Designing Based on Evacuation Risk and Crowd-Disaster Management (Case Study: A Subway Station in Tehran)

Zahir Mottaki [a], Masoud Khosrowtash [b], and Sobhan Mirzaei [c]*

[a] Assistant Professor of Architecture and urban planning, Shahid Beheshti University, Tehran, Iran.
[b] Ph.D. candidate of applied mathematics, Islamic Azad University of Yadegar Imam, Iran.
[c] MSc. in Civil Engineering, Maziar Institute of Higher Education, Faculty of Engineering, Iran.

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 10 May 2021

Abstract: Nowadays, individuals' lives in the community require communication with the environments outside the home and depend on presence in the community. In most urban communities, using public transportation is essential, meaning that public transportation sectors will witness a growing population every day. Crowd disaster and the collective panic shock are of the many human-made crises whose probability of incidence is higher after incidents like fire, earthquake, terrorist attacks, and so on. Tehran has one hundred and twenty-seven subway stations, each of which has been designed and built in a historic urban period and has generally failed in supplying the ideal space required given the financial, engineering, and urban pressures. In some stations, several stations intersect. By examining the studies conducted on crowd disaster and collective panic shock considering the roots and the factors exacerbating these phenomena, mentally and objectively, the study tried to find a way to evaluate the likelihood of crowd disaster in a subway station if an earthquake, threat Terrorist, gas leak, water intrusion or any obstruction occur in the rush hour at a busy subway station like Darvazeh Dowlat - which is the intersection of the two Tehran subway lines and one of the most significant nodes of human traffic in Tehran subway. In this study, using the stochastic differential equations (SDEs), the equation observing population behavior in a subway station was discovered and examined. Simulation was then done using MATLAB and the results showed that a crowd disaster is very likely to occur if anything happens to make all the people on a train leave through a busy station.

Keywords: Emergency evacuation, collective panic shock, risk-based planning, crowd disaster, subway station

1. Introduction

A significant number of people around the world are killed or injured by crises somehow related to human gatherings every year. Crowd-induced crises have been of the main challenges for human communities. In the book "Crowd Disaster Management: Concepts, Theories and Methods," Asgari and Arjangi introduced theories and basics of crowd disaster analysis. Haghani et al. (2016) studied discrete selection model based on output observations selected in two experimental modes in response to hypothetical evacuation scenarios and options done at the time of actual crises (using a sample independent of participants) [1]. The similarities and differences of estimates obtained from these two forms of observation are very important in terms of symptoms, statistical significance, measurement, individual variations, and behavioral interpretation of the estimated parameters and besides the applied scales (which reflect the randomness of decision dependence) they are significant as well.

Mousavi Mobarakeh et al. (2018) have examined the location of subway stations based on passive defense principles (Case study: District 31 of Isfahan) [2]. In the urban subway transportation system, underground subway stations are considered as one of the main components connecting underground and ground spaces. This important component is always exposed to natural hazards and man-made threats for different reasons, especially the crowding of passengers there. The multiple uses of subway stations, both in peacetime and crisis, have increased the importance of their functionality. Thus, one of the main and major measures of passive defense is selecting the right location for the subway stations. The study identified and categorized using documentary and library studies, field surveys, and interviews with four expert experts, four benchmarks and influential indicators in locating subway stations. Then using AHP weighted hierarchical analysis process, the relative indices identified are determined. The sample in the study was Isfahan Line 3 subway stations in Region 13. ArcGIS system was used to produce and analyze the weighted overlay map of spatial information layers related to the affective indices. The results indicated that locating designated stations based on passive defense considerations is technically compliant with designated locations. In this study, other paths have been proposed for Region 13 subway based on passive defense considerations.

Ammon and Fried (2008) showed that mismanagement of the population, besides creating negative psychological burden on the community, results in financial losses [3]. Proper training and information can both be effective in psychologically displacing the population and reduce the financial losses caused by poor population management. In this study, descriptive statistics is used to analyze data collected on demographics of the facilities, population management techniques. Moreover, risk management policies stress the need to use current population management standards for managers and designers of large human population populations, and make suggestions to be used in all facilities. Moreover, the results of the survey used by the authors will help make the applied knowledge available to safety experts in providing the best risk management approaches. Bouchard et al. (2014) simulated population distribution and collective behavior patterns in an emergency exit from a building platform like a train station in the absence of an alarm [4]. In this paper, three common scenarios in the population density phenomenon are considered:

1) Placing in an open hall
2) High density evacuation
3) Allocation of population resources

The study showed that population, movement destinations, degree of influence, and observance of social norms were flexible, applicable, and examinable during simulation of population behavior. However, these components are best used under certain constraints as domain extension levels. The model proved to be very consistent, although the ease of adaptation differed across scenarios. In some of the successes in the station platform model, some have shown promising outputs regarding population behavior. Thus, this model can be compatible to be used in other models. The flexibility expressed in the basic concepts of this model also means that many changes in the future can be made to enhance the existing performance or explore new ideas. The model by Bouchard et al. about the station platform can be used for POI placement, information dissemination, or various types of social networks. This model ultimately leads to an understanding of population behavior, leading to better models of human behavior in both normal and emergency exit situations, and this means improving evacuation planning, architectural design, and so on.

With the publication of the book “Introduction to crowd science” (2015), Kendrick presented a scientific and theoretical perspective on population risk analysis and safety engineering, along with the development of simple, practical and cost-effective analysis techniques for planning and performances on evacuation events [5]. Kuligowski et al. (2010) provided users with models and information that allow models to be used for specific projects [6]. Over time, more evacuation models are being developed and many of the current models are being updated by developers. Cocking et al. (2014) examined the outcomes and consequences of voluntary behavior of individuals during widespread participatory demographic behavior under crowd disaster emergencies and reported that the pattern of panic was inconsistent with the assumptions of selfish personal behavior [7]. Moreover, the evidence they have obtained to create a shared collective identity among the population shows that there was minimal attachment to others prior to emergencies; they identified the limitations of the attachment model in explaining all behaviors in the context emergency. Therefore, they stated that they are in agreement with previous criticisms (e.g., Keating, 1982; Sime, 1990) that the belief that mass terror is inevitable in emergencies. Xu et al. (2016) provided an automated and executable method for creating network data sets in a geographic information system and creating an efficient algorithm for optimally draining and directing populations from a room inside a building to the building external gates [8]. Xu et al. suggested TIN approach to accomplish this goal, which is effective for path detection in ArcGIS, requiring very small storage space and low processing time, but only examines a limited number of nodes in its network and nodes space not covered in equal density. Stairs are entered as multiple attributes, yet because of their properties, information about this type of connection cannot be used to create geometric links. Hence, as a simplification strategy in the study, Xu et al. considered stairs as points used to connect the interconnections between floors. Moreover, Xu et al. proposed a platform for generating and recognizing routing as ArcGIS to define a starting point that needs using current common GIS functions. Additionally, Xu et al. presented an efficient algorithm based on the ordered and shared lists expected between potential output gates of a room, for simulation purposes. According to the principle of the shortest time, the room can be emptied in approximately 2.3 times the time needed by the usual solutions according to the proximity of the gate.

