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***Research Article***

# IDENTIFYING AND PRIORITIZING THE FACTORS AFFECTING SAFETY OF INTER-CITY TUNNELS AND PROVIDING TUNNEL SAFETY CHECK LIST

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## ABSTRACT
Generally, in developing countries road transport is paid more attention to, among different modes of transport, due to its more infrastructure. Tunnels as a part of roads buildings, especially used more in mountainous areas, will have a significant impact on road safety. Driving conditions in the tunnel induce special performance effects to the driver due to restrictions such as changes in lighting, limited maneuverability, width limitation and so on. Safety and controlling the situations after the accident in the tunnel is also one of the issues that have been specifically focused on and special measures have been taken for in developed countries. This is while in developing countries not only to this issue but also to the designing with minimal equipment in the tunnels have not been given the least attention. This study has attempted to identify and prioritize the factors affecting the level of safety in the flow of traffic in tunnels. Factors are studied in three human, road and its surroundings, and the vehicle categories and each of these three main indices includes several sub-criteria to each of which a score is assigned by a prioritizing method. Results showed that alertness of the driver, not speeding, and respecting the distance between the vehicles, from human category, and ice, lighting, and the existence of emergency lane from road class and malfunction of vehicle parts have the greatest impact on tunnel traffic-flow safety. In order to introduce an index representing the tunnel safety level, a relationship including all criteria was used and after the case study, tunnel safety index number was ascribed to different tunnels.

***Keywords:*** *Suburban Tunnel Safety Index, Analytic Hierarchy Process (AHP), accidents*

## INTRODUCTION
Of the four basic models of road transport, rail, air, and sea, road trips have the greatest impact on the incidence of the risks of accidents for the users. In the last half century, with development of machine life and the ever-increasing traffic in cities and roads have increasingly added to the number and severity of traffic accidents.

Technological advances of the vehicles and overtaking the road safety standards in the old roads have led to the spread of a dangerous phenomenon of road accidents that is one now one of the leading causes of death in the world. In recent years, and due to the growing population in car production and consequently development of roads, the demand for different modes of transport and traffic within cities and suburbs have had increasing growth, as a result of which traffic accidents have become one of the problems in the transport sector.

Thus, vehicle, road, and environmental condition parameters along with the human factor, in combination or individually, have caused a high rate of road accidents. What is obvious is that in order to solve any problems and negative phenomena associated with at first the problem must be identified and analyzed in various aspects.

Then as the factors influencing the problems are identified and the weight of their effect becomes more specific, the possibility of providing the optimum solution increases. So the first step to reduce the occurrence of accidents and injuries and damage caused by it is to completely understand the factors causing this problem and then to try to provide the best solution to solve or reduce the adverse effects of these factors.

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***The Importance and Need for Research***

Tunnels as the technical buildings of the roads have a significant impact on transportation safety and traffic flow. Several studies on tunnel safety in form of accident prevention and post-accident measures have been conducted, indicating the importance of road building safety.

Usually, regarding physical characteristics tunnels are different from the rest of the track. Tunnel structure is usually narrower and more limited than the road leading to it is and thus lacks some safety features like road shoulders.

As tunnels are a critical component of the transportation system and many routes lead to them, they usually have high volume of traffic passing through them. Although little information has been released about the accident in the tunnel area, obviously unusual physical properties, and performance of tunnels are effective on the severity of the risk of vehicle accidents and the type of accident (Narimani, 2010).

In 2011, in research on the tunnels of Karaj-Chalous, six of the most important factors in the safety of the tunnels were defined including:

Lighting: weight 0.338
Curve: weight 0.254
Horizontal signs: weight 0.145
Vertical signs: weight 0.119
Drainage: weight 0.079
Furnishing: 0.066.

Next to each criterion in the tunnel, a score is given from 1 to 10 that by multiplying the weight of each criterion and the other criteria, final score is obtained. The higher this final value, the more secure the tunnel and vice versa (Hejazi and Sepahvand, 2012).

In 2012, during a study, risk factors were generally divided into seven main groups: 1) the geometry of the tunnel and road, 2) traffic monitoring and management, 3) emergency services and rescue management systems, 4) fire resistance, 5) communication system, 6) conditioning, and 7) lighting and power supply systems, each of these categories has its own sub-factors.

Other areas, such as the score (best 10 and the worst 0) are similar to previous research (Hejazi and Sepahvand, 2012).

In 2013, based on research on Karaj-Chalous tunnels, five factors were defined as the most important ones in the safety of the tunnels as follows:

Safety system index: weight 0.174
Lighting index: weight 0.145
Physical and geometric design index: weight 0.503
Signs and equipment index: weight 0.095
Conditioning index: weight 0.084

According to the considerable number of mountain tunnels in Iran, and therefore the existence of tunnels, the study of factors affecting accidents in places where there is tunnel seems to be necessary. Therefore, in line with the increase in road tunnels and the increase in the number of vehicles passing through, securing tunnel has been on the agenda of the Ministry of Transportation.

