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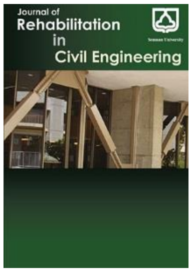

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Modeling of Speed in Vehicles Entering Two-Way Suburban Tunnels by Adaptive Neuro Fuzzy Inference System

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ABSTRACT

The behavior of drivers on the roads is elicited from the state of the surrounding environment. The author's research shows that the vehicle starts to decelerate at a certain distance from the tunnel when it is observed, and they have the lowest speed when reaching the beginning of the tunnel. As soon as the tunnel is passed, the vehicle increases speed again in a certain length. The main purpose of this study is to model the speed of vehicles entering suburban tunnels based on the speed changes before entering the tunnel using the neuro-fuzzy network. Then, to validate the designed model, the data of 30 different drivers were used who travel in the same conditions by a Renault Logan vehicle with a manual transmission system. Using the Pearson correlation analysis method, the relationship between the variables of the speed of entrance to tunnel and changes in vehicle speed was investigated. The value of the correlation coefficient is equal to -0.7, which means the strong negative correlation between the two variables. The results show that the neuro-fuzzy network method has the ability to predict speed changes with a high accuracy based on the initial speed of entrance to the tunnel. The results of this study are used to analyze the behavior of drivers in suburban tunnels. Due to the importance of abrupt speed changes in an unusual way, especially on two-way routes, the safety of tunnels can be increased by reducing the stressors in drivers.

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1. Introduction

Today, the behavior of drivers is one of the important issues to which researchers address to increase the safety. According to the previous research, to pass the two-way suburban tunnels, drivers significantly reduce speed before entering the tunnel, and after leaving the tunnel, they gradually increase speed. Also, in the tunnels without adequate shoulders, drivers increase the distance from the right wall of the tunnel as soon as they enter the tunnel. Nowadays, the use of tunnels has significantly grown for the reasons such as the high cost of urban land acquisition, minimal environmental degradation, and growth of construction technologies. The geometric design code of Iranian roads specifies some points to increase safety in tunnels, including lower design speed than the road in which the tunnel is located, providing appropriate lighting length at the beginning and end of the tunnel, avoiding the prediction of intersection or immediate access near the tunnel openings, etc. Accidents and fires in road tunnels depend on traffic congestion, and as traffic increases, the risks associated with accidents may increase. Tunnels have fewer accidents than open roads. Only 1% of serious accidents in the Netherlands occur in tunnels [1]. In Italy, 4% of serious accidents occur in tunnels. If the tunnel accidents are only taken into account, the risk of being killed on open roads is twice as high as being killed in tunnels [2]. The percentage of the accidents that result in serious injuries and death is 2.4% in the Shanghai River tunnel in China, but it is 1.2% in open roads [3]. Amundsen and Ranes (2000) concluded that the frequency of accidents is higher at tunnel entrances and lower along the tunnel where drivers continue on their way.

Table 1. Statistical summary of tunnel accident percentage based on severity [4].

		Fatal	**Seriously injured**	**Slightly injured**	**Total**	**No injury crash**
Amundsen & Engebresten, Studies on Norwegian Road Tunnels II, 2009	Number of injuries	20	77	465	562	-
	Percentage	3.6% (2.8%)	13.7% (11.7%)	82.7% (85.5%)	100.0%	-
Amundsen & Ranes, Studies on traffic accidentin norwegian road tunnels, 2000	Number of crashes	40	85	1005	1130	-
	Percentage	3.5%	7.5%	88.9%	100.0%	-
Ma, Shao, & Zhang, 2009	Number of crashes	5	6⁽¹⁾	24⁽¹⁾	35	81
	Percentage	14.3%	17.1%	68.6%		-
Nussbaumer, 2007	Percentage	8.0% (3%)	15.0% (15%)	77.0%⁽²⁾ (82%)	100.0%	-
Meng & Qu, 2012 ⁽³⁾	Number of crashes	0	45	458	503	-
	Percentage	0.0%	8.9%	91.1%	100.0%	-
Lu, Lu, Xing, Wang, & Pan, 2014	Percentage of injuries	0.5%⁽⁴⁾ (0.24%)	1.9%⁽⁴⁾ (0.96%)	97.6% (98.8%)	100.0%	-
Average		5.9%	11.2%	82.9%	100.0%	

Percentage related to motorways are given in parentheses.
Assumption:
(1) 20% of injury crashes (30crashes) are serious and 80% are slight.
(2) Slightly injured crashes include medium injuries.
(3) Only rear-end crashes (R-E) considered.
(4) 20% of fatal and seriously injured crashes (2.4%) are fatal and 80% are seriously injured.

