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ORIGINAL RESEARCH PAPER

Public transport risk assessment through fault tree analysis

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ABSTRACT: This study focused on the public transport risk assessment in District 1 of Tehran through Fault Tree Analysis involving the three criteria of human, vehicle and road in Haddon matrix. In fact, it examined the factors contributing to the occurrence of road accidents at several urban black spots within District 1. Relying on road safety checklists and survey of experts, this study made an effort to help urban managers to assess the risks in the public transport and prevent road accidents. Finally, the risk identification and assessment of public transport in District 1 yielded several results to answer the research questions. The hypotheses analysis suggested that safety issues involved in public transport are concerned by urban managers. The key reactive measures are investigation of accidents, identification of causes and correction of black spots. In addition to high costs, however, the reactive measures give rise to multiple operational problems such as traffic navigation and guaranteeing user safety in every operation. The case study highlighted the same fact. The macro-level management in the metropolis of Tehran is critical. The urban road casualties and losses can be curtailed by preventive measures such as continuous assessment of road safety.

KEYWORDS: *Public transport; risk assessment; Safety management; Fault Tree Analysis (FTA); Urban road accidents*

INTRODUCTION

The chances of an accident in a given traffic project and its safety performance can be figured out by examining the existing roads, those under construction and any other project in contact with road users. Pursuing its organizational mission and in line with the promotion of citizen safety, Tehran Municipality has been making great efforts to achieve sustainable urban development since 2007 by the establishment of Safety Community Policy Committee in charge of implementing a safe community model across Tehran municipal district. In this regard, Tehran District 1 Municipality set out to form a Traffic and Road Safety Task Force within the Safe Community so as to identify and resolve the potential safety loopholes in the urban road network (Tehran Safe Community Studies, 2007).

Comparison and Function of Safety Management, Crisis Management and Risk Management in the

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Transport Sector: This study examined each of the management practices in terms of stages, processes and area of function so as to compare their functions based on three indicators of scope under coverage, management cycle and the type/origin of dangers. The three management practices were employed to provide a well-structured system to deal with the consequent dangers and accidents, where risk management encompasses crisis management like an umbrella (Pourreza and Pouriari, 2006).

Risk Management and Assessment in the Rail Transport Network, Tehran Railway Headquarters, based on HSE-MS: In line with crisis management, one of the most important measures is to focus further on systematic preventive as opposed to reactive approach. In this light, Tehran Railway Headquarters implemented the HSE-MS and risk management system during 2008. This paper discusses the risk factors identified within the system at all the railway stations in Tehran (Rabbani et al., 2008).

Application of Security Risk Assessment within the Hazardous Materials Transport System: This study sought to propose an efficient model of security risk assessment for the threats facing the hazardous materials transport system. Finally, it employed the case study to calculate the security risk within the hydrocarbon transport system as well as to suggest several countermeasures against potential threats under special forms concerning identification of system's vital assets, threats, possible appealing objectives, security vulnerability analysis and coping strategies (Jamshidi *et al.*, 2012).

Risk assessment in special events

Tehran with a population over 12 million people is considered as a Mega city in the world. This city is also the capital of a county with a population over 70 million people and its own beliefs and special occasions. National and religious events, as well as the historical events, are of high importance. The Independence Day (Bahman 22), Eid Al-Fitr prayer, Imam Khomeini death anniversary and etc., are the most important Events that are held in Tehran. Risk management and providing safety and security maintenance for passengers and equipment's are the most significant issues. This paper states years of experience with Risk management in these special events in Tehran and metro stations; and indicates particular points, problems and difficulties of coordinating the whole public transportation systems. In addition a comparison will draw between implementing events in Iran and London (Abdollahpour, Khorasani, 2012).

Using Extent Analysis Method for Risk Assessment of Road Network in Hazmat Transportation

Risk is an important factor in hazardous material routing problem. In general, it is defined based on the probability of road accidents and their impacts. Due to lack of data for calculating risk factors, influenced by hazmat accidents and their impacts, this paper attempts to define road network risk factors to be used in hazmat transport field. In the present paper, risk is proposed according to its components including our types of accident, population, environment and infrastructure issues. Risk components are presented as linguistic variables by five experts and extent analysis method, a well-known method of converting fuzzy variables to crisp values, has been utilized to convert linguistic variables to crisp values. The proposed method was applied in Fars as case study, the second largest province in Iran and results, presented on details, show that normalized risk factors can be obtained using the extent analysis method and they will be used for finding the safest path in Hazmat transport planning (Mahmoudabad and Seyedhosseini, 2012).