In this study, given the resources available and negotiations with the relevant authorities, the issues affecting suburban tunnel safety of Haraz mountainous road were identified and after prioritizing by AHP approach, it was attempted to develop safety index model of tunnel safety.

The results show that the most important factors affecting the safety of tunnels were road, environmental, human and vehicle.

From the perspective of the human factors alertness of the driver, not speeding, and respecting the distance between the vehicles, from human category, and ice, lighting, and the existence of emergency lane from road class and malfunction of vehicle parts have the greatest impact on tunnel traffic-flow safety. The developed model includes 13 variables affecting tunnel safety in mountainous regions that maximum value of which is 2.28.

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## MATERIALS AND METHODS

### *Research Methodology*

In general, the research methodology of each study is based on its purpose. Various methods are used to conduct this research including the study of available resources such as articles and books in Persian and English and gaining sufficient information regarding factors affecting road safety in tunnel and prioritizing the impact of each factor according to the impact it has on trip safety. Finally, by using accident record form and assessing tunnels accident statistics, parameters affecting the safety of the tunnels are selected, and by the selection of the sample population, different samples will be discussed. By Case Study of Haraz road tunnels and determining tunnel safety parameters and obtaining accidents statistics, the body and structure needed to set up research are formed and by production of applied questionnaires according to AHP approach and measurement of this technology experts, safety evaluation index is determined and offered in relation to the index hit that is a quantitative coefficient. By AHP prioritization method at one level and analysis of accidents and parameters affecting it by weighting the parameters and providing safety evaluation index for tunnels, tunnel safety of the studied cases is assessed and exploited as a result. At the end, the last stage of the research that is data analysis, the information obtained from the first and second stages, through library and field studies, are set within the framework of the research subject, reviewed, and analyzed.

### *Determining Indices and Options Affecting Tunnel Traffic Safety*

In order to determine the indices and parameters affecting tunnel safety as well as the parameters affecting the number and type of accidents and the possible occurrence given the theoretical foundations of the field and also by reviewing the previous studies, some indices and parameters were selected. After much discussion with experts and professionals in the field of traffic, traffic police and transport, a list of factors affecting safety of traffic in road tunnels were prepared and categorized in three general categories of people, the environment and vehicle. These three main indices were analyzed and after removing the factors that overlapped or had little relative importance, they were divided into the following options:

1. Human

Vehicle lights on
Observing the distance between the vehicles inside the tunnel
Unauthorized speed
Illegal overtaking and deviation to the left
Alertness of the driver (non-impaired driving such as drug, fatigue, etc.)
Driver skills
Familiarity with the track
Driver's age
Driver's gender

2. Road and its surroundings

The percentage of heavy vehicles in traffic (Transit, passenger, combined)
The quality and type of pavement in the tunnel
Lighting inside the tunnel
Ventilation
Signs and traffic signals
Speed camera
The roadway width
Tunnel with one-way flow
The number of lines in the go or in the way back
Lining (type of covering and lighting)
Longitudinal gradient of the tunnel
Length of the tunnel
Stopping sight distance

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Horizontal arcs (radius - away or on height- vision distance)
Proper drainage of surface water in the tunnel road
Existence of emergency line (an increase of one lane to road width)
Ice and oily substances on the road surface
3. Vehicle
Technical defect of parts
Technical specifications (vehicle's being update)
Vehicle dimensions (size)
Safety indices of the tunnel in suburban road:
Length of the tunnel
The percentage of heavy vehicles in traffic (Transit, passenger, combined)
The quality and type of pavement in the tunnel
Lighting inside the tunnel
Ventilation
Signs and traffic signals
Speed camera
The roadway width
Tunnel with one-way flow
The number of lines in the go or in the way back
Horizontal arcs (radius - away or on height- vision distance)
Lining (type of covering and lighting)
Longitudinal gradient of the tunnel
The drainage system in the tunnel
Existence of emergency line (an increase of one lane to road width)
Ice and oily substances on the road surface

***Prioritizing Based on AHP Approach***

According to the criteria and sub-criteria obtained for research, paired comparison questionnaire was formed according to each criterion and answered by 30 experts in the field of shipping, transportation, and police. According to the results, pair wise comparison matrices are formed.

Formation of pair wise comparison matrix of human, road and the environment, and the vehicle:

The main indices of human, road and the environment, and the vehicle are compared two by two and given points.

For example, if human index score has gotten x score compared to the road, then road index will get the inverse score 1/x compared to human index.