The results show that 83% of tunnel accidents end up with minor injuries, 11% with serious injuries and 6% with death. The abrupt changes in the environment cause the stress in the driver, which can affect the way people drive [5]. According to Table 1, the average fatal and serious accidents in the tunnels are higher than the roads [6] [2]. The severity of the accidents that occur in tunnels is generally higher than open road accidents [3]. In general, fewer accidents occur in tunnels than on open roads, but if an accident occurs in a tunnel, the consequences are more serious than the open road. The consequences of an accident in a tunnel are much more damaging and dangerous, especially in the event of a fire due to the closed environment where heat and smoke do not escape. Also, there are severe fire-fighting restrictions and the users have difficulty in exiting the tunnel.

The tunnel fires not only are dangerous for users, but may also damage the tunnel structure and lead to irreparable consequences. Therefore, it is very important to prevent accidents in tunnels and make proper arrangements for the safe exit of users in accident situations. As a result, it is very necessary to increase the safety level of tunnels and reduce the number of accidents in cities, where the length percentage of tunnels is greatly increasing.

In this study, using Pearson correlation analysis, the relationship between the variables of the speed of entrance to tunnel and changes in vehicle speed is investigated. Then, a model is developed to determine the speed of entrance to the tunnel using the neuro-fuzzy network method based on the vehicle speed changes. Afterwards, to validate the developed model, the results are compared with the field surveys performed in the tunnels of the suburban Sanandaj-Hamedan routes.

Compared to the previous research of the author, in this study, the speed of entrance to the tunnel is modeled and predicted based on the changes in the speed of vehicles, which is the continuation of the previous research. However, in comparison with the study of Hassan pour and Shirgir, the effective criteria on the occurrence of accidents in tunnels are practically evaluated in this study. Also, unlike the research of Calvi et al. and Shimojo et al., in this study, the experiments are practically performed in a real environment.

This research consists of five general sections as follows:
1. Introduction: In this section, the problem statement is given.
2. Literature review: This section of the research reviews past literature related to the research.
3. Methodology: This section describes how to conduct the research in a detailed and complete manner.
4. Results: In this section, the results obtained from the research are presented.
5. Conclusion: The results obtained from the research are interpreted in this section and the implications are reported in a completely scientific and documented manner.

2. Literature review

Jahantabi, Keymanesh and Razavian (2019) modeled the transverse displacement of vehicles in suburban tunnels based on the gender and age. In this study, the neuro-fuzzy network was used to model and predict the speed of entrance to the tunnel. The results showed that the neuro-fuzzy network method has the ability to predict the speed of entrance to tunnel with a high accuracy [7].