The Risk Management Programing for Urban Systems

Risk Management is the process of identification, analysis and either acceptance or mitigation of uncertainty in investment decision-making. Essentially, Risk Management (RM) occurs anytime an investor or fund manager analyzes and attempts to quantify the potential for losses in an investment and then takes the appropriate action (or inaction) given their investment objectives and risk tolerance. Inadequate risk management can result in severe consequences for companies as well as individuals. Risk management is uncertainly management including identification, assessment, monitoring and reducing the impact on the business. A proper risk management program can be minimized with the adequate risk management strategies. A director for RM program required special tools and techniques like: avoiding risk with elimination of the factors and consequences of the risk, limiting risk with reducing the likelihood of damage, risk transfer with transmission the potential damage to another party such as insurance company. This paper identifies

significant need to Risk Management for urban systems and paraphrases the risks in Electronic Cards system. Hence the mangers can decide the adequate strategy for these risks and improve the system (Nataj, 2015). This study has been performed in district one of Tehran Municipality in 2013.

Significance of research

Road safety

For many years, road safety has been a major concern in most organizations involved in transportation. As for Iran, traffic and road accidents are one of the major causes of damage to life and property of citizens in the outdoor environments. In fact, more than 20,000 citizens (pedestrians, cyclists, bikers and car passengers) are killed annually as a result of traffic accidents, causing enormous losses in Iran. Hence, improvement of traffic safety in any large city can be counted as an essential factor contributing to a healthy and safe society. In order to achieve this goal, it is crucial to examine the road safety of each region (Road Safety Surveys, 2009).

Vertices of the urban transportation safety triangle (Haddon Matrix)

Human, vehicle and road are the three components of safety triangle, each making a contribution to the level of road safety. The primarily concerns of the public transport authorities is how to provide good-quality transportation facilities. Given the high rate of accidents in the country, one of the actions to be made by the Iranian road transport authorities and practitioners is to guarantee and promote the safety of the users within the road network (Mirabi Moghaddam, 2011).

Risk management

Risk assessment is an integral part of best practices whether at strategic or operational level. One of the essential steps taken in risk management is risk assessment. For this purpose, there are several qualitative and quantitative techniques yielding different outputs. Although there are several approaches to risk assessment, the FTA is applied on the public transport sector owing to its advantages (Omidvar *et al.*, 2011):

- Evaluating the different possible combinations of errors and faults within a complex system.
- Identifying the vulnerabilities in the system, taking appropriate control measures and utilizing the resources essential for controlling the identified risks.
- This technique can be employed to reconfigure a system in line with reduction of vulnerability.
- This can provide a useful tool to identify the root causes of equipment failure.
- It allows to concentrate on one system malfunction at a time.
- The FTA can be a well-structured technique for engineers who want to understand the system behavior and the interconnections between the constituent elements (Halvani and Mirmohammadi, 2011).

Research variables under a conceptual model

The independent variable was public transport safety, the impact of which was examined on curtailing the traffic accidents. The dependent variable was safety improvement in public transport. The three factors of human, vehicle and road constituting the vertices of safety triangle could facilitate the public transport risk management. This study involved several stages illustrated in the following flowchart as shown in Fig. 1.

Fig. 1: Data collection and analysis through FTA

MATERIALS AND METHODS

Risk management process

Risk management is often represented by the overall process of hazard identification, risk estimation, risk assessment and, if necessary, risk reduction or control. The main objective in risk analysis is to provide information for risk assessment. When risks are assessed (including the possible risk mitigation options), appropriate decisions are adopted in the final step of risk reduction/control. The two steps of risk evaluation and risk analysis are often considered as risk assessment. One important feature of risk management is its iterative process of continuous updating as soon as circumstances change and there is new information available (AZ/NZS., 2004).

Risk analysis process

The information and knowledge gained from risk analysis can be a pre-requisite to risk assessment and possible options for risk reduction. According to a definition of risk by Kaplan and Garrick (1981), risk analysis serves to provide information about the scenarios, probabilities and consequences.

