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Optimization of exit location in underground spaces

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ABSTRACT

Workplace evacuation is a significant emergency response strategy and evacuation planning is mandatory for the emergency safety plan. It is known that the evacuation effectiveness depends directly on the effective location and functionality of the exit route, which includes exit access and exit discharge. Apparently, the exit doors location affect both these elements.

The exit doors position is ruled by standards and regulations and depends on workplace use, building type, occupants' number and type, etc. In underground constructions, the selection of the appropriate location of the exits is not easy. The land surface, the area topography and the fact that emergency exits are involved in the space's ventilation, increase the engineers' difficulty to design.

The regulations mentioned above provide information about installing exits so that the workplace complies with the restrictions imposed. However, up to now a tool to help engineers select the best alternative combination of exits location for a given workplace does not exist.

The purpose of this paper is to present a new software application that takes into account the basic parameters of exit routes regulations (such as distance, exit routes angle, dead end - common path of travel distance limitation) and therefore providing all the possible combination of exit doors location. In addition, each combination acquires an efficient grade through a mathematical function. That mathematical function has derived from a study on the evacuation affecting parameters and provides optimized results for exits location. Therefore, on one hand, the users may observe those combinations that comply with the standards restrictions and on the other hand, they can choose the best alternative.

1. Introduction

An effective safety and emergency plan offers a comfortable and safe workplace that increases employee productivity and, at the same time, reduces the financial loss, as well as the probability of occupants' injury (both employees and visitors) in case of an emergency. Although a safety plan should focus on prevention, emergencies cannot be avoided. Consequently, organizations should offer a reliable safety mitigation plan for occupants and the project itself (Kallianiotis and Kaliampakos, 2012).

Evacuation plans of subterranean spaces in most countries are not mandatory by laws. In Greece for example, the lack of legislation is partially substituted by the obligation to submit a study on passive fire protection based on Decree 71/1988 (*Greek Law*) for each building, which is checked by the Greek Fire Service to suggest amendments, if necessary. This ensures an adequate level of safety. The only reference in subterranean spaces has to do with underground parking areas for up to three levels, which are only treated as buildings with increased risks and specific demands. However, the workplace depth from the surface (that exceeds 15 m) makes the nature of underground spaces remarkably peculiar: there are no openings for natural light, ventilation and lighting are artificial and the sense of orientation is low to none (Kyritsis, 2010). Consequently, there should be a thorough and effective plan for evacuation in case of an emergency to ensure the safety of people working or visiting an underground place.

Orderly and complete evacuation of all occupants and visitors requires careful provision for exit routes and accounting for all individuals after the evacuation. With planning taking into account all factors, quick and orderly evacuations can be achieved with minimal problems (Gustin, 2007).

Exit route means a continuous and unobstructed path of exit travel from any point within a workplace to a place of safety (including refuge areas). An exit route consists of three parts: the exit access, the exit and the exit discharge. Exit discharge (exit door) means the 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. An example of an exit discharge is a door at the bottom of a two-hour fire resistance-rated enclosed stairway

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that discharges to a place of safety outside the building (Occupational Safety and Health Administration, 2011).

Standards and regulations regarding evacuation plans and design, include restrictions and parameters that affect the exits location. These parameters concern, among others, the travel distance to exit door, the exit doors relative position and travel distance in dead end areas.

Evacuation calculations have become a part of performance-based analyses to assess the level of life safety provided in buildings (Nelson, 2003), by also taking into account the Required Safe Egress Time/Available Safe Egress Time (RSET/ASET) concepts. In most cases, engineers are using back of-the-envelope (hand) calculations that usually follow the guidelines and assumptions given by the codes or other researches to calculate evacuation procedures such as evacuation time and egress route flow rate. To achieve a more realistic evacuation calculation, save time or overview a complex scenario, engineers take the advantage of using evacuation computer models to assess a workplace evacuation safety (Kuligowski and Peacock, 2005). Evacuation modelling is a virtual representation of reality (as reliable as possible) 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).

