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Fire Impacts in Metro Railway Tunnel: A Mathematical Approach

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ABSTRACT

The growing need for more complicated underground urban systems has resulted to the development of evacuation procedures improvement. In addition, beside the fact that structures with massive public traffic such as mall or metro systems, have improved safety systems and plans, emergencies still occurs. The special and alternative circumstances and conditions, which characterize the underground spaces in contrast to surface constructions, as well as the severity of the consequences if an accident occurs, stimulated the research for prevention and forecast of the consequences.One major event that may affect human health and structure stability is fire. Byproducts of fire influence the evacuation by affecting vital occupants' points such as visibility and physical strain. The total time from fire ignition to the time that an area reach untenable conditions, in which people become unable to recue themselves, is crucial in order to evaluate structure safety or re-plan the evacuation routes and safety degree. The paper analysesthe effect of a fire in a typical railway Metro tunnel by using Fire Dynamic Simulation (FDS) and computer evacuation models. This is achieved by using pre-defined fire scenarios and measure three important parameters that affect evacuation occupants: CO density, Temperature and Visibility.

***Keywords**: railway evacuation, metrotunnel evacuation, tunnel fire simulation, exit routes, evacuation simulation*

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I. INTRODUCTION

Over the last decade, tunnel construction activities (road and railway) in Europe were accelerated, as a general need to facilitate the transportation of people and goods between large areas of the continental Europe and preserve the quality of the environment - inside and outside the cities. Although accident rates in road and rail tunnels are low and fires are not especially common in tunnels, the consequences in a tunnel can be far more severe than similar fires in conventional structures. Large tunnel fires have shown the devastating effects of smoke and heat on people escaping from tunnels. Additionally, the fires caused severe damage to the tunnel structure and financial losses due to interrupted operation. As a consequence, the required fire safety measures for tunnel infrastructures have become more stringent in recent years(ITA COSUF, 2014). Even though the construction works are evolving, it is only in the recent years that fire safety of such infrastructure has gained attention.

Therefore, and owing to the recent fire incidents, safety guidelines for road tunnels have reached high level of detail and exhibit substantial degree of international harmonization, which led to the EC directive 54/2004 which seeks to ensure that all tunnels longer than 500 meters, whether in operation, under construction or at the design stage and forming part of the trans-European road network, comply with the new harmonized safety requirements.

In contrast, safety requirements for rail tunnels and underground systems are limited to more basic and less uniform requirements. The standards for smoke control in metro systems, for example, might vary even within a country from project to project.

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National regulations (e.g. NFPA130 from USA or SIA 197/1 according to German standards) provide at times quite specific minimum requirements, e.g. with respect to the maximum allowable distance between emergency exits and to the minimum width of escape paths while the EU regulation 1303/2014 lacks of guidelines for the implementation.
Therefore, a successful evacuation process is critical to reach this objective. Currently, evacuation calculations are becoming a part of fire safety science performed either by hand calculations or by modeling and simulation (Kuligowski, Peacock, & Hoskins, A Review of Building Evacuation Models, 2nd edition, 2010).
As more and more people are affected by the impact of emergencies and disasters across the globe, it is imperative that response and recovery agencies, organizations and individuals focus on preparedness for a wide range of situations (Australia Emergency Management, 2005). Although a safety plan incorporates actions focusing on prevention, the establishment of procedures to govern and coordinate the available measures for the safe exit of the users in the case of an emergency is also a key element of the process. Thus, a reliable plan for the escape and evacuation of the users should be available and tested in order to identify problems and optimize the whole process. Orderly and complete evacuation of all occupants and visitors requires the careful provision for exit routes and accounting for all individuals after the evacuation (Gustin, 2007).

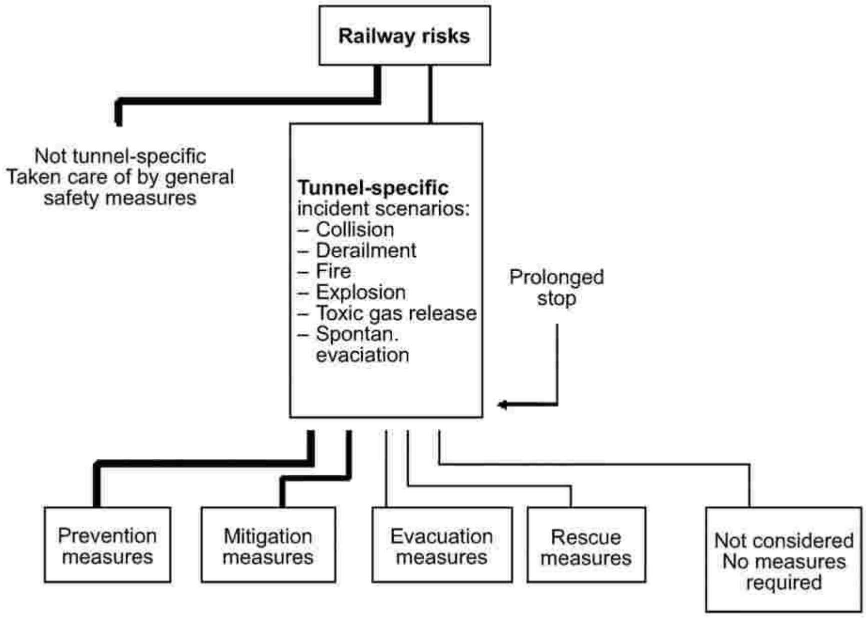

Figure 1. Railway risk scenarios (EU Commision, 2007)

Evacuation calculations have become a part of performance-based analyses to assess the level of life safety provided in buildings (Nelson H. E., 2003), by also taking into account the Required Safe Egress Time/Available Safe Egress Time (RSET/ASET) concepts. In some cases, engineers are using backof-the-envelope (hand) calculations thatusually follow the instructions and assumptions given by the codes to calculate mass flow evacuation.To achieve a more realistic evacuation calculation, and save time, engineers have been looking to computer models to assess a building's life safety (Kuligowski & Peacock, 2005).Evacuation modelling is a virtual representation of reality that relies on the theory and the data collected. This technique is used to simulate the course of the events that may occur during emergency scenarios (Ronchi, 2012).
This paper presents the impact of 4 fire scenarios in a typical railway tunnel evacuation passengers, regarding three parameters in major consideration: CO density, Temperature and Visibility.

II. TUNNEL EVACUATION

A disorganized evacuation can result in confusion, injury, and property damage. Therefore, when developing an emergency action plan it is important to determine the following(Occupational Safety and Health Administration, How to Plan for Workplace Emergencies and Evacuations, 2001):

- Conditions under which an evacuation would be necessary.
- A clear chain of command to control the evacuation process and designation of "evacuation wardens" to assist the evacuation and to account for personnel.
- Designation of what, if any, employees will continue or shut down critical operations during an evacuation

- Specific evacuation procedures, including routes and exits, posted and easily accessible to all employees, as well procedures to assist the evacuation for people with disabilities
- A system for accounting for personnel following the evacuation.