**Table 1: Matrix of Pairwise Comparisons of Human-Road and Surroundings –Vehicle Indices**

| | **Human** | **Road** | **Vehicle** |
|---|---|---|---|
| Human | 1 | 3 | 4 |
| Road | 0.33 | 1 | 2 |
| | 0.25 | 0.5 | 1 |
| Vehicle | | | |
| Total each column | 1.58 | 4.5 | 7 |

Pairwise comparison matrices obtained for the final calculation of the relative weight should be normalized. The relative weight of the final calculation is as follows:

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At first, the sum of each column is calculated. Then each element in the pairwise matrix is divided to its total of its column to normalize the pairwise matrix. Mean value of each row in the normalized matrix is calculated. After calculating the normalized matrix, and the mean of each row, the relative weight of each criterion is obtained and the final weight of each item is calculated by the following formula.

(1) Final weight of each option= Σ (weight of that criteria × weight of the option relative to criteria)

***Suggesting Solutions for Traffic Safety in Tunnels***

According to the results, some solutions in relation with their prioritizing are offered.

Guidelines related to affective human factors:

A) Education and culture of safe driving in road tunnels for future generations through education and generation of audio and video messages

B) First aid training and using safety equipment in the event of an accident in the tunnels through audio and video messages

C) Recording the place and reason of the accidents in forensic forms by the personnel involved in the registration process to create comprehensive statistics on this issue and therefore to identify and secure very dangerous places and black spots.

***Solutions Related to Factors Affecting the Index of Road and its Surroundings***

A) The promotion of safety in tunnels in conformity with international standards in terms of geometry, traffic control equipment, safety, communication equipment, lighting systems and so on

B) Creating road tunnels with minimum international standards

C) Getting compensation from the developers and designers of the tunnel who play a role in road accidents

D) Weekly visit of road tunnels by road safety patrols and correction of defects on an ongoing basis

E) Imposing traffic rules with higher fines for violations of driving inside the tunnel

F) Stopping the traffic from entering the tunnel in accidents by warning signs for the entrance to the tunnel or by police forces

***Solutions Related to Vehicle Factors Index***

A) Setting international standards for automakers and closely monitoring it.

B) Getting compensation from the car manufacturers that play a role in accidents

C) Organizing unsafe vehicles towards safety especially by equipping them with GPS and communications equipment

A) Creating conditions to develop and compete with global automakers in the country in order to improve vehicle safety.

Options are shown according to final weight, the highest weight is related to the driver's awareness in .human factors, and the lowest weight is for the lining of the tunnel

***Check List of Tunnel Safety***

Using the results of this study a check list road tunnel safety that includes influential factors related to tunnel safety level are provided.

A group of experienced expert in tunnel safety should visit the tunnel and give a point of (f) for each of the components. The rating is determined based on expert's judgment. In this research, points of the components of road in the tunnel are defined from one to five.

In the absence or inefficiency in the performance of a defined parameter, point one and in case of attaining the highest performance score five is given. If the assessed parameter is qualitative, it should be made quantitative.

All score levels from (very poor to excellent) can be determined by the quantity parameter. In this case, human errors are minimized due to the reduced need to rely on expert judgment and accuracy of the results and calculations will be higher.

If parameters such as the presence of ice and the horizontal arc are low within safety visit, the tunnel will get higher points in this segment. The following table shows the check lists prepared according to the parameters of the research.

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**Table 2: Prioritizing the Parameters of Human Index**

| Index | Related Parameters | Weight |
|---|---|---|
| Human Factor | Driver Alertness (no Disturbance in Recognizing Forces such as Narcotics Fatigue, etc) | 1.51 |
| | Illegal Overtaking and Deviation to the Left | 1.05 |
| | Observing the Distance Between Vehicles Inside the Tunnel | 0.99 |
| | Unauthorized Speed | 0.96 |
| | Driver Skills | 0.47 |
| | Lights on (Education and Right Culture) | 0.45 |
| | Familiarity with the Track | 0.42 |
| | Driver's Age | 0.23 |
| | Driver's Gender | 0.15 |

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**Table 3: Prioritizing the Parameters of Road and its Surroundings Index**

| Index | Related Parameters | Weight |
|---|---|---|
| Indices Related to Road and its Surroundings | Ice and Oily Substances on the Road Surface | 0.306 |
| | Lighting Inside the Tunnel | 0.296 |
| | Existence of Emergency Line (an Increase of One Lane to Road Width) | 0.244 |
| | Ventilation | 0.208 |
| | Horizontal Arcs (Radius - Away or on Height- Vision Distance) | 0.174 |
| | Stop Vision Distance | 0.172 |
| | Longitudinal Slope of the Tunnel | 0.120 |
| | Drainage | 0.117 |
| | Tunnel with One-Way Flow | 0.109 |
| | Signs and Traffic Signals | 0.102 |
| | Speed Camera | 0.091 |
| | The Percentage of Heavy Vehicles in Traffic (Transit, Passenger, Combined) | 0.089 |
| | Tunnel Length | 0.087 |
| | Roadway Width | 0.085 |
| | Quality and Type of Pavement | 0.074 |
| | The Number of Lines in the Way or Back | 0.071 |
| | Lining | 0.048 |