Hassan pour and Shirgir (2019) in a study titled "Analysis of traffic factors affecting the accidents in the urban tunnel entry areas" used a generalized additive model to identify traffic factors affecting the frequency of accidents in the access areas and entrances of urban tunnels and compared the results with those of a generalized linear model (GLM). Based on the results of the generalized linear model, the linear effect of the variables of logarithm of daily traffic volume, frequency of heavy vehicles, and difference between the average daily speed of vehicles passing through the tunnel and the highway speed limit on the frequency of accidents in access areas and tunnel entrances is significant [8]. In a study on the analysis of the frequency of accidents in freeway tunnels, Hou et al. (2018) investigated the effects of various factors affecting the safety of freeway tunnels using the data collected from the crashes over a 4-year period. The results show that the higher the percentage of truck, rutting failure, traffic volume and tunnel length, the more the number of accidents [9]. Kermani and Namazian Jam (2016) modified piarc's linear model of accident severity index to identify road's accident prone spots to rehabilitate pavements considered nonlinear effects of the traffic volume. This study presents the structural defects for correction of linear models based on the accident severity [10]. Ma et al. (2016) studied the factors affecting the severity of accidents in freeway tunnels. According to the results of the Chinese police reports from 2003 to 2004, the severity of accidents is classified into three general categories: fatal accidents, accidents with injuries, and accidents without injuries. In this study, a model was developed to investigate the relationship between and evaluate the 13 factors affecting the accidents, including date, season, hour, position, tunnel length, collision type, number of accident vehicles, relationship with heavy vehicles, speed, unfavorable weather, roadside, traffic volume, and percentage of heavy vehicles. After studying the coefficients in relation to the independent variables, the researchers concluded that the risk of fatal accidents is reduced in summer and the summer has a little effect on the occurrence of other accidents. However, it seems that the probability of an accident is greatly reduced in the night hours. Also, from the viewpoint of location, most accidents occur at the entrances and exits of tunnels. In addition, the length of tunnel can affect the severity of accidents. When the weather is unfavorable, drivers increase their alertness and thus, the accidents are reduced [11]. Chatzimichailidou and Dokas (2016) introduced and used a method of self-awareness risk in the safety of road tunnels. The obtained values show the extent to which each tunnel is able to detect threats and damages based on the elements [12]. Bassan (2015) examined the dimensions and aspects of sight distance and horizontal curves in the design of tunnels compared to the roads. According to the findings of this study, due to the increased stress of drivers inside the tunnels, the stopping sight distance is reduced according to the emotional conditions expressed in the regulations. As a result, smaller horizontal curves are needed inside the tunnels [13]. Miller and Boyle (2015) evaluated the stress level of drivers in tunnels and similar conditions such as 75 m before entering the tunnel. The used data is based on the behavior of 50 drivers, including the heart rate changes and standard deviation of distances. The vehicle speed and braking are also recorded. The evaluation of the diagrams of vehicle speed changes shows that drivers tend to decelerate before entering the tunnel and they increase speed upon exiting. The stress level of driver also increases in the areas where the transition occurs from open to closed environment [14]. A number of studies have investigated the factors affecting the accidents in tunnels. Yeung and Wong (2013) studied the accidents of Singapore highway tunnels. The study examined 608 accidents occurred in three highway tunnels in Singapore between 2009 and 2011. Each tunnel was divided into three areas and the desired specifications were studied. The studies showed that there are more accidents in the transition areas than the areas inside, and the number of accidents occurred in the tunnel entrance is higher than the number of accidents occurred in the tunnel exit. Although most studies show that the RTA rate in tunnels is lower than that on open roads, the researchers believe that drivers tend to pay more attention when passing the tunnel as long as they are a small part of the entire length of the road network [15]. Calvi et al. (2012) studied the effects of road tunnels on the driver performance. This research focused on the driving in road tunnels and aimed to determine how to drive at the tunnel entrance and exit. In this paper, the effect of tunnels on the performance of drivers was analyzed using a driving simulator. The findings showed that drivers move away from the right wall of the tunnel and decelerate. In addition, inside the tunnel, due to the lack of information of the driver, more attention is paid to driving and traffic [16]. In a study using a simulation method similar to the previous study, Shimojo et al. (1995) studied the performance of drivers in long tunnels. In this paper, considering the finalized construction of Uchiura tunnel (with an approximate length of 27 km), the behavior of drivers based on the cross-sectional model of the tunnel was investigated. According to the studies, there is no clear relationship between the average speed of drivers in the tunnel and the average transverse distance. However, when the right shoulder is narrow (width of 0.7 m), more than 70% of tests show that the driver psychologically decides to move away from the wall. The studies also show that in long tunnels, the smart signs and warning signs should be placed every few kilometers [17]. One of the disadvantages of this research is the lack of comparison of simulation results with the reality. The research shows that this occurred due to the lower percentage of tunnel lengths than open roads, and if the percentage of tunnel lengths increases in the coming years, most drivers in the tunnels will no longer feel excited and the stopping sight distance will not be reduced. The road safety research in car tunnels is related to the tunnel safety in the Netherlands. This study also noted that in general, it cannot be stated that the accidents in tunnels are more than open roads.

However, the biggest difference between tunnels and open roads is the lighting at the entrances and exits. The road safety increases using the emergency lanes that keep a distance from the tunnel wall by reducing the longitudinal slope of the route, thus reducing the speed difference and creating wider lanes in the horizontal curves. In addition, the entrances and exits of the tunnels should be sealed using the best materials in terms of water penetration. According to the latest accident data in the past year, the number of accidents in tunnels is higher in terms of length than other parts of the road network. Tunnels account for less than 0.5% of the length of roads, but 1% of serious accidents occur in tunnels. The safety in tunnels increases by adding emergency lanes that increase the distance to the tunnel wall, gentler slopes (or separation of heavy vehicle traffic) that reduce speed difference, and curves of higher radii [1].

3. Methodology

3.1, Overview

The experiment was performed using 34 participants, out of which 30 people completed the steps. The cluster sampling method was used to determine the number of participants. If a complete list of people in the study population is not available, the people in the population can be grouped into clusters. Then, the clusters were randomly sampled and the entire volume of the cluster was counted. The experiment started from Salavat Abad Village and led to the same point. All tests were performed in October 2018 between 10.5 a.m. to 5 p.m. Figure 1 shows a view of the route under study and the location of five tunnels on aerial maps. In order to prevent the effect of test conditions on the driving style of participants, no information was given to the drivers about how to perform the test during the test. Figures 2 and 3 show a view of the entrance to the third and fifth tunnels. According to field studies, the roadway width on this route is about 0.7 m. The cross-section of the tunnels is quite similar and they were opened in 1982. No asphalt shoulder was considered due to the small width of this road.