One major issue that should be designed and maintained appropriately, is the exit routes (Figure2). An exit route is a continuous and unobstructed way of exit travel from any point in a building or structure to a public way and consists of three separate and distinct parts: the way of exit access (portion of an exit route that leads to an exit), the exit (portion of an exit route that is generally separated from other areas to provide a protected way of travel to the exit discharge), and the way of exit discharge (part of the exit route that leads directly outside or to a street, walkway, refuge area, public way, or open space with access to the outside.).

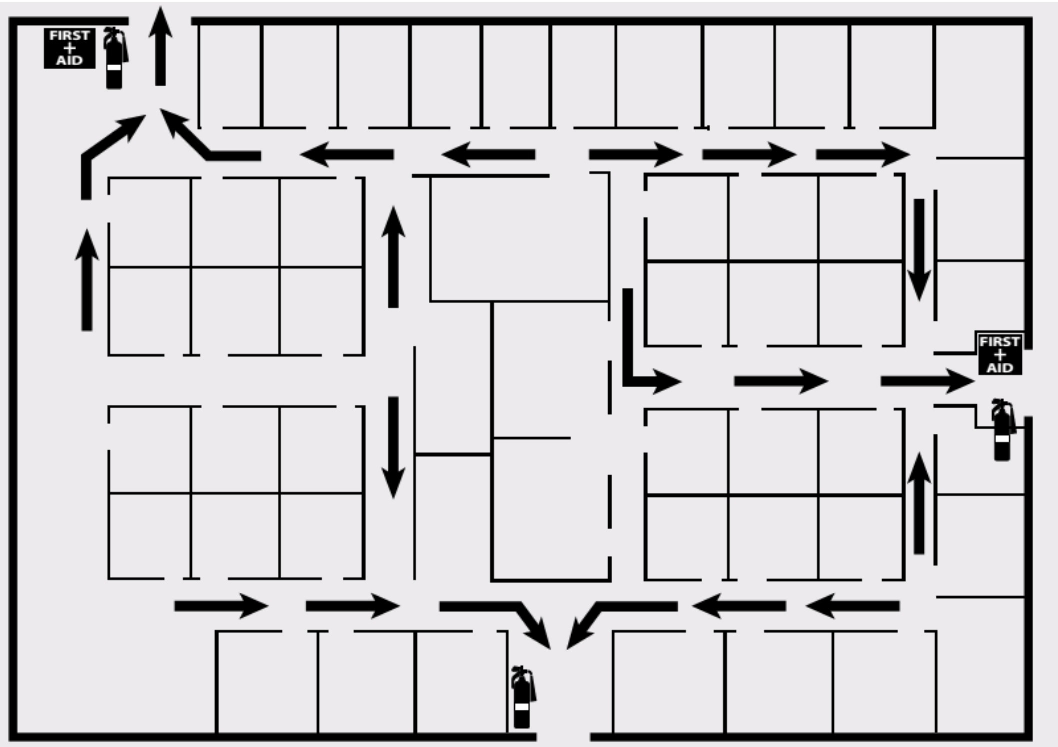

Figure2. Exit route paths drawn on a floor plan (Occupational Safety and Health Administration, Fact Sheet-Emergency Exti Routes, 2003)

To ensure the compliance with above requirements, organizations such as the National Fire Protection Association – NFPA(National Fire Protection Association, Life Safety Code - NFPA 101, 2015), the European Guidelines – CFPA(Confederation of Fire Protection Association Europe, 2009), the Building Code of Australia – BCA(Australian Building Codes, 2004), have defined some minimum requirements and standards that concern the limitation of certain parameters, as the following:

- exit route (path) width
- travel distance
- exit route capacity
- exits' door relative location
- occupants load
- evacuation time

The above parameters' limitations aim to achieve the best conditions during evacuation procedure and to minimize damage (human and property) as well. Of course some adjustments are to be made with respect to the type of the facility and the number/type of the occupants in it.

In order to calculate evacuation time, both evacuation models and hand calculations, consider human speed. There have been observations and experiments (Nelson & Mowrer, 2002) in order to create an equation to calculate human speed. From these observations, it is derived that human evacuation speed is always related to population density.

There are some main characteristics in underground spaces (as well as subway rails) that make the evacuation procedure more complex and dangerous for passengers.

Table 1 Characteristics of underground spaces in contrast to surface buildings

Underground spaces	Surface buildings
Upward travelling in stairwells	Downward travelling in stairwells
Smoke moves to escape routes	Smoke moves to the closest opening: window, etc.
Faster temperature increase for the same fuel	Slower temperature increase
Passengers have little sense of orientation	Easier orientation and (possibly) natural lighting
Passengers tend to leave the entrance - exit they entered	Occupants tend to follow signs and markings
Slower evacuation start	Lesser evacuation delay
Passengers fatigue due to upward movement on ramps and stairs	Lesser occupants fatigue

III. EVACUATION TIME

1.1 Required and available safe egress time

In general, life safety from emergency is achieved if the required safe egress time (RSET) is shorter than the available safe egress time (ASET), where the ASET is defined as the time when fire-induced conditions within an occupied space or building become untenable (Nelson & Mowrer, 2002). Untenable conditions when an occupant inside or entering an enclosure is expected to be unable to save themselves (is effectively incapacitated) due to the effects of smoke, heat or toxic gases (Confederation of Fire Protection Association Europe, 2009).

The Required safe egress time (RSET) can be subdivided into a number of discrete time intervals, the sum of which constitute the total RSET:

$$RSET = t_d + t_a + t_o + t_i + t_e \qquad \text{Equation 1}$$

where,

t_d is the time from fire ignition to detection,

t_a the time from detection to notification of occupants of an emergency,

t_o the time from notification until occupants decide to take action,

t_i the time from decision to take action until evacuation commences and

t_e the time from the start of evacuation until it is completed.

NFPA 130 adopts a restriction that sets as sufficient egress capacity for the platform occupant load to evacuate the station platform in 4 minutes or less (NFPA 130, 2014). In addition, the station shall be designed to permit evacuation from the most remote point on the platform to a point of safety in 6 minutes or less (NFPA 130, 2014).

Moreover, the worst-case scenario and the considerations of evacuation of Taipei MRT system, require that the occupants on the platform have to evacuate the place within 6 minutes. If the station is a multi-floor construction, in 6 minutes' egress time, should be added 2 minutes per added floor (Chien et al., 2004).