In the study “Redefining collective behavior in emergency planning in fear and terror” or “Resilience,” Drury et al. (2013) concluded that the psychological consequences of collective behavior in emergencies can be cited by referring to “collective panic shock” [9]. Nax et al. (2018) showed that inequality increases because of increased competence. In the study entitled “Subway station capacity analysis using queue theory”, Xu et al. (2014) presented the definition of subway station SSC based on the collection and dispersion processes [10, 11]. The analytical network model for the subway station has two subsystems, the first of which is built by a state-owned network and the second by probability theory. The state model created by the integration of IGEM and DTMC analyzes travelers from a macroscopic perspective. In the study entitled “Probable evacuation of safe evacuation for success in subway emergency fire emergency situations based on Bayesian Theory,” Wang et al. (2018) evaluated probabilities in probable evacuation of subway station evacuation, based on Bayesian Theory by event tree analysis and questionnaire survey [12]. Wang et al.'s model considers traditional fire control measures and the psychological and behavioral responses of the exiting population during evacuation as the key elements affecting probabilities in evacuation safety. According to the results from the questionnaire, fire control measures (like alarm system, exit system and emergency evacuation routes) and personnel evacuation behavioral options (like active escape and passive escape) were combined and 14 fire scenes were analyzed. Some safe evacuation events and scenarios have been considered in subway fires from 1976 to 2013 and are used to update safety evacuation probabilities based on Bayesian theory by ETA software. The results show that the probability of safe evacuation increases with decrease in time, while at the same time the fluctuation is 0.8%. The results show that there is a 0.2% chance that some passengers will be injured and even die in evacuation although many underground stations can safely evacuate people. Thus, a safety threshold of 0.2 has been proposed for the safe designing of evacuation at subway stations. The model can be used to evaluate the risk of subway fire evacuation based on historical events in a probabilistic way. Moreover, the questionnaire can show the psychological and behavioral responses of passengers at a real subway station. Kurdi et al. (2018) examined the effect of locating outputs in each salon on the evacuation process in the event of a crisis of overcrowding using AI modeling [13]. Kurdi et al. examined the evacuation time under various scenarios under ideal conditions. The results of Kurdi et al. can be described as follows:

• Developing an optimized output access model
• Facilitating evacuation with the proposed solution according to the nearest output using DFS algorithm

In the study “Evaluation of evacuation methods in underground subway stations”, besides examining evacuation models, Kallianiotis et al. (2018) used information to create a safety model through dynamic simulation besides determining exit time [14]. Moreover, Kallianiotis et al. studied the effect of stories on different platforms. Kallianiotis et al.'s results showed that in platforms designed based on NFPA; most of the population was evacuated from the main exit. In the study “Modeling the dynamic characteristics of collective panic shock dynamics,” Helbing et al. (2000) studied the degree of willingness of individuals to exit from a particular exit by considering the desire of other individuals and the distance from the exit [15]. Helbing et al.'s results show that the best escape strategy is a specific compromise between following others and individual search behavior. In “Flow analysis of passenger flows and security issues at airport terminals using modeling and simulation,” Curcio (2007) reconstructed all passenger traffic processes and operations at the Lommel International Airport in Calabria, Italy [16]. The analysis done using ANOVA simulation model studied the average waiting time for passengers before reaching the gate range as affected by various sources as well as the consistency of different passenger behaviors. Considering the flexibility of the model and applications of the ANOVA software, Curcio et al.'s results showed that this modeling software can be used for terminal analysis of similar airports.

In “Airport terminal passenger flow simulation methods,” Kavacs et al. (2012) carried out modeling according to two reservoir-propulsion and Petri method for passenger flow modeling in a small airport terminal. The results indicate that the Petri model is more accurate for calculating the time and the save-propulsion model requires less data for calculations. The results obtained indicated that the output of the reserve-propulsion model is more macroscopic and the Petri method should be used for accurate simulation. Both models could help risk management managers in managing population flow at airport terminals to reach the optimal cost reduction point at the least risk.

In the book “Flow representation model at airport terminals”, Wenbo Ma (2012) examined the methods of population flow modeling at airport terminals. Wenbo Ma argues that the interests of shareholders and users of the airport terminal, along with technical and financial constraints, have led to cultural changes that have increased the need to use the airport beyond the capacity considered at the time of design. The need to test the capacity of the venues and evaluate them based on the crowd congestion risk scenarios. In “Modeling and simulation of passenger flow distribution in the urban rail transport platform,” Gao and Jia (2016) identified the hub platform as the most significant part of the passenger flow distribution [17]. The volume of the hub platform passenger flow provides researchers and managers with essential information for designing hub capacity, organizing and managing operations. Gao and Jia did modeling at various time intervals as four basic definitions are proposed in this study, with their paper having certain limitations.

1.1. Simulation studies

Simulation studies are divided into three categories: macro, medium and micro. Overall, population simulation and population behavior models for a variety of purposes like artificial intelligence research, population management and control training by police and law enforcement, architecture and urban planning to determine the comfort, safety and health of the population in large urban spaces, planning and training and emergency exits. These simulations are dynamic and usually try to represent an intuitive model of population behavior and movement. Population simulation models can be divided into two general categories: macroscopic and microscopic models simulated by modern methods with a computer. Macroscopic models focus on the whole system and the large population behaviors. Instead, microscopic models deal with the individual levels of people's behaviors, practices, and decisions and their interactions with each other. Existing studies recommend the simultaneous use of macro and micro models, because valuable information about the behavioral patterns of individuals can be extracted and end in the emergence of a particular phenomenon throughout the system. In other words, modeling the movement and behavior of each element helps obtain movement information of the entire population.

There are many software types in the world to simulate emergency evacuation each of which examines a particular aspect of evacuation. For instance, the forerunners in emergency evacuation simulation focus more on constant spatial constraints of the building environment to optimize evacuator movement and minimize evacuation time.