3.2. Equipment

This study was performed using a Renault Logan model 2018 with a manual transmission system. The vehicle speeds were stored using GPS and MyTracks app version 1.0 and the diagrams were prepared.

3.3. Research process

The participants in the research meet the researcher in Salavat Abad village and the information is stored when they start moving. The beginning and end of the route intended for every driver are Salavat Abad village. The total round-trip route is about 21 km. The vehicle speeds are calculated and stored along the route.

3.4. Independent variables

In these studies, the independent variable is the vehicle speed changes based on the speed-time diagram, which are recorded and stored using MyTracks software. The speed changes are measured as a change in pressure on the brake pedal or the use of the accelerator pedal.

From the speed-time information, the speed difference for each participant is calculated from the moment the driver starts to decelerate before entering the tunnel to the moment of entering the tunnel, and it is stored as a variable of speed changes.

3.5. Dependent variables

The dependent variable of this research is the speed of entrance to the tunnel. The vehicle speed is calculated using the criteria and standard deviations of increased and decreased speeds for each participant in different sections of the road.

3.6. Data analysis method

In this study, the main variables of drivers' speed changes at the entrance to the tunnel are considered as independent variables and the speed of entrance to tunnel as a dependent variable, and the Pearson correlation analysis is used to investigate the relationship between the variables. The Pearson correlation analysis is used to examine the relationship between the two variables and the distance scale. The correlation tests are used to examine the relationship between two or more variables.