These time criteria are known as the ASET which means the time available for the occupants to leave platform and station before they become overwhelmed by the effects of the fire and smoke. In this code there is no reference about the railway tunnel evacuation time.

The determination of ASET is a complex procedure that need to take account many parameters.

IV. RAILWAY TUNNEL FIRE SIMULATION

One of the most severe emergency situations that can be materialized in an underground environment is a fire event. This can impose serious heat loads, but more importantly it can generate smoke quantities which can impede the users' ability to self-rescue or threaten their lives(Salmensaari, 2010).During the past years underground metro has experienced some severe threats as the one in Brussels or St. Petersburg. Unfortunately, the death toll was heavy but hopefully, the smoke volume was minimal which allowed for the passengers to reach for the nearest exit, as the train stopped inside the tunnel.

This paper represents the effects of a fire in a railway tunnel as regard 3 parameters: Temperature, CO density and Smoke visibility. The simulations take place in a typical Metro tunnel and the fire assumed to start close to station. More specified, the following assumptions have been taken into account:

- Distance between exits are 250m
- One exit is the entrance to the station and the other an ascending staircase
- Fire take place in the middle point of the exits

- Fire scenarios are based on “Guide to Road Tunnel Safety Documentation”, Booklet 4 of Centre d’Etudes des Tunnels.
- The simulated fires Heat Release Rate are 5, 10, 20, and 50MW
- There is no ventilation in the tunnel (pressure difference from exits – openings - are zero)
- The simulations achieved by using FDS and Pyrosim software packages
- Simulations run for 600 seconds (10 minutes)

All four fire scenarios, assumed to ignite 1m^2 fuel area and reach the highest heat release rate (HRR) in 180sec and keep it for at least 1000sec.
Figure 3 show the fire spread regarding to time for a 5MW fire in a railway tunnel as shown in smoke view, a support results’ visualization of FDS software.

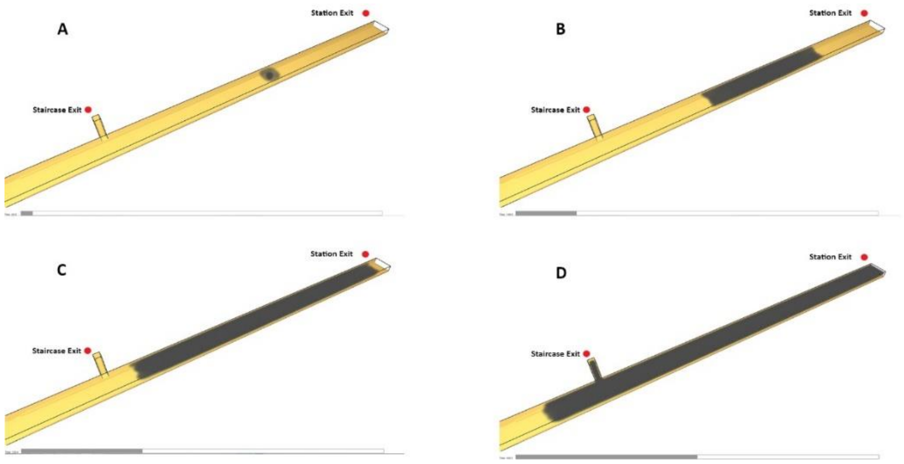

Figure 3 Smoke spread visualization regarding time (A-20”, B-100”, C-200”, D-300”) for 5MW fire

In order to account the temperature, CO density and visibility around the fire, plenty of device sensors are placed all over the space to measure the corresponding parameter.Figure 4 and Figure 5 shows in graph mode, the temperature increment regarding to time for different distance from fire origin. In these figures, are presented the lowest (5MW) and the highest (50MW) fire intensity respectively. In addition, in these graphs the high changes of temperature in very short time are derived from fire flashovers and computational error, so in short distance line of fire origin (5m) are removed from axes.

