Fire Risk Assessment and Its Economic Loss Estimation in Tehran Subway, Applying Event Tree Analysis

Sedigheh Atrkar Roshan*[1], Somayeh Daneshvar[2]

1) Department of Economics, Alzahra University Tehran, Iran.
2) Department of Occupational and Environmental Health, Faculty of Medical Sciences, ,Tarbiat Modares University, Tehran, Iran

**Author for Correspondence:* s.a.roshan@alzahra.ac.ir

Received: 31 Oct. 2014, Revised: 28 Nov. 2014, Accepted: 10 Dec. 2014

ABSTRACT
Subway system is one of the critical infrastructures in a society. In economic optimizations of risk control measures, valuing the loss of life and other financial losses in terms of money on the other hand, could influence the optimal investments in safety. The purpose is to contribute to the implementation of HSE in the transportation system. In this research, a fire risk assessment along with its economic loss estimation in the Direct Current (DC) trains and rectifier substation (RS) of Tehran subway is implemented. The number of fatalities, the extent of damage on the train equipment, etc., is then calculated in monetary unit.
By using Event Tree Analysis (herein ETA), after identification of initiating events through observation, interviews, and evaluation of documents, event tree was constructed for each of them and the probability of multiple scenarios were computed.
The scenario with the highest probability of fire in RS, including increased heats in the RTU panels generate a loss of at least 730 Million Rials. Accordingly, the minimum and maximum economic loss caused by fire on DC trains is minimum 510 and 1230 Million Rials, respectively.
Conclusion: Given the findings of this study, the financial and human life risks, along with all tangible and intangible losses, which is considerable, the relevant managers must compare investments in safety, with the decrease of calculated economic risks as a result of fire accident in Tehran subway.
Key words: Safety, Event Tree Analysis, Fire, Subway, Direct Current train, Rectifier substation.

INTRODUCTION
We live in a world of systems and risk. With systems and technology that come exposed to accidents, as such systems can fail or work improperly resulting in damaging, injury, and death. Since the industrial revolution, technical hazards, such as airplane crashes, train derailments, tunnel fires and industrial accidents also disrupt society on a regular basis. Subway system is among the infrastructure systems in the transportation industry that can be exposed to the risk of fire, flood, earthquake and similar events can be made in addition to the catastrophic losses caused a shock to the society [1, 2]. The occurrence of fire is most threatening risk to people in the subway space, so that according to the previous studies irreversible losses of the occurrence of fire in the subway stations and tunnels are created [3-7].
Based on studies of the International Association of Public Transport in 2009, the occurrence of fire in the subway system can be divided and be examined into train and station subsystems [8]. Fire caused by electrical current is one of the most significant causes of fire stations, tunnels and subway trains [9].Based on the SFPE (book of fire protection engineering) Fire risk, is defined as the identification of potential unintended risks and its adverse consequences on people's lives, health, properties and the environment [10]. Statistics show that the highest percentage of fires in the subway (34%) is due to problems with the electrical system, which can occur in two major subsystems of the stations and trains [11]. Typically any station subway has different parts that Light Power Substation (henceforth LPS) and Rectifier Substation (henceforth RS) with regard to their important role as power supplies for the station and the train are more important [12]. The task of Rectifier Substation is power supplies for third rail and train. In this unit, the power of 20 KV is converted to the three-phase 592 V and then to 750 V DC, by transformer and is used for the third rail and train feeding.
Panel of 20 KV; obtain this voltage from the High Voltage System (HVS) and Resin transformers is feed by two transformer feeders. Rectifier transformer converts voltage to 592 volts and give it into power rectifier to rectify it, on the other hand the AC voltage of 592 volts is converted to 750 volts DC. Then the voltage of 750 volts DC is placed to 750 V DC boards. The panel consists of