Moreover, evacuation simulation models have been used to study the effect of variety of parameters that may affect the evacuation procedures, such as the effect of uncertain parameters (concerns occupant behavior) on evacuation time in commercial buildings (Xie et al., 2012) or even an optimization of evacuation instructions while anticipating traveler compliance behavior (Pel et al., 2010). Other researches are aimed to study more particular parameters such as the average staircase width and the maximum upstairs speed for subway stations (Jiang et al., 2010).

The paper describes the development of an algorithm combining all critical evacuation parameters, so as to provide the best exits location. It derives from a thorough analysis of the evacuation parameters. Moreover, the algorithm is able to determine all the combinations of the possible exits location and performs an evaluation of them. Also, the software offers a graphical visualization by mapping the designed space based on regulation's compliance and evacuation effectiveness.

2. Evacuation parameters

Evacuation regulations were designed to optimize three key parameters related to safe evacuation and to minimize property damage:

- Hazard identification and evacuation decision immediacy.
- Evacuation completion pace.
- Risk minimization of the evacuation process such as minimization of disorientation, overcrowding and panic.

Regulations which come under the safety standards and codes are affected directly by the exit routes. This includes the number, design, type of exits (exit doors) and location of exit doors which is of major importance. Although the first three ones depend on the type and amount of occupants in the workplace, the exits location is a more complicated issue due to its dependency on building design.

Considering worldwide regulations or standards such as the National Fire Protection Association – NFPA (National Fire Protection Association, 2009), the European Guidelines – CFPA (Confederation of Fire Protection Association Europe, 2009), the Building Code of Australia – BCA (Australian Building Codes, 2004), there are just three parameters determining the exit doors location, related to their specific location.

More specifically:

- Each point in the workplace space should have a given maximum distance from the nearest exit discharge (Fig. 1).
- The travel distance into a dead end area must be under a maximum value (Fig. 2).
- The angle between any point in space and two exits must have a minimum value (in case of more exits in place, this regulation must be applied to at least two of them) (Fig. 3).

Also, some regulations mention a restriction about the exits relative position, such as the minimum distance between them that depends on the building dimensions. For example, National Fire Protection Association (NFPA) Life Safety Code requires that at least two of the required exits shall be located at a distance from

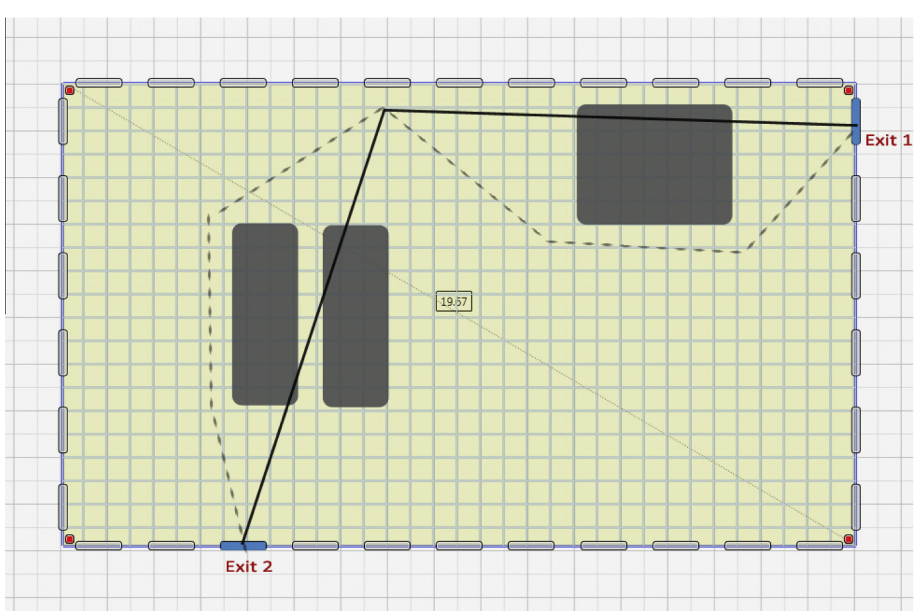

Fig. 1. Maximum distance regulation from exit door (continuous line represents direct distance and dashed line represents actual distance) (Greek Fire Brigade Headquarters, 1999).