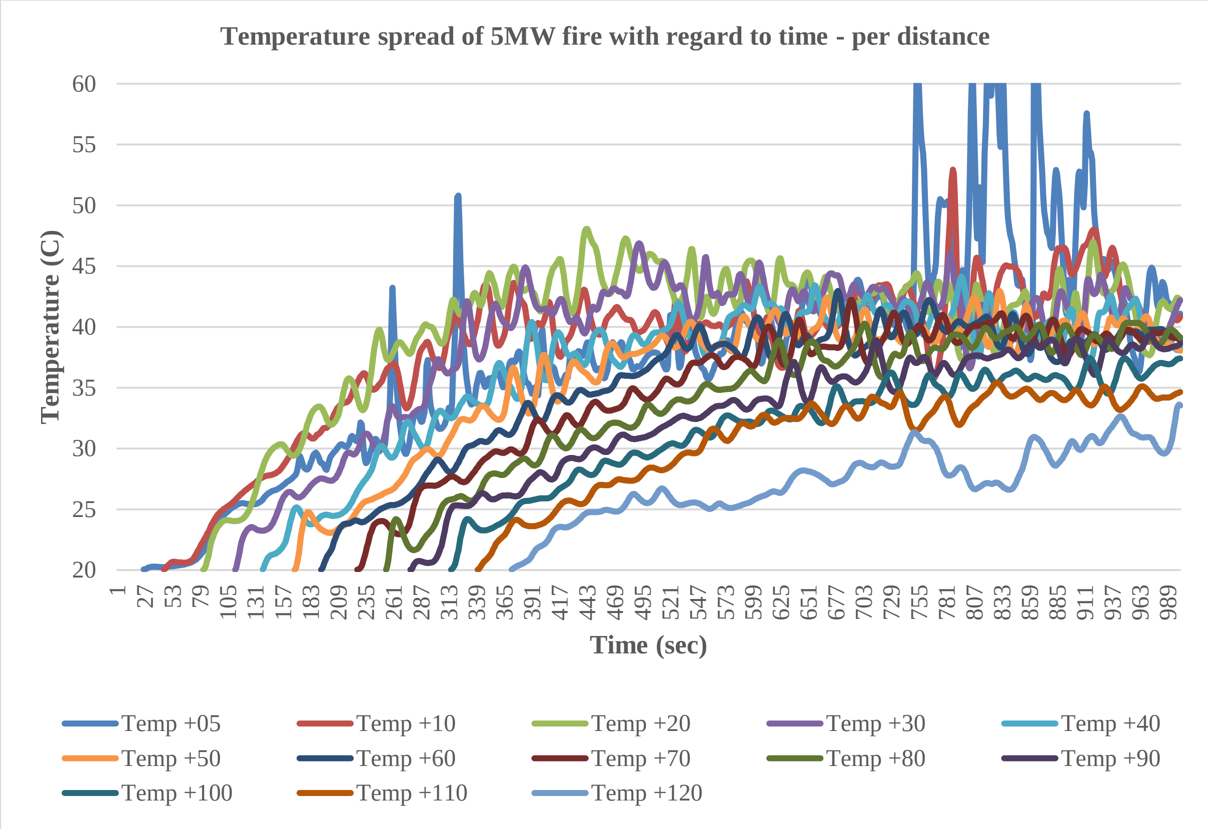

Figure 4 Temperature spread for 5MW fire

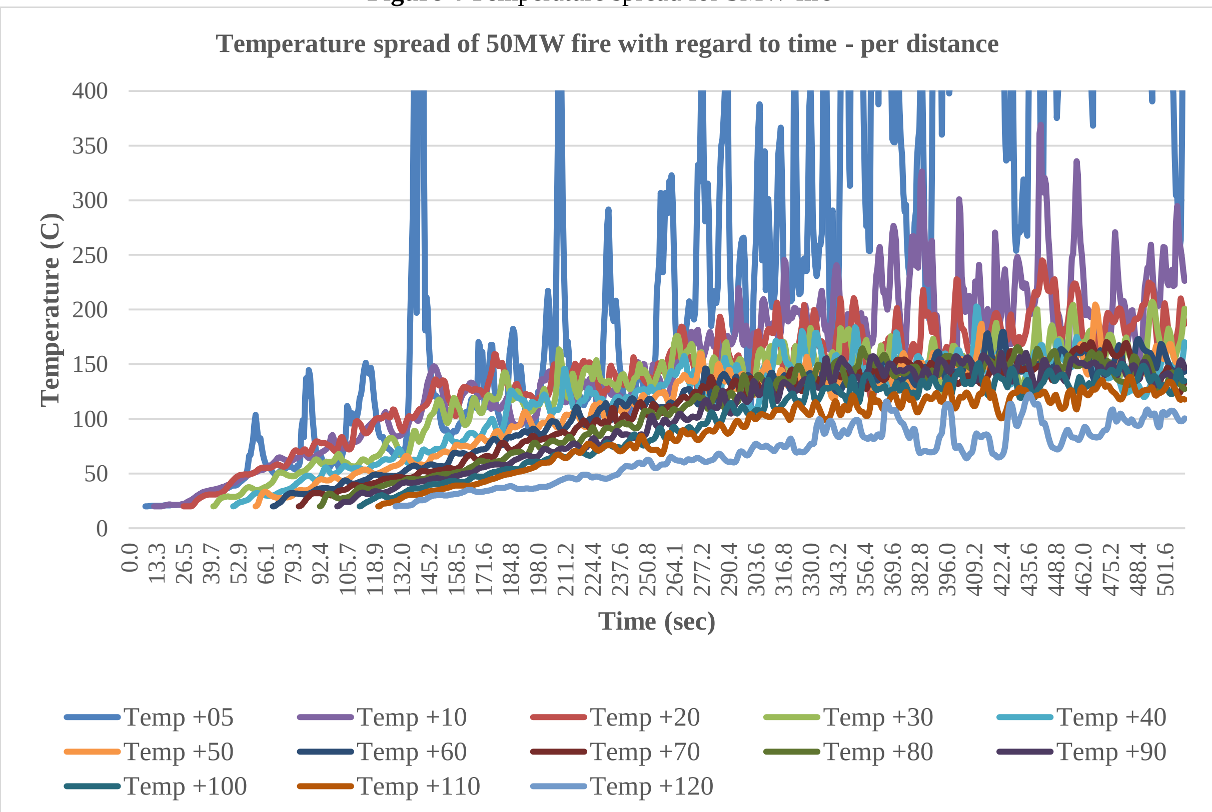

Figure 5 Temperature spread for 50MW fire

Therefore, by using excel trendline option, an optimal function for these graphs is:

$$f(t) = aln(t) + b \qquad \text{Equation 2}$$

Where t is the time in seconds and a, b constant numbers that depend on fire intensity and distance. In Figure 6 and Table 2 the values of a and b constant numbers in reference to distance for 5MW fire are presented. The r-square number is a measure of the goodness of fit of the trendline to the data (a value of 1 is a perfect fit). InFigure 6a and b curves and trendlines for 5MW fire are presented the trendlines for a and b constant number with regard to distance for 5MW fire. Therefore, a function with two variables that gives the temperature for given time and distance is the follow (5MW fire):

5MW fire, Temperature: $f(t,d) = (0.04 * d + 8.34)\ln(\text{t}) - (0.33 * \text{d} + 5.62)$ Equation 3

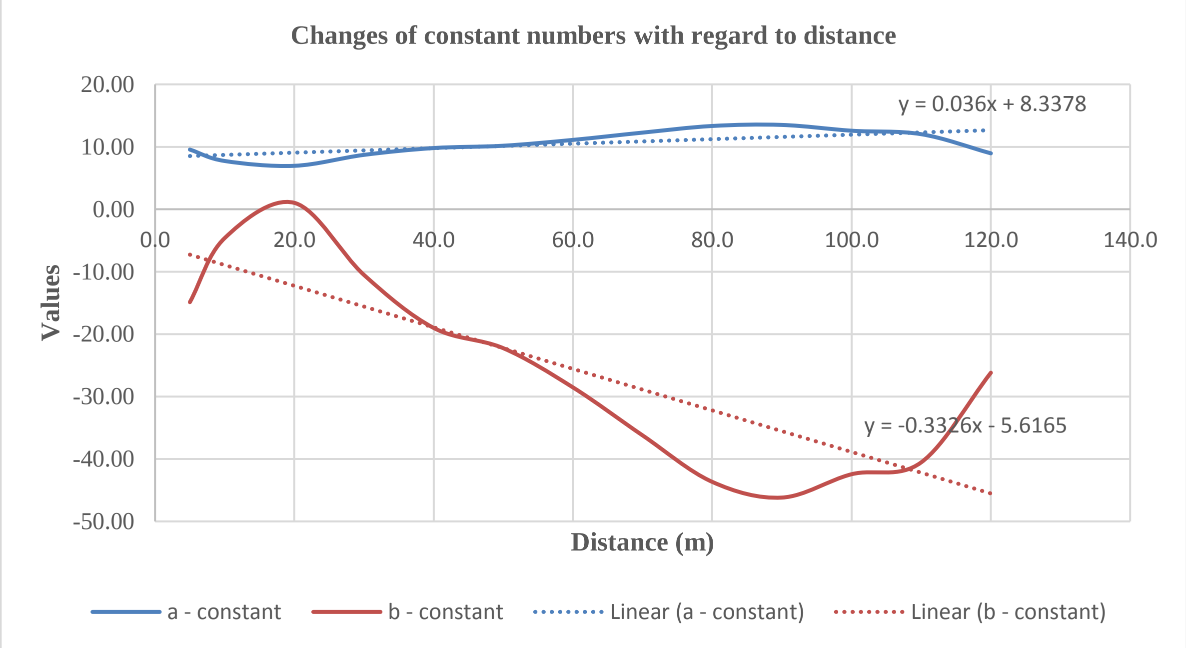

Figure 6a and b curves and trendlines for 5MW fire (temperature function)