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**Table 4: Prioritizing the Parameters of Vehicle Index**

| Index | Related Parameters | Weight |
|---|---|---|
| Indices Related to the Vehicle | Technical Defect of Parts | 0.856 |
| | (Technical Specifications Update Vehicle) | 0.329 |
| | (Vehicle Dimensions Size) | 0.188 |

**Table 5: Prioritizing the Factors Affecting the Level of Traffic Safety by Using AHP Approach**

| Row | Options | Final Weight of the Options | Multiple of Ten Weight of Options |
|---|---|---|---|
| 1 | Driver's Alertness | 0.1509 | 1.509 |
| 2 | Illegal Overtaking | 0.1048 | 1.048 |
| 3 | Observe the Distance | 0.0986 | 0.986 |
| 4 | Unauthorized Speed | 0.0961 | 0.961 |
| 5 | Technical Defect of Parts | 0.0856 | 0.856 |
| 6 | Driver Skills | 0.0473 | 0.473 |
| 7 | Lights On | 0.0451 | 0.451 |
| 8 | Familiarity with the Track | 0.0418 | 0.418 |
| 9 | Technical Specifications | 0.0329 | 0.329 |
| 10 | Glacial | 0.0306 | 0.306 |
| 11 | Lighting | 0.0296 | 0.296 |
| 12 | Emergency Line | 0.0244 | 0.244 |
| 13 | Driver's Age | 0.0234 | 0.234 |
| 14 | Ventilation | 0.0208 | 0.208 |
| 15 | Vehicle Dimensions | 0.0188 | 0.188 |
| 16 | Horizontal Arc | 0.0174 | 0.174 |
| 17 | Distance of vision | 0.0172 | 0.172 |
| 18 | Driver's Gender | 0.0153 | 0.153 |
| 19 | Longitudinal Slope | 0.0120 | 0.120 |
| 20 | Drainage | 0.0117 | 0.117 |
| 21 | One-Way Flow | 0.0109 | 0.109 |
| 22 | Signs and Signals | 0.0102 | 0.102 |
| 23 | Control Camera | 0.0091 | 0.091 |
| 24 | The Percentage of Heavy Vehicles | 0.0089 | 0.089 |
| 25 | Tunnel Length | 0.0087 | 0.087 |
| 26 | Roadway Width | 0.0085 | 0.085 |
| 27 | Quality and Type of Pavement | 0.0074 | 0.074 |
| 28 | Number of Lines | 0.0071 | 0.071 |
| 29 | Lining | 0.0048 | 0.048 |
| 30 | Total Weight | 1 | |

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**Table**

| | **Excellent** | **Good** | **Acceptable** | **Weak** | **Very weak** |
|---|---|---|---|---|---|
| | 5 | 4 | 3 | 2 | 1 |
| Ice and Oily Substances on the Surface in the Absence of Ice and Oil the Score is More | | | | | |
| The Lighting System Inside the Tunnel Emergency Lights - Navigation Lights on the Sidewalk in the Event of Fire | | | | | |
| The Existence of Emergency Line (an Increase of One Lane to Road Width) | | | | | |
| Ventilation Natural - Piston Effect to the One-Sided Flow- Longitudinal Ventilation Transverse Ventilation | | | | | |
| Horizontal Arcs (Radius - (Away or on Height If Horizontal Arc has a Low Radius, it gets Greater Score | | | | | |
| Stopping sight distance Obstacles such as lamp base or panel | | | | | |
| Longitudinal Slope of the Tunnel | | | | | |
| Drainage | | | | | |
| Traffic Signs and Safety Signals Such as Marginal panels – Facade-Crossing Line Margin Line Continuous - Line in the Middle Emergency Exit Map-Sign | | | | | |
| Speed Camera | | | | | |
| Roadway Width | | | | | |
| Quality and Type of Pavement | | | | | |
| Lining Tunnel Wall Covering | | | | | |

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## RESULTS AND DISCUSSION

### *Results*

The result of this survey has been prioritization indices affecting traffic safety in the tunnel and tunnel safety checklist. Among the indices analyzed in the flow of traffic safety in road tunnels, three main indices of human, vehicle and road and its environment have been studied, each of these three indices have parameters given in Table 4.

### *Recommendations for Future Research*

A) Development of methodology using other scoring techniques such as fuzzy AHP or regression models for verification of the results

B) The application of this research to other tunnels of the country

C) Studying the effects of human error and vehicle parameters in tunnel safety index

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