The main stages in risk analysis include determining the scope, risk identification and risk estimation. Depending on the type of system and risk involved, the analysis may vary. It should also be noted that a risk analysis can, in accordance with its purpose, be either quantitative or qualitative. Furthermore, risk analysis can be a combination of quantitative and qualitative analysis known as semi-quantitative analysis (Aven, 2003).

Fault Tree Analysis methodology

The Fault Tree Analysis (FTA), was first proposed at Bell Telephone Laboratories during 1961-1962. Later on, it was developed by Watson to assess and improve the reliability of the intercontinental ballistic missiles control system. In the following years, the FTA was systematically expanded by Boeing. The first paper about the FTA was presented by the University of Washington and Boeing at the System Safety Symposium in 1965. From 1965 onwards, the application of FTA extended to various industries such as aerospace engineering, nuclear energy, chemicals and so on. The technique has been widely employed so far to analyze the reliability, accessibility and safety of systems. Nowadays, the FTA is known as one of the most powerful tools for the analysis of system safety process particularly when it comes to the assessing extremely sophisticated systems. Due to the adoption of deductive method in the FTA, many system safety analysts believe that the technique can be useful in examining the various possible scenarios leading to desirable/undesirable events within a system (Mohammadfam, 2009).

The FTA involves creating a fault tree, importing the probability of error in basic events, determining the probability distributions of errors as well as the primary event and specifying the cut sets. A cut set is a group of initiators, which might coccus together leading to the primary event. A minimal cut set (MCS) refers to the smallest set of initiators which might happen together leading to the primary event.

Owing to its great flexibility, this technique can be used throughout the system's lifespan such as the design stage. The FTA can predict the potential defects during the design phase and specify the necessary modifications. Moreover, this method can be used during the operational phase so as to determine the nature of desirable/undesirable events arising from the system's performance.

Fault Tree Analysis Terminology

Gates

Gates link the various events within the body of fault tree. Depending on its type, each gate receives one or more output, but provides only one output. The FTA gates follow the logic of Boolean algebra. The major types of gate in the FTA include:

AND Gate

The output event occurs only if all inputs occur. The output event can be either primary or intermediate. The input event might be intermediate, final or a combination of the two.

Priority AND gate

The output occurs if the inputs occur in a specific sequence from left to right or vice versa specified by a conditioning event.

OR Gate

This gate represents the scenario where the output occurs if any input occurs. The output event can be either primary or intermediate. The input event might be intermediate, final or a combination of the two.

M out of N Gate

The output event occurs when *m* inputs from *n* inputs occur.

Conditioning gate

This gate entails an input event from the conditioning event (on one side) and other events. The output of the conditioning gate occurs when the conditioning event and other inputs occur together. The conditioning event is always an input of the gate, which is a certain type of AND gate.

NOT Gate

This logic gate can only have one input. The output event of this gate occurs when its input does not occur. NOT Gate is very rare and uncommon.

Figs. 2 and 3 illustrate the main symbols involved in the FTA. The construction of a fault tree will be easier by understanding the meanings, concepts and application behind each symbol mentioned above. (Mohammadfam, 2001).

All analyses in this study involved the Monte Carlo uncertainty simulation model with 10,000 iterations for each analysis. The simulations were implemented in OpenFTA.

Data analysis method

Depending on the operational stage, the data were analyzed through the information extracted from the Excel questionnaire. Then, the spota with the greatest number of accidents were identified and the causes and risks of road accidents were investigated through OpenFTA.

This research has been performed in District One of Tehran Municipality, where is located in the northernmost part of the city as shown in Fig. 4. It is located on the heights of Tehran in a district of about 210 square km based on statistical data. It embraces over 433,500 people out of the population. Piles of finished and semi-finished buildings would increase the population of the district to the border of 500,000 people.

This district borders Alborz Mountain to the north, Darakeh River to the west, Shahid Chamran Highway to the south and Lashgarak Road and Jangali Park of Qoochak to the east. It is divided into 10 areas and 26 neighborhoods. District One is a mountainous place and has abundant orchards, rivers, valleys, watercourses as well as two major faults with a record of landslide. It has residential suitability (urban and summer residence). This district, due to its urban design, possesses a semi-village texture and can be called a 'garden city'.