Table 2 Constant values for different "isocurves" of distance for 5MW fire

Distance	a	b	r - square
5,0	9,55	-14,89	0,72
10,0	7,72	-4,62	0,82
20,0	6,95	1,02	0,60
30,0	8,71	-10,53	0,68
40,0	9,79	-19,01	0,81
50,0	10,17	-22,26	0,84
60,0	11,10	-28,54	0,86
70,0	12,27	-36,23	0,90
80,0	13,33	-43,67	0,94
90,0	13,50	-46,19	0,95
100,0	12,57	-42,45	0,95
110,0	12,02	-40,55	0,89
120,0	8,95	-26,19	0,82

Using the same methodology follows the below functions of each fire intensity:

10MW fire, Temperature: $f(t,d) = (0.06 * d + 17.25)\ln(\text{t}) - (0.59 * \text{d} + 31.87)$ Equation 4

20MW fire, Temperature: $f(t,d) = (0.02 * d + 35.16)\ln(\text{t}) - (0.56 * \text{d} + 92.08)$ Equation 5

50MW fire, Temperature: $f(t,d) = (0.06 * d + 64.68)\ln(\text{t}) - (0.98 * \text{d} + 212.58)$ Equation 6

Similarly, are defined the mathematical functions that connects distance and time to CO density (counted in ppm). Figure 7 shows the changes to CO density (in ppm) with regard to time, for different distances from fire origin (are presented only 4 distance curves to avoid graph confusion). As well as temperature case, the relation of CO density and time may mathematically appear as $f(t) = a\ln t{+}b$ Equation 2. In addition, Figure 8 presents the a and b constant number changes (and their trendlines) with regard to distance for 20MW fire. Finally, Figure 9visualizes the spread of CO density for 50, 150, 300 and 500 sec after 50MW fire ignition.