Urban transportation is one of the most significant and fundamental issues in town planning and designing. A thorough transportation system can have various spatial effects on the surrounding properties and their use. These effects could sometimes be observed at points in transportation stations, sometimes longitudinally around transport corridors and in some cases a combination of the two (Perk & Katala, 2009). The introduction of the subway system into urban transport networks has made major changes to the urban traffic flow with a variety of effect on population recruitment and the development of areas around its stations. One of the most significant effects is to make people more accessible to employment activities, markets, business areas, educational facilities as well as other amenities [18]. Nowadays, experts promote the transportation-driven development approach as one of the key factors in increasing the viability of subway stations. When the concept of public transport-based development entered the urban planning and design, many people considered it as a common and dispersed spreading strategy for smart growth (Bernick & Cervero, 1997). Some others define public transportation-based development as a mix of land uses with various densities within a 500-meter radius of a station. Indeed, this type of development is a kind of functional integration between land use and transportation (Tribby, 2009). The evacuation can be mandatory, suggested or voluntary, and may vary in scale, purpose of relocation (people versus property) and level of control by officials. Given the type of incident, prognosis of the incidents that will start suddenly can leave sufficient time for an event to evacuate (Kooakez & Mancoff,, 2007). Furthermore, the subway stations are part of the public space of the city and the urban design components are effective in its formation and quality [19]. Subway lines of the transportation systems are high-frequency population lines characterized by population instability. The instability in the subway lines is that with the upheaval and the accident in one of the halls, the population present or entering or leaving the other halls is affected by the instability of the population as well (Campion et al., 1985). The introduction of the subway system into urban transportation networks has made major changes to the urban traffic flow, and has subsequently had different effects on population mobilization and the development of areas around its stations. One of the most important effects is to provide individuals with better access to employment activities, markets, business areas, educational facilities as well as other amenities [18].

In Tehran metropolis, the development of public transportation systems like the subway makes it necessary to properly manage and locate these stations. This is while the differences in facilities and opportunities in the north and south of Tehran have caused socioeconomic and physical-spatial polarization between these areas with the inferior and southern areas having much lower value than the affluent northern regions and most of the recent urban renewal measures have managed to bridge this gap (Kheiraldin, 2010). Besides subway operating company costs and customer satisfaction although the most important time-planning feature of underground subway trains is their accuracy in satisfying passenger transportation, one can show that the population flux of the stations crosses the station by coordinating with other components of the optimal urban transport network. In optimizing the duration of train stops and trains departure, the inbound and outbound people at the stations have a main role in the satisfaction of the service. In this regard, Chen and Wei consider population flow as an effective input in transportation management and at all stages of transportation planning, facility development and improvement, system performance planning and scheduling as well as system profitability management (Chen and Wei, 2011).

Lexically, risk means danger and from a financial view it is the likelihood of deviation from the return and the difference between the present and desired risk status. Estimating the portfolio's variance is far more complex than calculating its return and the risk is divided into systematic and non-systematic classes. Although various definitions are used for risk, the contents of all these definitions are the same. Risk is defined as the occurrence of any event or incident that potentially undermines the ability of the organization in reaching its goals by enforcing and restricting the capacity and activities of the organization. Emergency evacuation is one of the first steps in crisis management that should be done in the shortest time possible, since the haste in moving the injured people can have a significant effect on reducing the mortality rate due to the risk (Yi and Özdamar, 2007).

2. Methodology:

The purpose of the study was to determine SDE parameters of evacuating subway station in a crowd disaster situation.

2.1. Aims:

1. Identifying the factors affecting the creation of collective panic shock
2. estimating the time needed to evacuate the subway station in normal and emergency situations
3. Modeling emergency evacuation

Thus, the questions in this study are:

1. Under what conditions does collective panic shock happen?
2. What is the time length needed to fully evacuate in hazardous conditions and in critical conditions of crowding at the subway station according to the number of floors, spaces, bottlenecks, and crossings,?
3. Can population evacuation modeling be done in critical situations using SDEs?

Statistical analysis and library study methods were used to perform this study, which is applied in terms of practicality, descriptive in terms of goals, in terms of information is of qualitative and quantitative type and in terms of data is of primary type. First, by conducting library study and reviewing photos, videos and other documents of the subway station, the scientific basics and literature of the study were examined and then the following steps were conducted:

1. Determining the factors affecting evacuation scenario design based on population behavioral theories
2. Designing exit scenario under normal conditions in the studied building
3. Designing exit scenario under crowd disaster conditions in the studied building
4. Identification of the places prone to collective panic shock based on SDEs or other research methods
5. Estimating the casualties due to collective panic shock and presenting a risk-based design model of evacuation

2.2. Population

Two or more people working collaboratively in harmony have comes from one or more directions of a large group of people assembled in a specific physical environment with a common goal (watching a match, performing religious rituals, and so on) form the population. People in the community may show various behaviors when compared to individuals.

Table 1: Some of the most important events of crowding

Year	City/country	Ritual	Number of deaths
1982	Moscow - Russia	Sport event	340
1987	Mecca –Saudi Arabia	Religious festival	402
1990	Mecca –Saudi Arabia	Religious festival	1426
1974	Mecca –Saudi Arabia	Religious festival	270
2004	Mecca –Saudi Arabia	Religious festival	251
2005	Baghdad - Iraq	Religious festival	965
2005	Wai - India	Religious festival	267
2007	Mecca –Saudi Arabia	Haj	345
2008	Himachal Pradesh - India	Religious festival	162
2008	Jadpur - India	Religious festival	425
2010	Chen - Cambodian	Water festival	347
2011	Kerala - India	Religious festival	102
2013	Madhya Pradesh - India	Religious festival	115
2013	Santa Maria - Brazil	Night club	242
2015	Mecca –Saudi Arabia	Haj	717

Source: World crowd disasters web app (http://arcg.is/1b5COP)

2.3. Size

As a population criterion, size means that some people must gather to form a large enough population. The size of a group is usually defined by more than one person, but at what point does a group become a population? For a group of people to be called a population, their numbers must be significant.

2.4. Density

The question here to define population density is how far the people should be to be considered as a population, whereas the existence of 100 people across a park may not be considered a population, if the same number gathers in a corner of the park to watch and or to perform is considered population.

2.5. Time

Some gatherings like sports and soccer matches have a definite and fixed number of crowds during the competition and program. However, in some other places, like train stations and terminals and the like, people usually move. However, the composition and characteristics of the population are constantly changing with the arrival and departure of individuals. However, individuals must be grouped together in a specific place, for a specific purpose and for a set period of time to form a population.

One of the unique features of the population is the ability to act concurrently without any prior knowledge, contact and communication about group norms and values. Thus, the individuals must come together in a new and unfamiliar state and at the same time act in unity to have a population as was defined.

2.6. Types of population

Proposing a definition to cover all types of population seems somehow hard. Thus, it is better to provide definitions appropriate to the type and characteristics of the population. For better and more successful management of the population, it is better to identify their various forms to reduce the potential for crisis. On the other hand, over-simplification of the population may lead to its ineffective management and consequently unpleasant and dangerous consequences. The crowd attending a big event can be considered as smaller populations, each with their own characteristics, personalities and social identities. Various personalities and identities of each population must be managed simultaneously to be effective in managing populations.