disconnect switch and a motion rail voltage protection panel [13].
Experience has shown that electrical fires in tunnels and subway stations can be happened in the incidence of arc or short circuit in the power cables in panels and electrical equipment [14, 15]. At present, two types of trains including Alternative Current (henceforth AC) and Direct Current (henceforth DC) in Tehran subway lines are used. Based on available statistics during the years of 2003 to 2012,145 cases of ceiling resistance fire have occurred in the DC trains [16].
In this study, it has been attempted to evaluate the risk of fire in the DC trains and RS in Tehran subway line 1 station. The key to system safety and effective risk management is the identification and mitigation of hazards. To successfully control risks, it is necessary to understand the hazards and to identify them in the first place. The elimination of hazards can prevent death, injury, system loss and damage to the environment. In other words, since traditional safety management pattern is highly dependent on people's experience and thus hard to cope with serious safety situation, it is urgent to start research on safety risk management system, technology and relevant standards to cope with serious situation in today world. The risk analysis is defined as all the methods that are involved in evaluating the safety of facilities, verifying the risk from recognizing dangers, identifying models for certain events, and estimating the risk in a quantitative way. A checklist technique and hazard and operability method (HAZOP) can be used to verify the risk and a fault tree analysis (FTA) and event tree analysis (ETA) is used to model events and estimate the risk [17].
Several studies have used ETA technique. For instance, Paul Mann (2005) applied a combination of two techniques including the fault tree and the event tree, to do a quantitative risk assessment model (QRA), for assessing the risk of fire in high-speed train [18].Another study of fire risk assessment in Bucharest underground public transportation system was done in which, several related theoretical pieces to specific risks during the paneling underground transportation system were considered [19].
The purpose of this study is to contribute to the implementation of HSE (health, safety, and environment) in transportation, as well as development projects such as the development of efficient urban transport system. To this aim, since quantitative methods are widely applicable method to fire risk assessment [10], Event Tree Analysis (ETA) technique is used to evaluate the fire risk in stations and trains in Tehran subway. The number of fatalities, the extent of possible damage on the train equipment, etc., were then calculated in terms of monetary unit, so that, the investments in safety is compared (by relevant managers) with the decrease of calculated economic risks as a result of fire accident.

MATERIALS AND METHODS

In this study the Event Tree Analysis (ETA) technique was used to determine the damage caused by fire in the DC trains and RS in Tehran subway line 1 station. The frequency of occurrence and the potential consequences that arise from the fire risk, in terms of financial loss is then computed. Event tree is an analysis technique for identifying and evaluating the sequence of events in a potential accident scenario following the occurrence of an initiating event. ETA utilizes a visual logic tree structure known as an event tree (ET).
In this method, an initiating event such as the malfunctioning of a system, process, or construction is considered as the starting point and the predictable accidental results, which are sequentially propagated from the initiating event, are presented in order graphically. ETA is a system model representing system safety based on the safeties of sub events. It is called an event tree because the graphical presentation of sequence events grows like a tree as the number of events increases. As it is shown in Fig. 1, ETA consists of several steps [17].

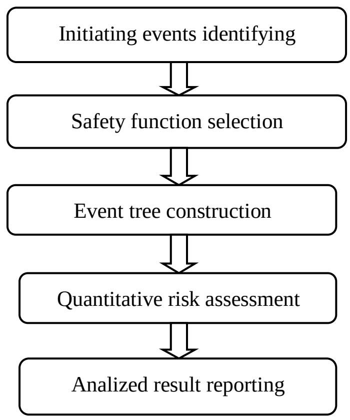

Fig. 1: Flow chart of the ETA
Reference: Korea Occupational Safety and Health Agency, 1997

The objective of ETA is to determine whether the initiating event will develop into a serious mishap or if the event is sufficiently controlled by the safety systems and procedures implemented in the system design. The ETA is a very powerful tool for identifying and evaluating all of the system consequences paths that are possible after an initial event occurs. The purpose of ETA is to evaluate all the possible outcomes that can result from an initiating event. Generally, there are many different outcomes possible from an initiating event, depending upon whether the design safety system work properly or malfunction, when needed. ETA provides a probabilistic risk assessment of the risk associated with each potential outcome.

The present research is conducted in four steps: the first step is to identify the initiating events based on observation, interview and documents review. A system or equipment failure or human error which may be initiating event, depending on how the system or operators responds to the event, which could result in the desired effects. The second step is identifying the barriers (safety factors) designed to respond to the initiating event. The Barriers arise in response to the initiator factors or reducing agents as a defense system against potential outcomes of the initiating event are considered.
The analyst should identify, all safeguards that can protect against or mitigate the effect of the starting event, in the chronological order in which, they are expected to respond. The description of such barriers should state their intended purpose. The third step is constructing the event tree. In this step, the initiating event and barriers that apply to the analysis is entered. The initiating cause or loss event is shown on the left-hand side of the page, and the barriers are listed across the top of the page. The next pace is to evaluate barriers. Normally only two possibilities are considered including the failure or success of the barrier.
The analyst should assume that the initiating cause has occurred, define the success or failure criteria for barrier, and decide whether the success or failure of the barrier affects the course of the incident. If the incident is affected, the event tree divides into two paths to distinguish between the success and failure of the barrier. Normally, success of the function is denoted by an upward path, and failure of the function, by a downward path. If the barrier has no impact on the course of the incident, the incident path proceeds, with no branch point, to the next barrier. In the fourth step, due to the absence of detailed documentation, exponential quantity based on the expert opinions take place (interviews included individuals with related work experience, technical and supervision staff). Then sequence of predicated consequences of events is described. The probability of different consequences is calculated by multiplying the probabilities of each factor in the branch for each scenario. The following formula is used to calculate the probability of each branch [20, 21]:

$$\textbf{Pr (chain A) = Pr (Initiating event)}.\prod_{j=1}^{n} \Pr(\boldsymbol{Subsystem\ j})$$

Then according to obtained scenarios, the amount of economic losses caused by fire in DC trains and RS is determined.