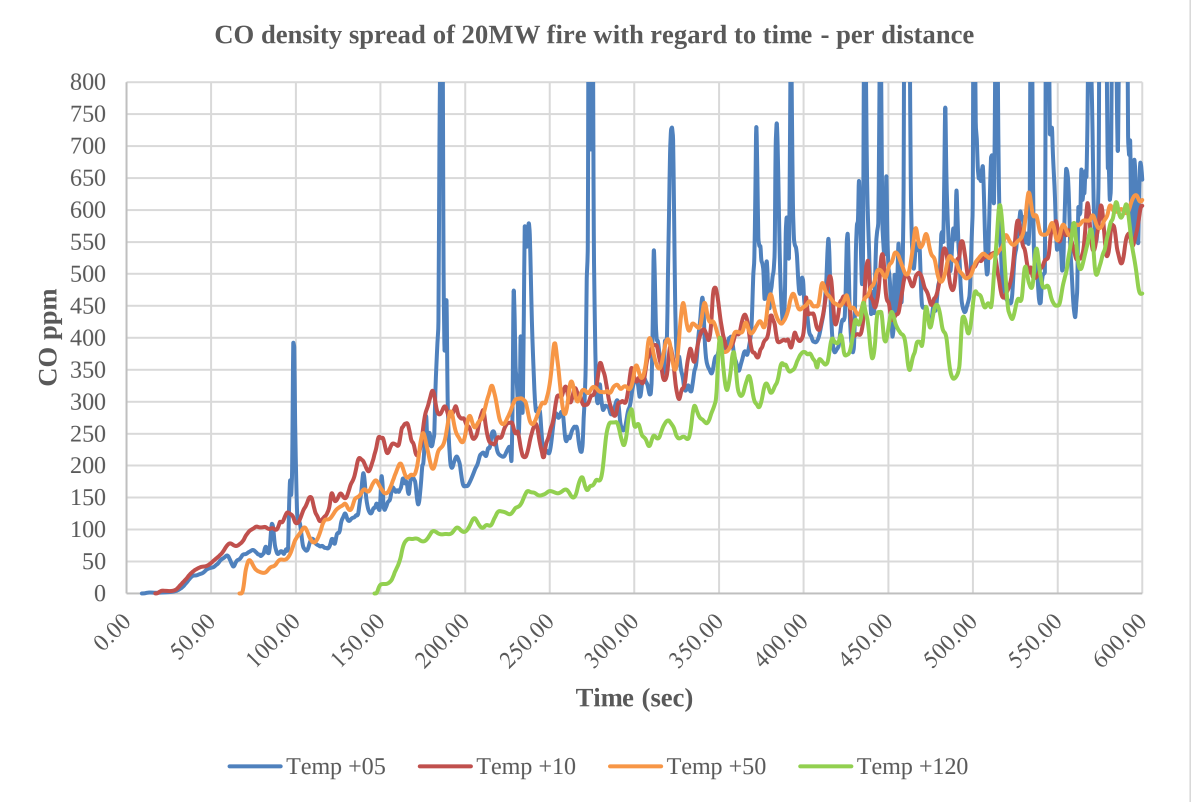

Figure 7 CO density spread for 20MW fire

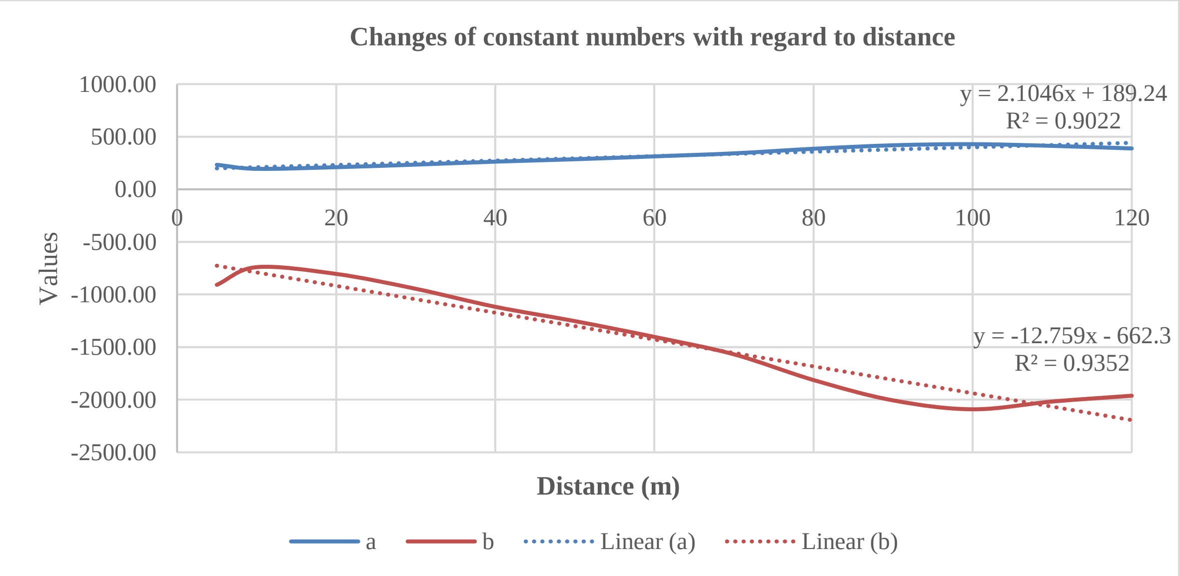

Figure 8 a and b curves and trendlines for 20MW fire (CO density function)

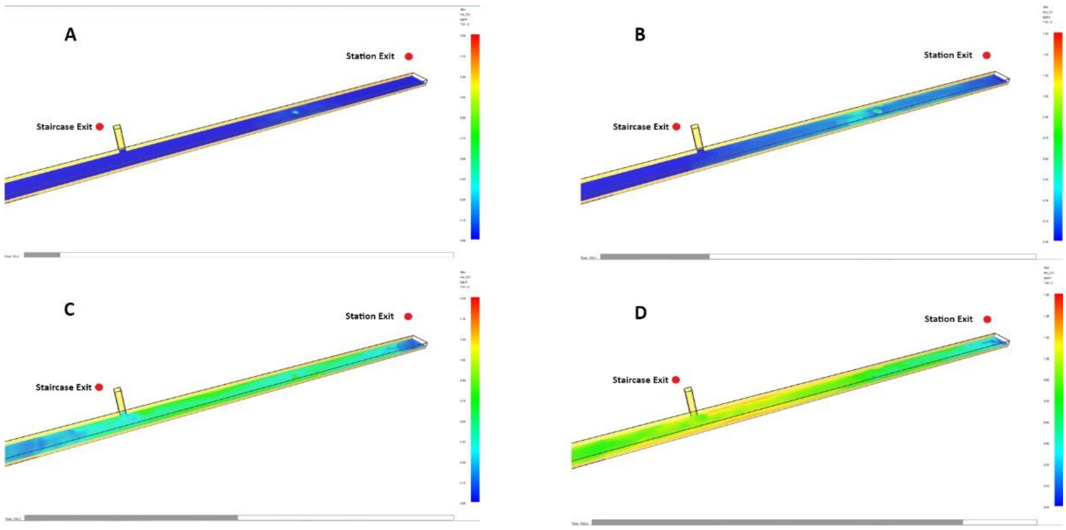

Figure 9 CO spread visualization regarding time (A-50", B-150", C-300", D-500") for 20MW fire

Therefore, the approximate functions for CO density spread are the follows:

5MW fire, CO density: $g(t,d) = (0.61 * d + 43)\ln(\mathrm{t}) - (3.83 * \mathrm{d} + 147)$ Equation 7

10MW fire, CO density: $g(t,d) = (1.27 * d + 91)\ln(\mathrm{t}) - (7.48 * \mathrm{d} + 307)$ Equation 8

20MW fire, CO density: $g(t,d) = (2.10 * d + 189)\ln(\mathrm{t}) - (12.76 * \mathrm{d} + 662)$ Equation 9

50MW fire, CO density: $g(t,d) = (3.7 * d + 517)\ln(\mathrm{t}) - (23.95 * \mathrm{d} + 1989)$ Equation 10

Regarding the smoke visibility spread, the facts are quite different since when the smoke reach an area, the visibility drops to 0.5m rapidly (Figure 10).Table 3presents in one hand the moment that smoke reaches the point of interest and on the other hand the moment when visibility drops below 1m. This rapidly drop occurs in average of 110" for 10 MW, 80" for 20MW, 60" for 50MW and 200" for 5MW fires.

Obviously, an optimal function for these graphs is:

$$h(t) = \frac{\mathrm{a}}{(\mathrm{t}-\mathrm{b})}$$ Equation 11

Where t is the time in seconds and a, b constant numbers that depend on fire intensity and distance. More specifically, b represents the time in which the smoke reaches the area of interest. Therefore, by making the graph relation between b and distance an approximate trendline is determined (Figure 11).