Environmental factors in large populations, their behavior and movement are not just affected by individual factors. Many large rituals are held in open spaces. In these situations, the characteristics of the external environment like the weather, the stability of the earth, the location of the population affect the movement and behavior of the population as well. Weather conditions affect people's decisions to be present in the population and how the population moves and concentrates. For instance, the degree of rainfall and precipitation are weather conditions that greatly affect a person's decision to walk or move. On the other hand, some studies show that people's average speed increases in mild snow and rain. Generally, various studies have yielded different results.

2.7. Interactive factors

One has to note that people moving is not always towards empty spaces. People interact with other people on the move as well as the physical complications and obstacles on the way. This interaction may be through talking or physical encounters.

2.8. Situational factors of population

Population movement is affected by several factors. The population is composed of various people with different characteristics, goals and purposes. There have been some studies in this regard, each one examining it from a specific angle. In terms of motor status, the studies have shown that populations moving in one direction have an inverse relationship with population velocity. In populations where there are places where the width of the passageways narrows, the speed of movement is inversely related to the passageway width, which may be linear or stepped. At the same time, as people pass through the narrow passageway, their speed increases. However, the movement of the population before, within, and after the narrow passages varies. The existence of angles in the direction of a unilateral movement of the population also affects the flow and speed of movement of the person, thus slowing the movement. Moreover, the walking speed and flow rate of the population at intersections with different angles reduce. For instance, Daias et al. argue that the population flow rate on a route that has a 2-degree page will decrease by 21%.

2.9. Studying population behavior theories

Theories of population behavior are of the most significant aspects of population studies, recognition and study of population behavioral traits. This means how and in what ways population behavior can be described in normal times with the crisis conditions considered in this book. This chapter tries to explain the most important theories used to describe population behavior. Moreover, the most important ideas of each theory and its critiques are examined. Overall, the most important theories of population behavior are:

Leben (1908) presented one of the oldest and the most influential theories of population behavior in his time. He argued that the behaviors of the population were pathological and unusual in that civilized behavior disappeared and replaced by animal behaviors. He believes that people lose the sense of responsibility when they are in the crowd. They no longer consider themselves as individuals and no longer assume responsibility for their behaviors. On the contrary, they become members of an unknown group. Regarding this, given their large numbers and the group mentality that is created, people feel powerful and invincible. When people are recognized as a member of the population, they become contagious, which their ideas and opinions are quickly transmitted: they transmit to each other and lead to a sudden change in their behavior. Thus, unconscious, antisocial, and uncivilized motivations emerge from them, and the population operates on animal instincts. In other words, the population operates according to the law of population mental unity, where the characteristics of a population are quite distinct from those of its constituents. The main problem with this theory is that it excludes population behavior from its social context. This theory suppresses the population as well since the population is not rational, and it is natural, energetic, without thinking in this model. Hence, the best way to control the population and prevent its chaos is its repression at the very beginning of its formation. Similarly, this theory discourages the population as a thoughtless, meaningless group from expressing its views in society.

According to Freud's theory (1921), population acts as a factor to open the subconscious mind. Ethical standards in society and civilized behaviors are usually controlled by superhuman characteristics, though individual sense is affected by population leadership when individuals are brought together. Thus, the individuals are easily affected by the leader of the population and may feel uncomfortable with the feeling that his personality is no longer in place. This theory has also been criticized for calling the behavior of the population abnormal, pathogenic, and instinctive. Therefore, as the behavior of individuals in the community is out of their control, the individuals are irresponsible and the emergence of antisocial behaviors is inevitable.

For the first time, Bork suggested a form of mathematical calculation and modeling of population behavior based on decision theory. This theory has five stages of the theory of self-destruction based on the classical theory of Leben, Fostenberger and Pitten and Newcombe in the field of social psychology to explain the antisocial and unusual behaviors of individuals when in the population. All these theories have been greatly welcomed and used by many scholars. Non-individualism theory describes a process where the criteria that control one's behavior under normal conditions like guilt, shame, commitment, and individual control, which are weakened when one joins society. In other words, people's self-awareness and self-esteem are reduced in these situations, and individuals lose their individual identity in the society and are easily affected by the group's motivations, feelings, and interests. Overall, these factors render the individuals of a population with a group to engage in non-social or antisocial behaviors. According to this theory, along with the increase in anxiety within the population, people are heavily absorbed and respond to it usually in response to an external action such as a specific incident or inappropriate action by population control forces. Thus, people in the population lose control and lead to situations for disorder by population leaders. Accordingly, the focus of the theory of non-personality is on the effects of anonymity on the public. Peoplee's perception is that when they are in the population they become anonymous and thus consider individual responsibility and individuals' fears of being judged reduces. Thus, other people do not consider themselves as an individual, yet rather as part of a group and no longer responsible for their actions by controlling their behavior. In other words, people find some justification for their non-social behavior.

Studies indicate that this sense of anonymity increases with the increase in number of people in the population. Hence, the probability of non-social behavior occurring in larger populations is higher; however, it has to be noted that not all researches support these claims. Some, on the other hand, argue that non-aggression and anonymity may lead to reduced violence and better interpersonal relationships and, thus, showing abusive behaviors may not be an unavoidable consequence of being in a group in response to these differences. In response to these reactions, Diner reviewed the theory, so that focuses attention on the anonymity of people in the concept of objective self-awareness or the awareness of the individual as the subject of others' attention, which means on the contrary, people want to focus on others rather than thinking when they are in the crowd that attracts them to become better known.

Prentice and Rogers developed the subject of objective self-awareness according to the difference Carver and Shire perceived between personal self-awareness and public self-awareness. In the public consciousness of the individual, their focus is on how others see him, whereas in the individual's self-consciousness the focus is more on the individual's views, thoughts, and feelings. When one's self-awareness reduces, he becomes inactive and thus loses the ability to control behavior and is more affected by collective emotions. On the other hand, when general self-awareness reduces, people are less attentive to others' opinions and thus lose control and show abnormal behaviors.

Studies indicate that this sense of anonymity enhance with increase in number of people in the population. As a result, the probability of non-social behavior that happens in larger populations becomes higher, but ones should note that not all researches agree with these claims. On the contrary, some scholars argue that non-aggression and anonymity may lead to reduced violence and better relationships between individuals, and therefore, showing abnormal behaviors may not be an inevitable consequence of being in the group. In response to these reactions, Diner reviewed the theory, so that focuses attention on the anonymity of people in the concept of objective self-awareness or the awareness of the individual as the subject of others' attention, which means on the contrary, people want to focus on others rather than thinking when they are in the crowd that attracts them to become better known. Prentice and Rogers developed the subject of objective self-awareness according to the difference Carver and Shire perceived between personal self-awareness and public self-awareness. In the public consciousness of the individual, their focus is on how others see him, whereas in the individual's self-consciousness the focus is more on the individual's views, thoughts, and feelings. When one's self-awareness reduces, he becomes inactive and thus loses the ability to control behavior and is more affected by collective emotions. On the other hand, when general self-awareness reduces, people are less attentive to others' opinions and thus lose control and show abnormal behaviors.