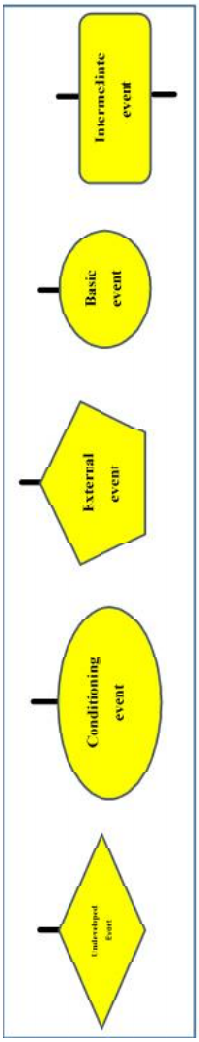


Fig. 2: Symbols used for a variety of events in construction of a fault tree

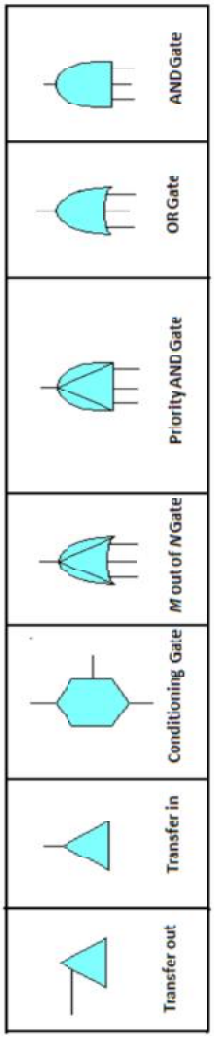


Fig. 3: Symbols used for a variety of logic gates and transfers in a fault tree

Various scenarios under analysis

In order to correctly carry out the risk assessment of public transport within District 1, five candidate scenarios were analyzed as follows:

-Vehicle-motorcycle accident at Qods Square
-Vehicle-pedestrian accident from Bahonar Square to Saeedi Street
-Vehicle-vehicle accident in Shahid Sabari (Ajodanieh) Street
-Vehicle-pedestrian accident in Andarzgoo Street
-Vehicle-pedestrian accident in Moghadas Ardebili Street

The next section will explore the FTA for each scenario and obtain the corresponding probability OpenFTA. For instance, the FTA for the first scenario has been given in the Fig. 5. This section will explore the FTA for each scenario (Johnson, 1973).

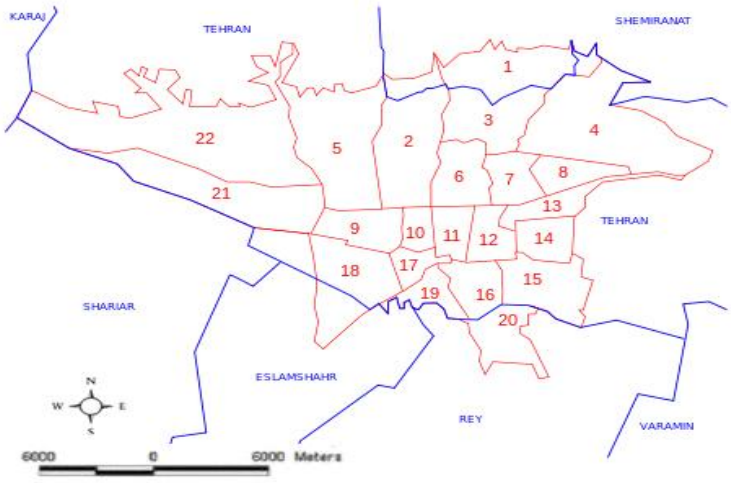


Fig. 4: Displays the location of District one-Shemiranat on top of 22 municipal districts of Tehran