RESULTS

According to the applied Event Tree Analysis technique, 32 scenarios obtained for rectifier substation that 16 scenarios lead to fire. In table 1, the initiating events and safety factors identified is presented.

Table1: Initiating events and safety factors

	Initiating events	Safety factors(barriers)
1	Increase heat in thepanels20 kV	Failure of over load relays operating, Non-functioning detector, The absence of fire extinguisher, The absence of sprinkler
2	Increase heat in the transformer windings	Non-function of transformer temperature controller , Non-functioning detector, The absence of fire extinguisher, The absence of sprinkler
3	Increase heat in the AC/DC panels	Failure of over load relays operating, Non-functioning detector, The absence of fire extinguisher, The absence of sprinkler
4	Increase heat in the RTU panels	Failure of over load relays operating, Non-functioning detector, The absence of fire extinguisher, The absence of sprinkler
5	Accumulation of H2 gas in the battery room	Lack of operating of explosion proof fans, Non-functioning detector, The absence of fire extinguisher, The absence of sprinkler

Given that, it is not possible to provide the whole event tree in this paper, the scenario with the highest probability of fire on RS, including "increased heat in the RTU panels, non-functional over load relays, non-functioning detectors, no fire extinguishers, no operation sprinkler" is presented (figure 2)

A: Increase heat in the RTU panels B: Failure of over load relays operating
C: Non-functioning detector D: The absence of fire extinguisher
E: The absence of sprinkler F: false S: successful

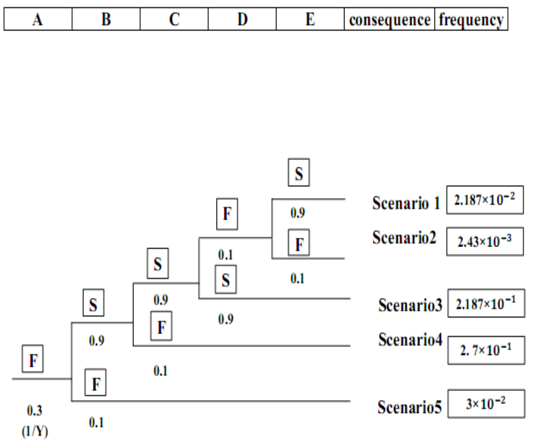

Fig.2: Event tree with increase heat in the RTU panels in RS scenario

Considering the above scenarios, the consequences, including the loss of RTU panel and the deaths of at least 2 people (people working in the post), the amount of damages was specified [based on the atonement of 2012 in Iran]. Then the levels of risk scenario through multiplying the probability of the scenario outcomes to the maximum amount of 730 million Rials were identified (based on the price of 1391 Iranian calendar year). Also, the tree has been drawn to DC train, where, 5 scenarios were identified. In this part most occurrence probability related to scenario 3, the rate of 6.3 × 10-3 has been proposed (see figure 3)

A: fire resistance of roof B: fire detection C: response operator
D: passengers evacuation E: fire control

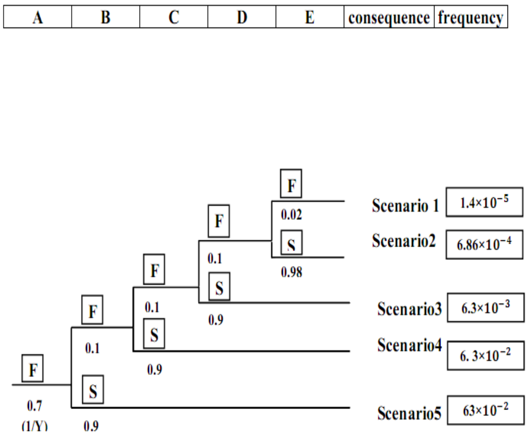

Fig. 3: Event tree with fire resistant scenario in DC train

Considering the number of people at risk and the extent of possible damage on the train equipment, the damage caused by the fire was specified. Accordingly, the minimum and maximum economic loss caused by fire on DC trains was computed about 510 million Rials and 1230 million Rials, respectively (calculated based on the price of 1391 Iranian calendar year).