The theory stresses the effect people have on their behavior and performance, stating that people are more effective when they are in the crowd. In other words, presence in the community has positive effects on the behavior and performance of individuals. However, the effect depends on how easy or complex the task to be done is. The explanation of why people behave like this is through judgment. The individuals in the crowd and doing something know they are being judged by others. Thus, when people are in the crowd, they have a lot of motivation to try and do well. The main problem with this theory is that the areas where individuals act ignore the nature of the participants and the contents of the behaviors.

Social evasion theory focuses on the efforts individuals have while performing in a group compared to acting alone. According to this theory, when people are in a group and attempt to reach a goal, they are less likely to try and so-called avoid doing the task. Thus, the performance of the group and population decreases.

The emergence of norms, in contrast to earlier theories that considered individual behavior in the population as pathological and instinctual, considers collective action as normative behavior. The theory tries to indicate why collective action is natural and normal. In other words, the theory tries to indicate how collective effort is driven by the norms that emerge in the population. According to this theory, when the people are in a crowd for a specific event and program, there is initially no specific law to behave, the distinctive behaviors of the pioneers or celebrities of each population are overthrown by others in the very first minutes of the event, the base of which is the attempt to identify the situation. The behaviors that these people show form the norm of collective behavior gradually, with individuals gradually emphasizing conformity with their own and others' behaviors.

According to the theory of the small group paradigm, which is the minimum number of people forming a small group, they prefer the interests of the small group to the interests of the larger group. This kind of intra-group preference occurs because of social classifications and so on. The theory has been criticized in different aspects. The methods and steps used to examine this phenomenon have been questioned. The theory has also been criticized as people's preferences for their group are because economic benefits with social classifications.

The theory of social identity is based on this and to enhance the theory of the minimal group paradigm. The theory tries to provide a model for explaining group membership and intergroup relations according to the group as a whole and not its individuals. This theory distinguishes between individual and collective identities.

2.10. Population factors affecting individual behavior

However, as was seen in population behavioral theories, population and the presence of individuals in the population affect their behavior. Thus, this section examines the effects that population has on the behavior of its members. Overall, the effective factors can be classified into two categories: fixed and situational.

2.11. Gender

Several studies have been done regarding the effect of population on individuals according to gender differences. Generally, the results indicate that males are more violent and aggressive than females, and that populations composed only of males or have a high composition of males are more violent. The studies conducted among sports, cultural, recreational and political populations indicate that men are more likely to engage in verbal arguments and violent behaviors than women in these populations. Thus, population managers should expect that populations with a larger number of men are more likely to experience violence as well.

2.12. Social identity

As already stated, the theory of population social identity indicates that individuals are members of various groups simultaneously and populations have various social identities, behaviors and norms, and the significance of each of these identities varies depending on the situation. According the situations where there are populations, there are many differences in the ability of these populations to create social identities for those present. For instance, the viewers of sports competitions and with cultural festival attendees acquire a relatively strong social identity as a sponsor or a member of a particular artistic group. In contrast, the population at a passenger terminal like rail, air, and so on does not have such a strong and shared social identity. The practical consequence of this is that certain behaviors are more likely to occur in populations whose individuals have strong and shared social identities. Thus, population managers can take the necessary measures for understand this issue better.

2.13. Gates

Using entry and exit gates has become common recently. The following should be born in mind in case of gates:

1. The speed of opening and closing of the gate does not damage the passer.
2. The pass rate of the gate is how many people per minute
3. The number of gates should be enough for the participants to fully pass at the start of the program
4. Gate structures should not cause physical injury to people in crowd disaster situations
5. Gate structure must be removable so that it can be removed or displaced by the population in case of crowd disaster and the exits should not have gates at all.

2.14. Random differential equation

An SDE is as follows:

Equation 1: Format of an SDE equation

$$\frac{dX_t}{dt} = b(t, X_t) + \sigma(t, X_t) W_t$$

Where $b(t,x)$ and $\sigma(t,x)$ are real functions and the process of white noise or pure perturbation is one-dimensional and B_t is a one-dimensional Brownian motion procedure.

Equation 2: One-dimensional Brownian motion process

$$w_t = \frac{dB_t}{dt}$$

$$\frac{dX_t}{dt} = b(t, X_t) + \sigma(t, X_t) \frac{dB_t}{dt}$$

$$dX_t = b(t, X_t)dt + \sigma(t, X_t)dB_t$$

The above equation can be written as a random integral equation:

Equation 3: Random integral equation of one-dimensional Brownian motion

$$X_t = X_0 + \int_0^t b(s, X_s)ds + \int_0^t \sigma(s, X_s)dB_s$$

Alternatively, it can be written in the following differential form:

Equation 4: Differential Form of random integral equation of one-dimensional Brownian motion

$$dX_t = b(t, X_t)dt + \sigma(t, X_t)dB_t$$

Some SDEs can be solved using the Ito formula.

Data obtained from the subway

The data were used according to the data obtained in the field survey and considering the maximum capacity of Tehran subway trains. The data used are explained in Table 2.

Table 2: Data collected from the subway

Row	Data type	Min.	Max.
1	People on a train	No one	2100 people
2	People standing on the platform	No one	300 people
3	Platform dimensions	4 meters	120 meters
4	Number of train doors	16 in	
5	Platform exits	2 exits	4 exits
6	Width of corridors	3 meters	5 meters
7	The slope of the staircase for people	33%	
8	Escalator slope	44%	
9	Rotation angle of the corridor	90 degrees	
10	Dimensions of integration hall	8 meters by 10 meters	10 meters by 12 meters
11	Exit hall dimensions	10 meters by 10 meters	
12	The number of exit gates	4 gates	6 gates
13	Exit gate passage rate	10 people per minute	
14	Gender segregation	40% females	60% males

15	Disabled	0%	30%
16	Wheelchair and blind	0%	1 percent
17	Train distance	3 minutes	9 minutes
18	Time to discharge each train	30 seconds	45 seconds

Emergency evacuation simulation

The equation proposed in this study was simulated according to Table 2by MATLAB 2014 Beta version.