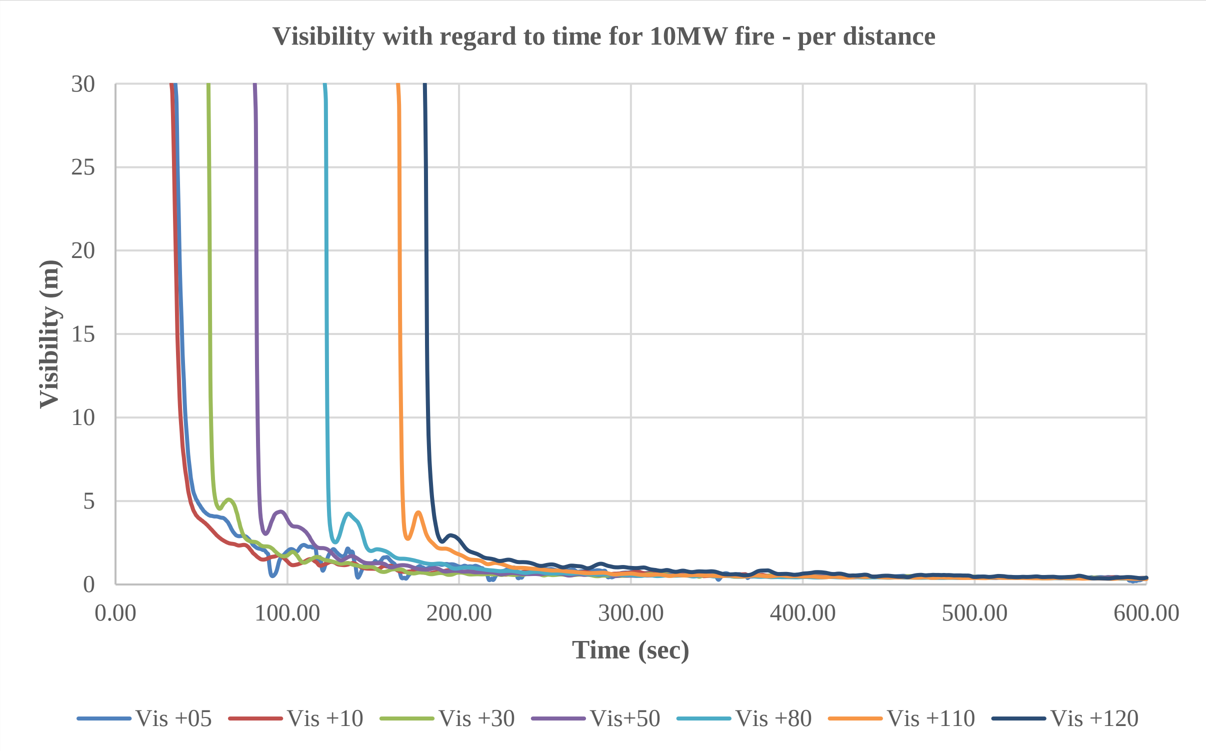

Figure 10 Visibility with regard to time for 10MW fire

Table 3 Smoke affect timings for 10MW fire

Distance	Time smoke reach point of interest (sec)	Time visibility drops below 1m (sec)
5	34	150
10	32	160
30	54	170
50	81	185
80	121	210
110	164	255
120	180	305

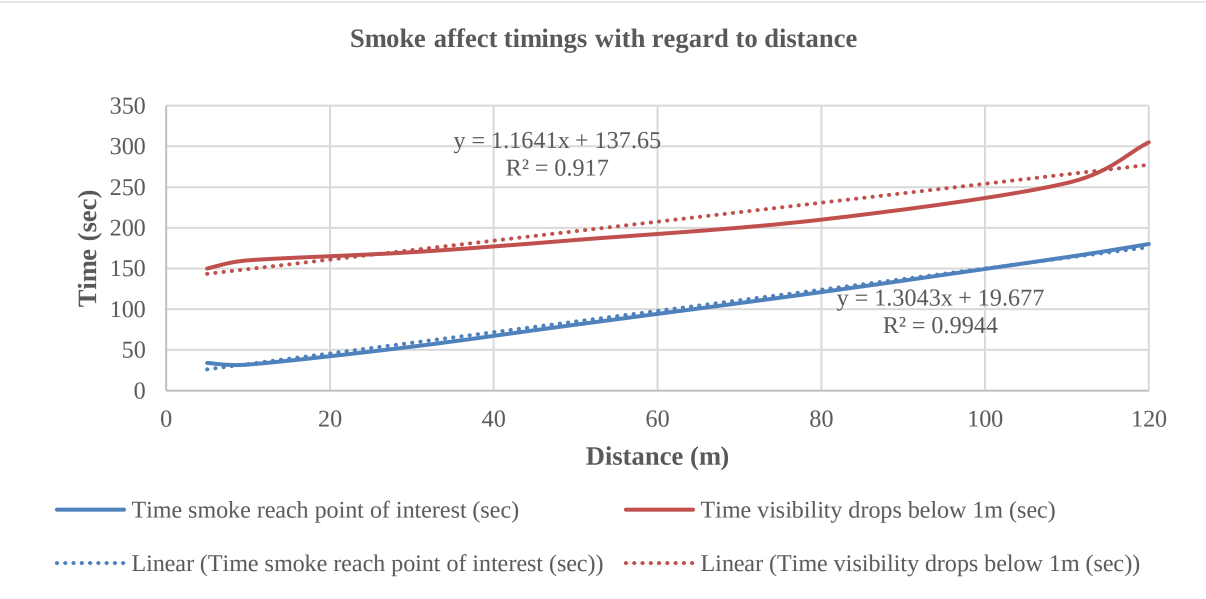

Figure 11 Smoke affect timings with regard to time for 10MW fire

Therefore, the approximate functions for visibility are:

5MW fire, CO density: $h(t,d) = \frac{30}{(t-(1.62d+26))}$ Equation 12

10MW fire, CO density: $h(t,d) = \frac{30}{(t-(1.30d+20))}$ Equation 13

20MW fire, CO density: $h(t,d) = \frac{30}{(t-(1.08d+17))}$ Equation 14

50MW fire, CO density: $h(t,d) = \frac{30}{(t-(0.98d+13))}$ Equation 15

V. CONCLUSIONS

The main conclusion from this study is that the fire impacts can be mathematically predicted and determined by making a deterministic analysis in Fire Dynamic Simulation (FDS) software.

Since a fire is a rapidly developing chemical procedure, the area close to it may give unpredictable results and obviously may harm instantaneous the occupants that waits or pass through that area. This effect becomes more intensive as the fire HRR increasing.

The most rapidly impact spread is the smoke density that affects visibility. Smoke high density (visibility<1m) gives 40” to 70” (depends on fire HRR) to passenger to start moving without being affected and spreads with a speed of 1 to 1.3 m/s. Considering that occupant speed in low crowded area assumed to be 1.2m/s, the need of initiateevacuation is major. Trapped in an over smoked area may drive to disorientation and high evacuation time in an area that heat and toxic gas continue to affect the body.

The results of mathematical approach may be used in area like tunnels that consist of a long unobstructed corridor. More geometrically complex structures may affect the spread of fire (and its byproducts) with impact (positive or negative) to human and structure, as well as the existence of ventilation may improve or aggravate the fire affects.

Finally, combining the mathematical functions that arises from this paper and human toxic limitation, is a promising methodology to calculate the fractional effective dose on passengers and determine the available safe egress time (ASET).

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REFERENCES

[1]. Adjiski, V., Mirakovski, D., Despodov, Z., & Mijalkovski, S. (Volume 14, Issue 3). Simulation and optimization of evacuation routes in case of fire in underground mines. Journal of Sustainable Mining, 133-143.

[2]. Association, N. F. (2000). NFPA 130 Standard for Fixed Guideway Transit and Passenger Rail Systems. Quincy, Massachusetts: National Fire Protection Association.

[3]. Australia Emergency Management. (2005). Australian Emergency Manual Series - Evacuation planning_Manual Number 11. Dickson: Commonwealth of Australia.

[4]. Australian Building Codes. (2004). Building Code of Australia (Volume one ed.). Canberra: CanPrint Communications Pty Ltd.

[5]. Capote, J. A., Alvear, D., Abreu, O., Cuesta, A., & Alonso, V. (2013). A real-time stochastic evacuation model for road tunnels. Safety Science, 52, 73-80.

[6]. Casavant, D. A. (2007). Emergency Preparedness for Facilities: A Guide to Safety Planning and Business Continuity. Plymouth: Government Institutes.

[7]. Centre d'Etudes des Tunnels. (2003, September). Guide to Road Tunnel - Safety Documentation_Booklet 4, Specifi Hazard Investigations. France: Actaes Editions.