DISCUSSION

Fire accidents are one of the most possible events especially in subway systems. As from 1999 to 2010 media reports, ninety-two accidents happened in metro rail transit projects, 68 people died from these accidents and direct economic losses stood at least 4.1 billion Yuan in China [22].

According to the U.S. national fire date center (2014), an estimated 25900 residential building electrical fires are reported to fire departments within the United States each year. These fires caused an estimated 280 deaths, 1125 injuries and $1.1 billion in property loss [23]. As the Cascee and Raconin; report (mentioned in Duarte, 2004), the causes of electrical fire in nuclear plants of United States and Europe are including 26% transformers, 26%switches and circuit switches, communication terminal 15%, and also 10%wires and cables[24]. Based on the result of the Event Tree Analysis of the present research in rectifier substation, the most important cause of electrical fire spread on boards and systems, was the malfunction of embedded control systems on equipment. This could happen because of several reasons among which are the lacks of effective inspection and maintenance programs for early detection of possible defects.

Our results are consistent with a number of studies such as Amiri (2010). Her findings indicates that, the main causes of fires in passenger trains are specified in subsets of motor generators and mechanical systems, generators and electrical systems, telecommunications, steam generation, electricity and ventilation of passenger cars[25].

The worst possible outcome of the Event Tree Analysis technique in the DC trains including the scenario of events “if the roof fire resistance would occur, -fire detection is not done-, leading does not respond imply and appropriately - the fire is not quenched”. In another study, Jafarian2011 investigated the reasons for the exit of the train line in Iran using fault tree analysis techniques and event tree integration fussy. According to his results, from the 41 final detected events," incorrect pin adjustment" and "not recognized fault for part of the line" was identified as the root causes of risks and uncertainties of fuzzy output. His results also show that, the scenario of events "the exit of the train from the Line, the train would be diverted to the adjacent line, at least one of the train wagons fall aside, a secondary collision occurs, the second train is passenger train " were identified as the main scenario for total risks [26].

In summary, considering the economic loss estimation in Tehran subway that implemented in this study, metro rail transit is basically subject to safety risks, which are part of the technical risks. In general, to mitigate these accidents, there are several principles which should be followed. First of all, all parties relevant to the project should participate in the safety risk management, such as the government, metro rail transit projects owners, the design institutes, the construction companies, the supervision companies and the third party monitoring companies. Secondly, safety risk management should run through the lifecycle of metro rail transit projects, regardless of stages of feasibility study, prospecting, design, construction and trial operation. Thirdly, cyclically monitoring and testing the key safety risks must be sustained. Finally, safety risk management participators should constitute task force for the purpose of sharing their professional knowledge, moreover sharing rewards or undertaking punishments linking up to success or failure [27].

CONCLUSSIONS

Our findings indicate that, scenario with the highest occurrence probability of fire in RS including "increased heat in the RTU panels generates at least a loss equivalent to 730 Million Rials. Accordingly, the minimum and maximum economic losses caused by fire on DC trains are including 510 and 1230 Million Rials respectively (based on the price of 1391 Iranian calendar year).Thereforeو based on the findings of this study, financial and human life risks, show that the losses are significant. However, much more work needs to be performed to identify, quantify, rank and mitigate the potential hazards posed by the fire risk in Tehran Subway. Finally, given that, rail transportation safety is achieved only, when every single one factors are considered in a comprehensive safety management system, and because transportation system is run and controlled by public sector, the political costs also (which needs to be considered in a separate research) have to be added to the economic costs.

ACKNOWLEDGMENT

The authors would wish to express their gratitude to Tehran Urban & Suburban Railway operation staffs for their collaboration.

REFERENCES

[1] Kyriakidis M, Hirsch R, Majumdar A. Metro Railway Safety: An Analysis Of Accident Precursors. Safety Science. 2012;50(7):1535-48.

[2] Cheong S. Fire Safety Design For Rapid Transit Systems. 2004; Fire India

[3] Gao R, Li A, Hao X, Lei W, Deng B. Prediction Of The Spread Of Smoke In A Huge Transit Terminal Subway Station Under Six Different Fire Scenarios. Tunnelling And Underground Space Technology. 2012;31(1):128-138.

[4] Beard AN. Fire Safety In Tunnels. Fire Safety Journal. 2009;44(2):276-8.

[5] Fridolf K, Nilsson D, Frantzich H. Fire Evacuation In Underground Transportation Systems: A Review Of Accidents And Empirical Research. Fire Technol. 2013;49:451-75.