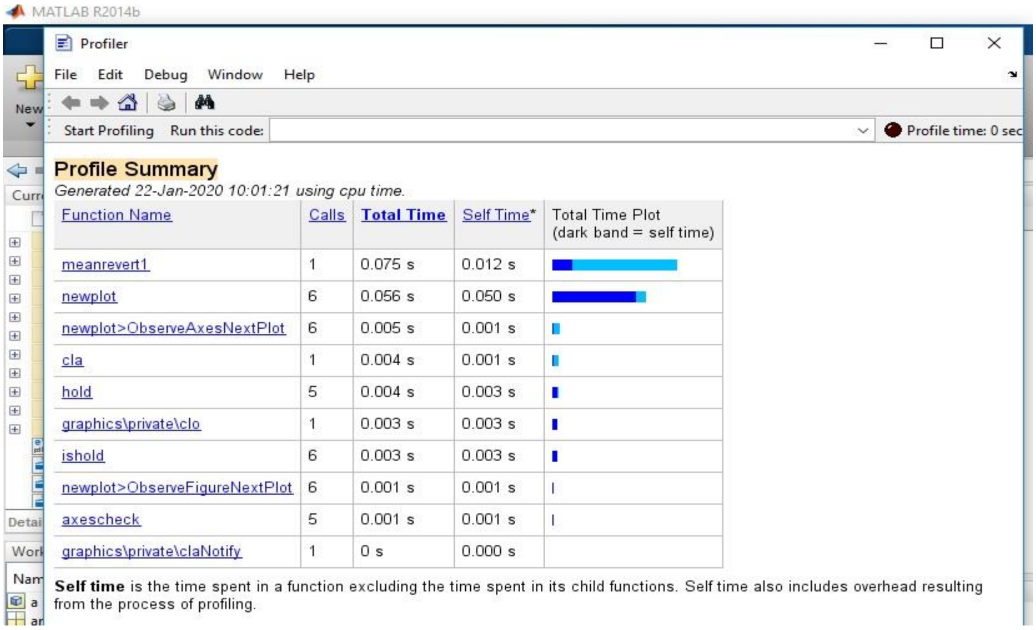

Figure 1: CPU Timing

MATLAB software entered the code 10,000,000 times, and then showed the following outputs, which means that the outputs were simulated 10 million times. Three general simulations are shown in Figures 1, 2 and 3.

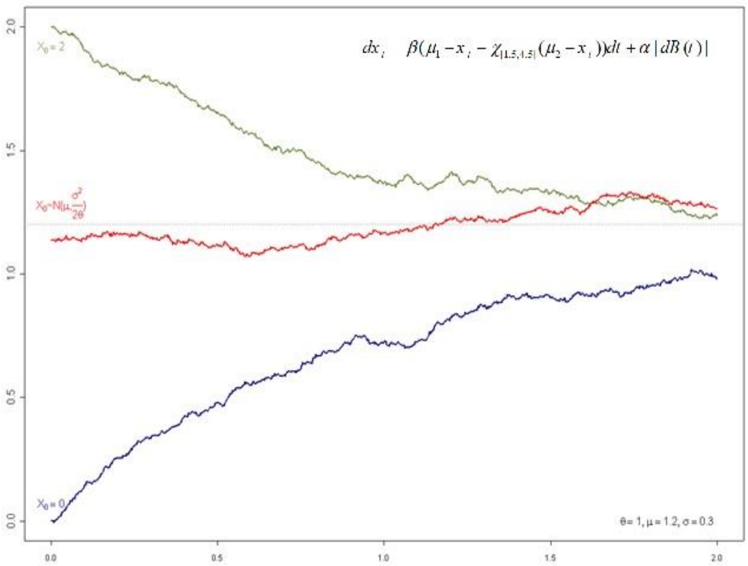

Figure 2: Base state

In this mode, the green line relates to the simulation with twice the capacity of the station, the red line to the simulation with 100% of the station capacity, and the blue line the first train evacuation assuming the platform is empty. Given the limited capacity of the evacuation corridor and that the number of exit gates is six, we witness have heavy but smooth traffic under normal conditions and the population evacuations takes about four to five minutes. However, in the event of a crisis, the evacuation capacity is not enough for the population as the simulations show that evacuation times are approximately 2.5 times higher when applied twice. Additionally, if the ratio is assumed to be almost constant, in the event of an emergency like an earthquake, the capacity of the evacuation corridor is not enough in less than six minutes because of the geometrical shape of the gates that prevents the passage itself. If we assume a gate pass rate of ten people per minute as normal. In this case, evacuating three hundred through the six gates takes an average of five minutes. However, in critical condition the number of people behind the corridor may reach about 2,000 people per train, which is by no means an appropriate time for evacuation. The practical solution is to design larger corridors where in many stations it is impossible to redesign, or at least the gates should be removed and wall card readers be used for the exits. In this case, people's pass rates will almost triple, which will allow better evacuation. Moreover, the likelihood of a catastrophic situation will reduce in crisis, although this reform alone cannot definitively determine the likelihood of a crowd disaster.