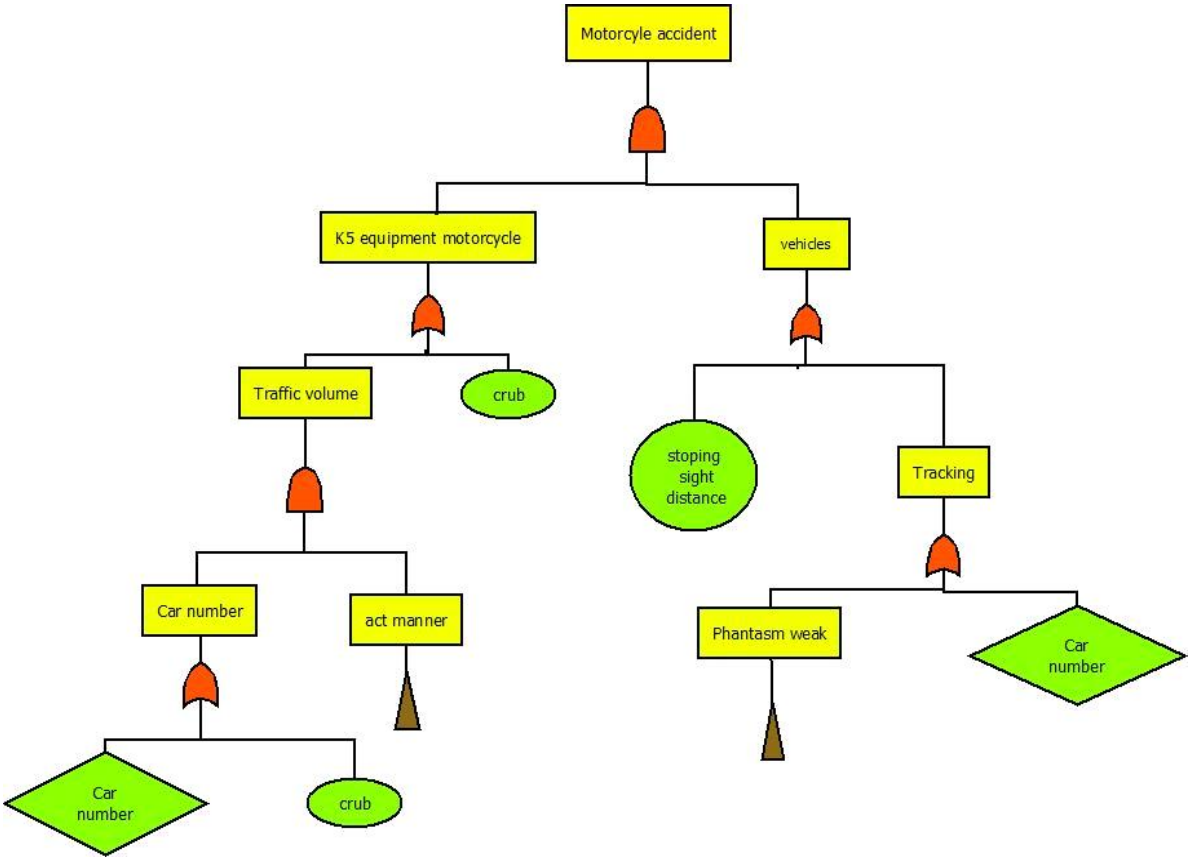


Fig. 5: Fault tree for vehicle-motorcycle accident at Qods Square

RESULTS AND DISCUSSION

After the formation of fault trees for the system under study, the probability data in various scenarios calculated were analyzed through Open FTA. Based on the results obtained from the analysis of 5 case studies, this section will propose a few solutions to each case study (Zomer and Lavie, 1990). The definite cause of accidents in the scenarios has been illustrated in Fig. 6.

The chances of an accident in a given traffic project and its safety performance can be figured out by examining the existing roads, those under construction or any other project in contact with road users. Risk management in the metropolis of Tehran is crucial given the growing population, urban complex structure, uncoordinated networks and infrastructure as well as great risk of dangerous road accidents. Great steps can be taken by risk assessment of accidents and subsequently controlling the critical situations and curtailing the damages across Tehran (Whitty *et al.*, 2000). As a results three general solutions are proposed to reduce risk of accidents: promoting the culture of driving and traffic, traffic demand management, and dynamic management of traffic events.

Figs. 7 to 11 show the result of accident probabilities after the adoption of these three proposed solutions in the mentioned previous section scenarios.

