga.ovaj rad je napisan da pokaže moguće evakuacione situacije i izračuna minimalno vreme za evakuaciju u slučaju 3600 m dugog metroa sa izlazima za slučaj opasnosti na svakih 1200 m.

Ključne reči: *evakuacija, simulacija, metro*