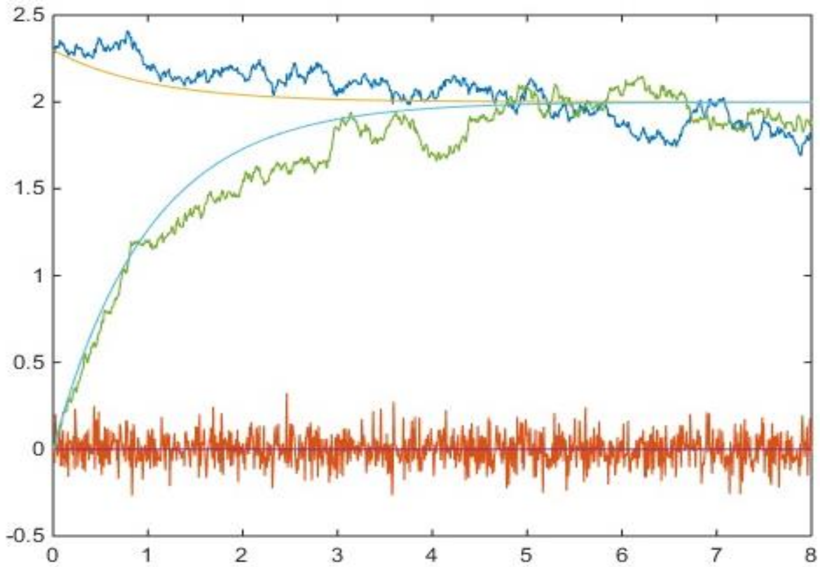

Figure 3: Normal model in case of two and three tenths of loads capacity

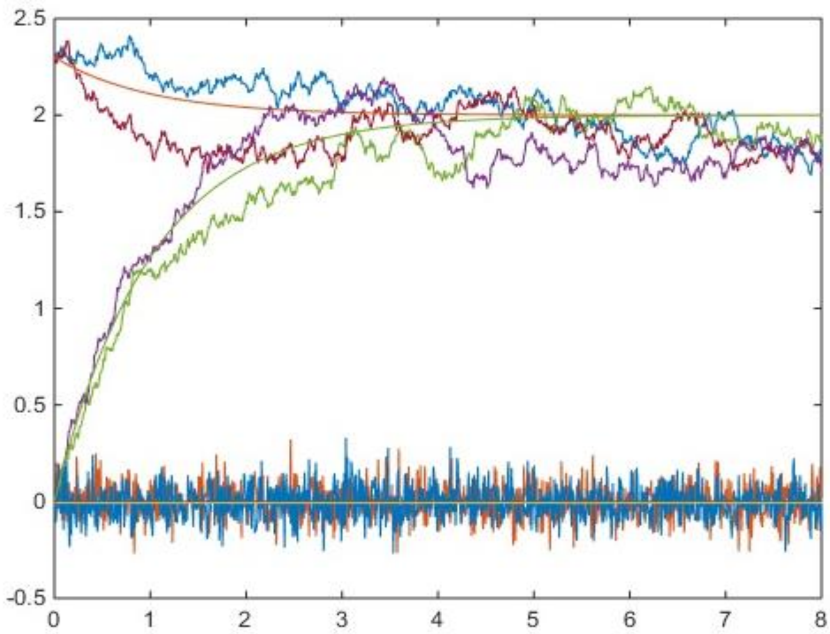

Figure 4: Normal model and applying two and three tenths of loads in two simulation modes

3. Conclusion:

After examination of the case study and according to library studies, it was found that the exiting population behavior of the subway station before and during crowd disaster can be modeled in SDE by determining the appropriate factors. The exit corridor, connected to the exit gate in the subway, is the most important exit for people to evacuate.

The behavior of the population leaving the subway station before crowd disaster and during it can be modeled by determining the appropriate factors in SDE. The behavior of the population leaving the subway station before crowd disaster and during it can be modeled by determining the appropriate factors in SDE. The exit, connected to the exit gate in the subway, is the most important exit for people to evacuate.

The most basic model can be considered as linear $\frac{dx_t}{dt} = \mu$, yet it quickly becomes clear that the model does not respond to the status justification. The second model is based on an exponential saturation process $x_t = \mu(1-e^{-\beta t})$ that shows the reality to a great extent. However, as the number of people differs each time the platform is filled and emptied, the model should be presented such that it shows the average in commute time.

μ = Average people per evacuation of train (300 people on average);

β = Retardance coefficient of exit from platform to exit gate.

Proposed model in general

$$\frac{dx_t}{x_t} = \text{Deterministic change + Random change}$$

$$dx_t = \beta(\mu - x_t)dt + \alpha\,|dB(t)|$$

The model can show one side of the train in three minutes, complete with different entry gates x_0. The sign of absolute value is because usually the corridor being filled by people occurs randomly. As the next train arrives at the other side of the corridor in the next one minute and half, the next people go to the exit before the full evacuation and the extra load happens towards the exit gates. Thus, we proposed a more complete model that can model the population regarding the time delay of the second series of platforms from the next platform.

$$dx_t = \beta(\mu_1 - x_t - \chi_{[1.5,4.5]}(\mu_2 - x_t))dt + \alpha\,|dB(t)|$$

Introducing the parameters:

μ_1 = Average people getting off the first train;

μ_2 = Average people getting off from the second platform train;

$dB(t)$ = Partial random walk (Brownian motion model)

α = Noise magnitude coefficient means that the number of people is lower or higher than the average

$\chi_{[1.5,4.5]}$ = The time function that gets one at a given time and takes zero at the rest of the axis length.

x_t = Indoor population volume behind the exit gate

Retardance coefficient:

$$\beta^{-1} = \frac{woman \times 2 + man \times 1 + kid \times 3 + old \times 4 + preg \times 5 + wh \times 4 + PSF + GAF}{n}$$

Points:

Here, the number of women is multiplied by two, considered as slowness

- ✓ The number of minors is multiplied by three
- ✓ The number of pregnant women is multiplied by four as the hardness of passage
- ✓ Multiplies by four for senior
- ✓ Wheelchairs are multiplied by four as well

$$PSF = panic - stampd - factor$$

$$GAF = geometrical - and - architectural - factor$$

The factors affecting movement, speed, space under normal and emergencies conditions at the subway station can be determined as factors of an SDE. In the first step, issues like crowding, congestion, crowding, movement wave, people pushing each other, people pushing the fences, turbulence, shouting and asking for help, people falling, and rolling over each other are carefully examined. The purpose of observing the above is to evaluate the movement of people and problems to take the necessary measures in diminishing the risk in any situation. As after selecting a specific subway station to use the model, the aspects of the platforms and halls, the number of gates, the number of corridors, the slope of the corridors, and the like, are directly calculated, there is no need to assume coefficients for them or components and the interactions between space can be measured by calculations. Hence, the components obtained in this study are related to probabilistic factors, typically number and frequency.

The components obtained are:

μ_1 = Average people off the first train

μ_2 = Average people off the second train

$dB(t)$ = Partial random walk (Brownian motion model)

α = Noise magnitude coefficient meaning that the number of people is lower or higher than the average

$\chi_{[1.5,4.5]}$ = Time effect function that gets one at a given time and takes zero at the rest of the axis length

x_t = Indoor population volume behind exit gate

Slow motion factor:

Coefficient of retardance

$$\beta^{-1} = \frac{woman \times 2 + man \times 1 + kid \times 3 + old \times 4 + preg \times 5 + wh \times 4 + PSF + GAF}{n}$$

Moreover, the underlying factors behind the creation of a collective panic shock can be identified. According to the results, whenever a natural (flood, earthquake, fire, gas leak, and so on) or man-made factors (terrorist operations, and so on) cause fear in the population in an underground subway station and escaping happens, collective panic shock occurs if the population density is more than 6 people per square meter, the exits are smaller than the density of the congestion corridor and the population is large enough that people cannot interact with one another by talking. Observing the situation can be divided into nine categories, the first of which has to do with the time when the conditions are normal and the other eight to the cases when crowd disaster is emerging and intensifying.

Table 3: The stages of approaching crowd disaster

Row	Observation	Evaluation
1	Density less than 2 -3 people per square meter	Normal situation with low risk
2	People gather. Some spaces are rapidly becoming crowded.	People's moving is blocked because of the narrow path or hurdle.
3	Population congestion is shaping and developing.	Inappropriate exit flow can cause serious problems (such as high congestion) over time, especially in confined spaces.
4	Start and stop waves begin (this only happens in a very dense moving population and people are pressed)	Continuous flow is broken. The exit capacity is significantly reduced. The situation may get critical soon.
5	People cannot easily move and push each other. People are pushed here and there.	Population density has reached a critical point. People may be injured at any moment.
6	People do not care about fences and barriers and try to get away.	The situation is critical and there is probability of getting out of control.
7	Population turbulence occurs. People are screaming and asking for help.	Killing and wounding are likely. Crowd disaster may happen at any time.
8	People fall to the ground. People raise their hands.	People are in a very bad situation. Many people are expected to be injured. Crowd disaster is happening.
9	People roll over each other.	The crowd disaster has already happened.