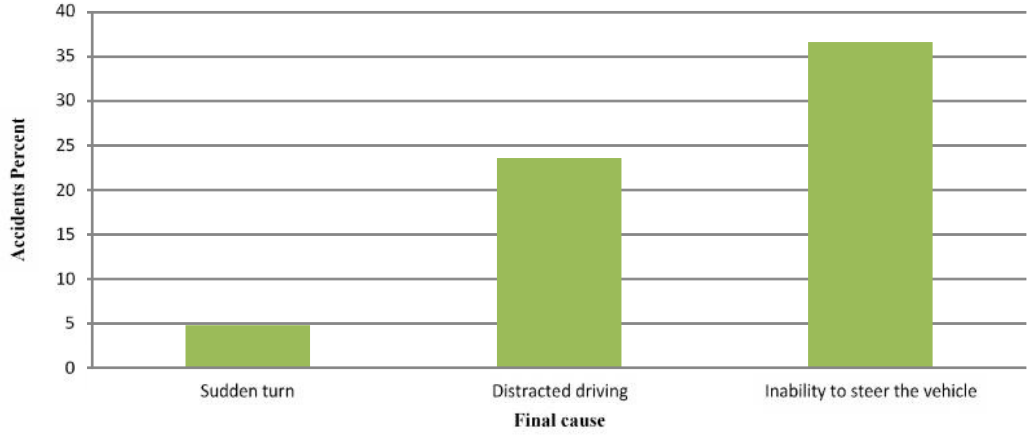
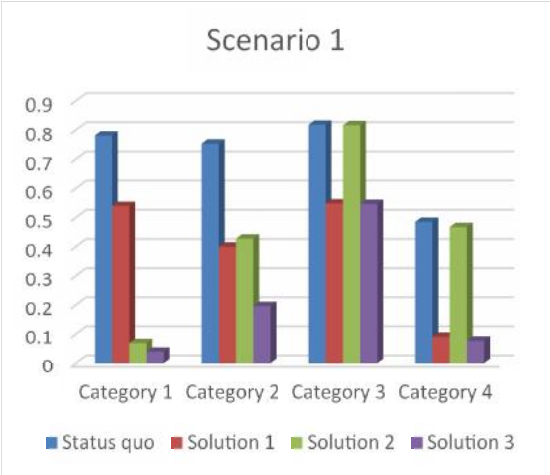
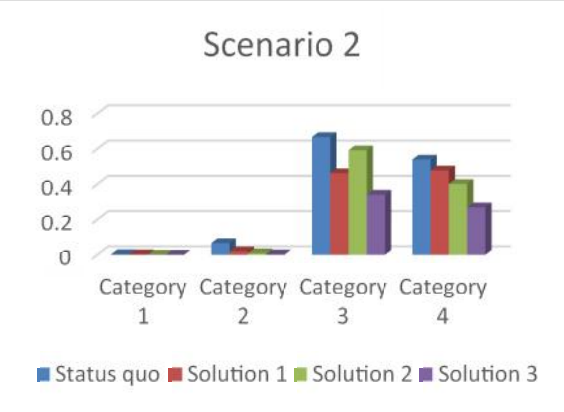


Fig. 6: The definite cause of accidents in the scenarios



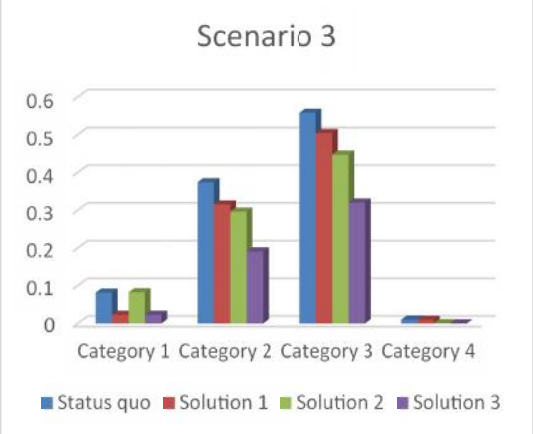
Scenario 1			
Status quo	Solution 1	Solution 2	Solution 3
0.7811	0.5393	0.0692	0.0394
0.7533	0.4	0.4276	0.1966
0.8176	0.5485	0.816	0.5463
0.4848	0.0911	0.467	0.0773

Fig. 7: The results of Vehicle-motorcycle accident probabilities after the adoption of the proposed solutions at Qods Square



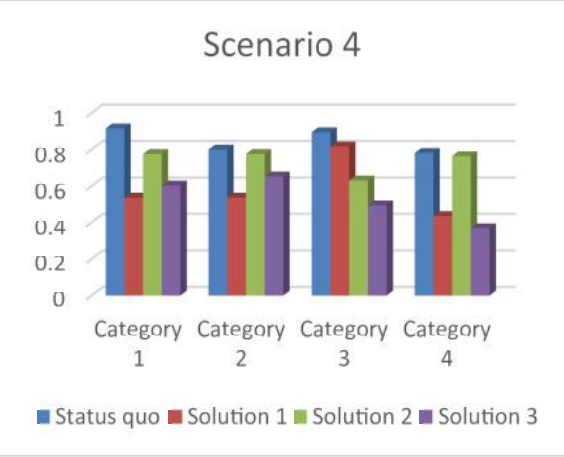
Scenario 2			
Status quo	Solution 1	Solution 2	Solution 3
0.0027	0.0018	0.00007	0.00005
0.0661	0.0193	0.0081	0.0017
0.6673	0.4623	0.5917	0.3401
0.5399	0.4773	0.401	0.269