[6] Thomas AA. A Recent Fire Incident On London Underground. Fire Safety Journal. 1984;8(1):47-52.

[7] Zarboutisn, Marmaras N. Searching Efficient Plans For Emergency Rescue Through Simulation: The Case Of A Metro Fire. Cognition, Technology &Work. 2004;6(2):117-26.

[8] Raiway Safety Statistical Report 2009 [Database On The Internet]. Office Of Rail Regulation. Availablefrom: http://Transit Safety.Volpe.Dot.Gov/Publications/Order/Singledoc.Asp?Docid=1102

[9] Burnett J. Fire Safety Concerns For Rail Rapid Transit Systems. Fire Safety Journal. 1984;8(1):3-7.

[10] DiNenno PJ, Drysdale D, Beyler C.L, Walton WD., SFPE Handbook Of Fire Protection Engineering. Third ed.National Fire Protection Association; USA, 2002.

[11]fire risk in metro tunnles and stations. Http://Hkarms.Org/ASUS_Server/Myftp_Web_Resources/2005_Conference_Presentation/Fire_Risk_ Metro_Tunnels_Stations.Pdf

[12] Khabaznia M. General Designe Criteria And Selection Of Equipement Station Metro. 1th ed. Urban Rail Operation Company of Tehran and Suburban. Tehran; 2009. Chapter 4. pp. 68-90.

[13] Montazeri M. Urban Rail Systems. 1th ed. Urban Rail Operation Company of Tehran and Suburban. Tehran; 2009. Chapter 2. pp. 45-60.

[14] Chow W, Qu L, Pang EC. Incidents On Fire And Ventilation Provision In Subwaysystems In Hong Kong. International Journal On Engineering Performance-Based Fire Codes, Accepted To Publish. 2011;10(3):41-47.

[15] Chen F, Guo S-C, Chuay H-Y, Chien S-W. Smoke Control Of Fires In Subway Stations. Theoretical And Computational Fluid Dynamics. 2003;16 (5):349-68.

[16] Daneshvar S, Mortazavi S.B, Atrkar Roshan, S.Fire Risk Assessment In The DC Metro Trains In Tehran With Fault Tree Analysis Method. Occup Med J. 2013; 5(3): 42-48.

[17] Hong E, Lee I, Shin H, Nam S,Kong J. Quantitative risk evaluation based on event tree analysis technique: Application to the design of shield TBM Kong Tunnelling and Underground Space Technology 24 (2009) 269–277

[18] Mann P. Fire Risk Assessment Study For A High Speed Train .2005. PMSC Limited Paper OnGeneric Approach To Fire QRA For High Speed Trains, Http://Www.Pmsafety.Com/Downloads/Technicalpapers/Fire%20Risk%20Assessment%20Study.Pdf

[19] Udor A. Fire Risk Management In Public Underground Transport System - Bucharest Metro, Romania, Proceedings Of The World Tunnel Congress And 32nd Ita Assembly: 22–27 April; Seoul, Korea, 2006.

[20] Center for Chemical Process Safety (CCPS). Guidelines For Hazard Evaluation Procedures. Third ed: JOHN WILEY & SONS, Hoboken, New Jersey. 2008. chapter 5. pp. 158-166.

[21] Rausand M, Høyland A. System Reliability Theory: Models, Statistical Methods, And Applications. 2th ed. John Wiley & Sons; Hoboken, New Jersey,2004, chapter 3, pp. 108-118 .

[22] Liu G.W, Zeng G. The Metro Project Construction Safety Risk Managing System of GMC.Open Journal of Safety Science and Technology.2014;4:36-41.

[23] USFA. Statistical Reports: Electrical And Appliance Fires 2014. Available From: http://Search.Usa.Gov/Search?Utf8=%E2%9C%93&Sc=0&Query=Subway+Fire+2013&M=&Affiliate=Usfa&Commit=Search

[24] Duarte D. A Performace Overview About Fire Risk Management In The Brazilian Hydroelectric Generating Plants Andtransmission Network. Journal Of Loss Prevention In The Process Industries. 2004;17(1):65-75.

[25]Amiri N. Fire Risk Assessment Of Passenger Trains With Fuzzy FMEA- Gary Theory. Transportation Engineering. 2010; 1(4): 30-34.

[26] Rezvani M.A., Jafarian E. developed an analytical model of the causes and consequences of

departure of passenger trains on the railway line Islamic Republic of Iran. Journal of transportation engineering. 2011; 2(4):317-333.
[27] Federal Highway Administration (FHA), Asset Management Primer, U.S. Department of Transportation, Federal Highway Administration 1999, www.fhwa.dot.gov/.../amprimer.pdf