The time needed for complete evacuation in danger-free and crowd disaster cases at a station can be estimated based on the number of floors, spaces, bottlenecks and subway crossings. According to the results, the optimal time for safe evacuation of the population in crowd disaster can be estimated. One has to note that at a subway station, it normally takes three minutes to evacuate passengers leaving the station. However, because of the dangers of passengers' presence in underground urban spaces generally lacking the good access to open air and there is no possibility of evacuation of potentially toxic and fatal gases from accidents such as fire, the evacuation has to be done at the shortest time possible.

References

1. M Haghani, M Sarvi, Z Shahhoseini, and M Boltes. "How simple hypothetical-choice experiments can be utilized to learn humans' navigational escape decisions in emergencies". PloS one. vol. 11, no. 11, (2016), e0166908.
2. P. Mousavi Mobarkeh, and S. Khazaei, S. "Locating Subway Stations Based on Passive Defense Principles (Case Study: District 31 of Isfahan)", Journal of Passive Defense, no. 2, (2018), pp. 6-49.
3. R Ammon Jr, and G. Fried, "Crowd management practices". In Journal of Convention & Exhibition Management. Taylor & Francis Group, vol. 1, no.2-3, (1999), pp. 119-150.
4. M Bouchard, J Haegele, and H Hexmoor. "Crowd dynamics of behavioural intention: train station and museum case studies". Connection Science, vol. 27, no. 2, (2015), pp. 164- 187.
5. G. K. Still. "Introduction to crowd science". CRC Press, (2014).
6. E. D. Kuligowski, R. D. Peacock, and B. L. Hoskins. "A review of building evacuation models. Gaithersburg, MD: US Department of Commerce", National Institute of Standards and Technology, (2005).
7. C. Cocking, J. Drury, and S. Reicher. "The psychology of crowd behaviour in emergency evacuations: Results from two interview studies and implications for the Fire and Rescue Services". The Irish Journal of Psychology, vol. 30, no. 1- 2, (2009), pp. 59- 73.
8. M Xu, I Hijazi, A Mebarki, R E Meouche, and M Abune'meh, "Indoor guided evacuation: TIN for graph generation and crowd evacuation". Geomatics, Natural Hazards and Risk, vol. 7, no. sup1, (2016), pp. 47-56.
9. J. Drury, D. Novelli, and C. Stott, "Representing crowd behaviour in emergency planning guidance:'Mass panic'or collective resilience?". Resilience, vol. 1, no. 1, (2013), pp. 18- 37.
10. M Mäs, and H H Nax, "A behavioral study of "noise" in coordination games". Journal of Economic Theory, vol. 162, (2016), pp. 195- 208.
11. X Y Xu, J Liu, H Y Li, & J Q Hu. "Analysis of subway station capacity with the use of queueing theory". Transportation Research Part C: Emerging Technologies, vol. 38, (2014), pp. 28- 43.
12. J Wang, W Yan, H Xu, Y Zhi, Z Wang, and J Jiang, "Investigation of the probability of a safe evacuation to succeed in subway fire emergencies based on Bayesian theory". KSCE Journal of Civil Engineering, vol. 22, no. 3, (2018), pp. 877- 886.
13. H A Kurdi, S Al- Megren, R Althunyan, and A Almulifi. "Effect of exit placement on evacuation plans". European Journal of Operational Research, vol. 269, no. 2, (2018), pp. 749- 759.
14. A Kallianiotis, D Papakonstantinou, V Arvelaki, and A Benardos, "Evaluation of evacuation methods in underground metro stations". International Journal of disaster risk reduction, vol. 31, (2018), pp. 526- 534.
15. D Helbing, I Farkas, and T Vicsek. "Simulating dynamical features of escape panic". Nature, vol. 407, no. 6803, (2000), 487.
16. D Curcio, F Longo, G Mirabelli, and E Pappoff. "Passengers' flow analysis and security issues in airport terminals using modeling & simulation". In European Conference on Modeling & Simulation, Praga-Repubblica Ceca, (2007), pp. 4- 6.
17. L. Gao, and L Jia. "Modeling and Simulation of Passenger Flow Distribution in Urban Rail Transit Hub Platform", (2016).
18. E. Boucq, and P. Francis. "Assessment of the Real Estate Benefits Due to Accessibility Gains Brought by a Transport Project: the Impacts of a Light Rail Infrastructure Improvement in the Hauts- de- Seine Department". Trasporti Europei, no. 40, (2008), pp. 51- 68.
19. M Golestaneh, and A R Hoveydafard. "Developing Passive Defense Requirements in Subway Stations (Case Study: Mashhad Subway Line 2)", 1st International Conference on Engineering Application in Iranian Development and Progress 1404, Mashhad, Saj Gostar Co. Caspian (2017).

20. Steinkuller, F. (2009). A review of cataract in stable and conflict zones in Africa (Doctoral dissertation, The University of Texas School of Public Health).
21. Bernick, M., & Cervero, R. (1997). Transit villages in the 21st century.
22. Tribby, C. (2009). Assessing the effects of new public transportation routes: an equity analysis on the changing accessibility of Albuquerque, New Mexico.
23. Mancoff, F. B., & Kaka, S. (2007). Microwave Excitations in Spin Momentum Transfer Devices. Handbook of Magnetism and Advanced Magnetic Materials.
24. Glynn, R. J., CAMPION, E. W., BOUCHARD, G. R., & SILBERT, J. E. (1985). The development of benign prostatic hyperplasia among volunteers in the Normative Aging Study. American journal of Epidemiology, 121(1), 78-90.
25. Ostadi, S. N., Akbari, B., Khalatbari, J., & Kheiraldin, J. B. (2010)The Comparison of the Effectiveness of Quality of Life Therapy Techniques Training and Dialectical Behavioral Therapy on Distress Tolerance among Female Students with Smartphones Addiction.
26. Chen, Y. W., Prange, J. D., Dühnen, S., Park, Y., Gunji, M., Chidsey, C. E., & McIntyre, P. C. (2011). Atomic layer-deposited tunnel oxide stabilizes silicon photoanodes for water oxidation. Nature materials, 10(7), 539-544.
27. Yi, W., & Özdamar, L. (2007). A dynamic logistics coordination model for evacuation and support in disaster response activities. European journal of operational research, 179(3), 1177-1193.