[8]. CFPA. (2009). Fire safety engineering concerning evacuation from buildings, CFPA -E No 19:2009. Zurich: CFPA-E Guidlines.

[9]. Chien et al., S.-W. (2004). A Study on the People Evacuation Safety for the Underground MRT Station. 6th Asia-Oceania Symposium on Fire Science and Technology (pp. 292-304). Daegu, Korea: International Association for Fire Safety Science.

[10]. Confederation of Fire Protection Association Europe. (2009). European Guidlines, Fire Safety Engineering concerning Evacuation from Buildings. Zurich, Stockholm: CFPA.

[11]. Erkan, İ., & Hastemoglu, H. (2015). Building Evacuate Module for Urban Underground Passages: Subway Station in Turkey. Journal of Transportation Technologies, 1.

[12]. EU Commision. (2007, December 20). Concerning the technical specification of interoperability relating to ‘safety in railway tunnels’ in the trans-European conventional and high-speed rail system. Official Journal of the European Union.

[13]. Greek Fire Brigade Headquarters, D. o. (1999). Building Fire Safety Regulations (Decree 71/88), (In Greek). Athens: Fire Brigade Headquarters.

[14]. Gustin, J. F. (2007). Disaster & Recovery Planning: A Guide fro Facility Managers, Fourth edition. Lilburn, Georgia: The Fairmont Press, Inc.

[15]. ITA COSUF, . (2014). An Engineering Methodology for Performance-Based Fire Safety Design of Underground Rail Systems.

[16]. Jong-Hoon Kim, Woon-Hyung Kim, Sam-Kew Roh, Duck-Hee Lee, & Woo-Sung Jung. (2009). Experiments of the subway car egress.

[17]. Kallianiotis, A. (2015). Optimization Of Underground Spaces Evacuation Procedures: Evaluation and Optimization Of Exits Position, Ph.D. Thesis. Athens.
[18]. Kallianiotis, A., & Kaliampakos, D. (2012). Improving Evacuation Plans in Underground Spaces: The Role of Emergency Exits Location. 13th World Conference of ACUUS: Advances in Underground Space Development (pp. 100-102). Singapore: Research Publishing.
[19]. Kallianiotis, A., & Kaliampakos, D. (2014). A Study on Undergound Evacuation Plan Parameters. Seoul.
[20]. Kallianiotis, A., & Kaliampakos, D. (2016). Evaluation of Underground Spaces Evacuation Effectiveness. Procedia Engineering, Volume 165, 2016, Pages 564-574.
[21]. Kallianiotis, A., & Kaliampakos, D. (n.d.). Optimization of exit location in underground spaces.
[22]. Kuligowski, E. D., & Peacock, R. D. (2010). A Review of Building Evacuation Models, 2nd Edition. Washington: National Institute of Standards and Technology Technical Note 1680.
[23]. Kuligowski, E. D., Peacock, R. D., & Hoskins, B. L. (2010). A Review of Building Evacuation Models, 2nd edition. National Institute of Standards and Technology, Technical Note 1680.
[24]. National Fire Protection Association. (1999). NFPA 520 Standard on Subterranean Spaces. Quincy, Massachusetts: National Fire Protection Association.
[25]. National Fire Protection Association. (2013). NFPA 130 Standard for Fixed Guideway Transit and Passenger Rail Systems (2014 Edition ed.). Quincy, Massachusetts: National Fire Protection Association.
[26]. National Fire Protection Association. (2015). Life Safety Code - NFPA 101. Quincy, Massachusetts: National Fire Protection Association.
[27]. Nelson, H. E. (2003). Personal Communication.
[28]. Nelson, H. E., & Mowrer, F. W. (2002). Emergency Movement. In Philip J. DiNenno et.al., SFPE Handbook of Fire Protection Engineering (pp. 367-380). Quincy, Massachusetts: National Fire Protection Association.
[29]. Occupational Safety and Health Administration. (2001). How to Plan for Workplace Emergencies and Evacuations. OSHA.
[30]. Occupational Safety and Health Administration. (2003). Fact Sheet- Emergency Exti Routes. OSHA.
[31]. Occupational Safety and Health Administration. (2003). Fact Sheet: Emergency Exti Routes. OSHA.
[32]. Occupational Safety and Health Administration. (2011, June 8). Regulations (Standards - 29 CFR). Retrieved January 16, 2013, from Occupational Safety & Health Administration - OSHA: www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12886
[33]. Papakonstantinou, D., Benardos, A., Kallianiotis, A., & Menegaki, M. (2016). Analysis of the Crowd Evacuation Modeling Approaches for the Case of Urban Underground Spaces. Procedia Engineering, Volume 165, Pages 602-609.
[34]. Prawdzik , E., Clifford, P., & Nightingale , S. (2013). Evacuation Assessment In Transport Planning Models. AET 2013.
[35]. Proulx, G. (2002). Movement of People: The Evacuation Timing. In P. J. et.al., SFPE Handbook of Fire Protection Engineering (pp. Section 3, 342-366). Quincy, Massachusetts: National Fire Protection Association.
[36]. Ronchi, E. (2012). Evacuation Modeling in road Tunnel Fires (Ph.D. thesis). Lund.
[37]. Ronchi, E., Colonna, P., Capote, J., Alvear, D., Berloco, N., & Cuesta, A. (2012). The evaluation of different evacuation models for assessing road tunnel safety analysis. Tunnelling and Underground Space Technology, 30, 74-84.
[38]. Salmensaari, T. (2010). Safety in Long Subsea Rail Tunnels. Helsinki: Aalto University.
[39]. Schachenmayr, M. P. (1998). Application Guidelines for the Egress Element of the Fire Protection Standard for Fixed Guideway Transit Systems - For Use with NFPA 130. New York City: Parsons Brinckerhoff Quade & Douglas, Inc.
[40]. Thematic Network FIT, ‘. i. (2006). Fire in Tunnels_General Report. Brussels.
[41]. Vigne, G., Herrera, F., Jönsson, J., & O´Donnell, D. (2011). The use of advanced evacuation modelling for building design.
[42]. W.L.Wang, & JacquelineLo, T. (Volume 71, 2014). A Simulation Study on Passenger Escape in Rail Tunnels. Procedia Engineering, 552-557.
[43]. Wang, W., & Lo, T. J. (2014). A Simulation Study on Passenger Escape in Rail Tunnels. Procedia Engineering, 71, 552-557.
[44]. Wang, Z., Chen, F., & Li, X. (2012). Comparative Analysis and Pedestrian Simulation Evaluation on Emergency Evacuation Test Methods for Urban Rail Transit Stations. Scientific Journal on Traffic and Transportation Research, 6, 535-542.

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