Fig. 8: The results of Vehicle-pedestrian accident probabilities after the adoption of the proposed solutions from Bahonar Square to Saeedi Street



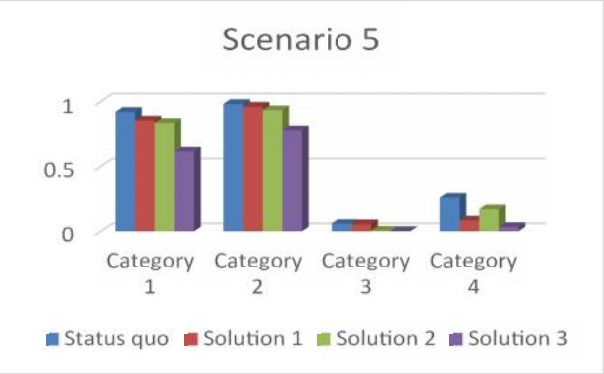
Scenario 3			
Status quo	Solution 1	Solution 2	Solution 3
0.082	0.0226	000826	0.0226
0.3743	0.3153	0.2965	0.1908
0.5582	0.5046	0.4472	0.3203
0.01	0.0095	0.0012	0.0005

Fig. 9: The results of Vehicle-vehicle accident probabilities after the adoption of the proposed solutions in Shahid Sabari (Ajodanieh) Street



Scenario 4			
Status quo	Solution 1	Solution 2	Solution 3
0.9153	0.537	0.776	0.603
0.7998	0.537	0.776	0.653
0.895	0.817	0.631	0.4934
0.7811	0.4346	0.7642	0.3675

Fig. 10: The results of Vehicle-pedestrian accident probabilities after the adoption of the proposed solutions in Andarzgoo Street



Scenario 5			
Status quo	Solution 1	Solution 2	Solution 3
0.9196	0.853	0.8356	0.6167
0.981	0.96	0.9337	0.7789
0.06	0.0556	0.006	0.0038
0.2603	0.0854	0.1716	0.0341

Fig. 11: The results of accident probabilities after the adoption of the proposed solutions

CONCLUSION

Evidently, the Fault Tree Analysis is a very efficient technique for analyzing complex systems considering the interactions between the components of a given system. The numerical results of the analysis are not the only important achievement, but the formation of a fault tree can also be significant, since it provides an in-depth insight into the interaction between various components of a system. The results of FTA provide a desirable resource to adopt critical decisions on various fields concerning the system under study, such as emergency response. The main reason behind lower risk of accidents in non-urban roads is less traffic congestion. Nonetheless, it is unfair to overlook the efforts made by legal and technical authorities in curtailing the number of accidents. Obviously, the risk of accidents in non-urban roads is decreasing more rapidly. This highlights the need for more serious and well-calculated measures taken to improve the urban road network. The results of the analysis indicated the major factors contributing to road accidents were deficiency or absence of traffic signs, narrow roads, poor road geometry (slope, curve, twist, low field of view).

The results of the analysis concerning the drivers indicated that the major factors were inattention to traffic regulations, violating the right-of-way, distracted driving and failure to keep the longitudinal distance from the vehicles ahead. The results of the analysis indicated that the definite causes of accidents were inability to steer the vehicle, distracted driving and sudden turn. The results of the analysis on the number of accident during 2009-2012 indicated a declining trend particularly in the last year. This reflects the appropriate measures taken by the Traffic Police Department in District one of Tehran. The results indicated that the third solution, dynamic management of traffic events, is the best overall suggestion to reduce accidents across north of Tehran. Ranking second and third best solutions were promoting the culture of driving/traffic and demand management.

Three proposals are recommended for future researches:

- Studying the other aspects of risk such as cost-benefit analysis and strategies for risk reduction in public transport.
- Identifying the risk factors to which the system is more sensitive.
- As an administrator of urban road safety, the municipality is expected to assess the safety of roads through urban development plans.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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