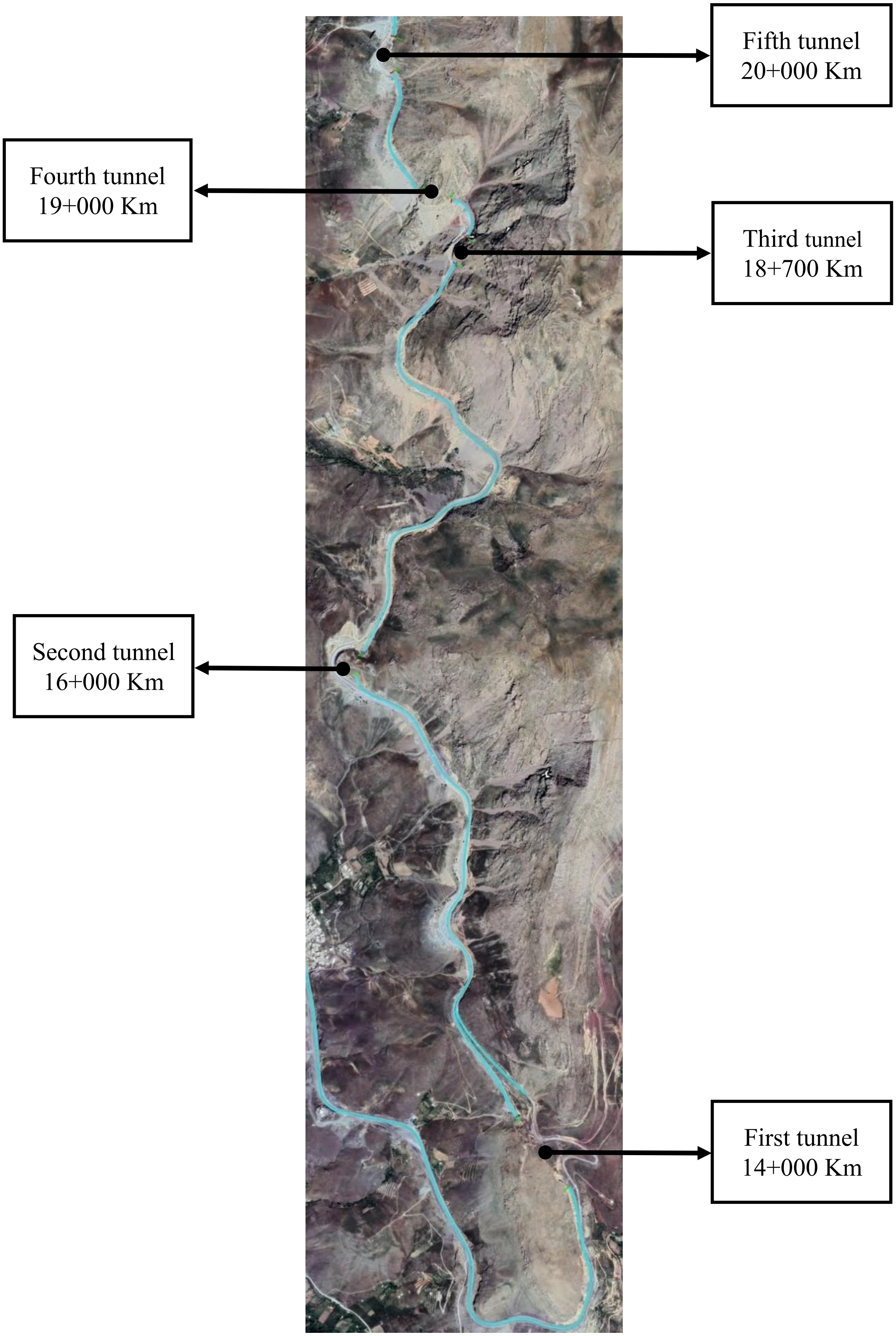

Fig. 1. View of study route [18].

Fig. 2. View of entrance to third tunnel.

Fig. 3. View of entrance to fifth tunnel

Correlation means the covariance of two variables from which it is inferred that the increase or decrease of one variable is associated with the increase or decrease of another variable. Correlation tests are divided into two categories: parametric and non-parametric tests. If the scale of the variables is an interval or relative scale and the variables have a normal distribution, the parametric correlation tests, such as Pearson correlation test, are used; otherwise, the nonparametric correlation tests are employed. The Pearson correlation coefficient is a parametric statistical test that indicates the degree of linear relationship between two variables. It is presented by Carl Pearson and is denoted by the letter r. It varies between +1 and -1 and the absolute value of the correlation coefficient indicates the intensity or degree of the relationship between the two variables and its sign (positive or negative) shows the relationship direction (direct or inverse). Pearson correlation coefficient is a symmetric index, meaning that the correlation between the variables X and Y is equal to the correlation between the variables Y and X. Finally, the collected data were analyzed using SPSS software.

3.7. ANFIS modeling method

In 1965, the theory of fuzzy logic was proposed by Professor Asgarzadeh to describe complex systems, which can be a powerful and flexible tool for modeling the uncertainties in the real world and expressing the linguistic expressions derived from human experience and knowledge in the form of mathematical relations. To model ANFIS, a variable is used as input. This variable is the vehicle speed changes. This variable is defined in 20 membership categories in the ANFIS toolbox of MATLAB environment.

The ANFIS model is based on the structure of the Sugeno fuzzy inference system using the subtractive clustering, which is analyzed using the ANFIS toolbox in MATLAB software. A schematic view of the designed ANFIS model is shown in Figure 5. The result of the ANFIS model is the speed of entrance to the tunnel, which is stored in the software as Speed. The best membership function was identified after examining various membership functions such as triangular, trapezoidal, simple Gaussian, compound two-way Gaussian, bell-shaped, sigmoid, differential sigmoid, S-shaped, and Z-shaped. Table 2 provides examples of ANFIS model inputs.

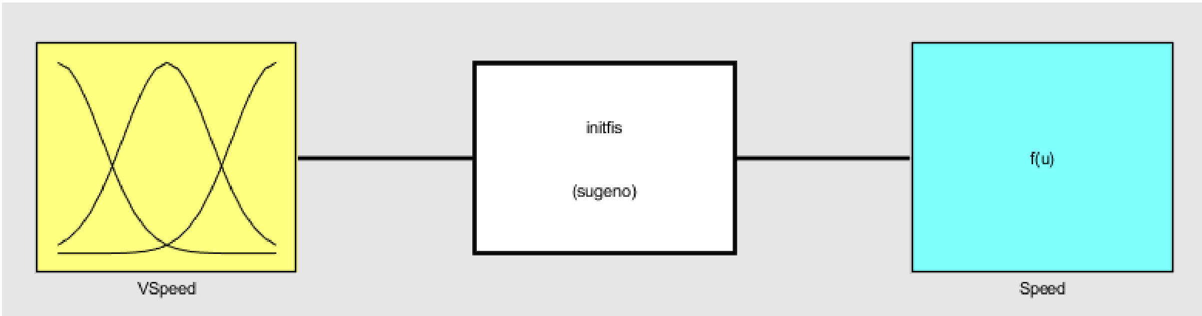

Fig. 4. Schematic view of developed ANFIS model.

Table 2. Examples of ANFIS model inputs.

	Speed changes before entering the tunnel	Speed of vehicles entering tunnels
1	31.7	33.56
2	30.75	43.90
3	29.72	43.47
⋮	⋮	⋮

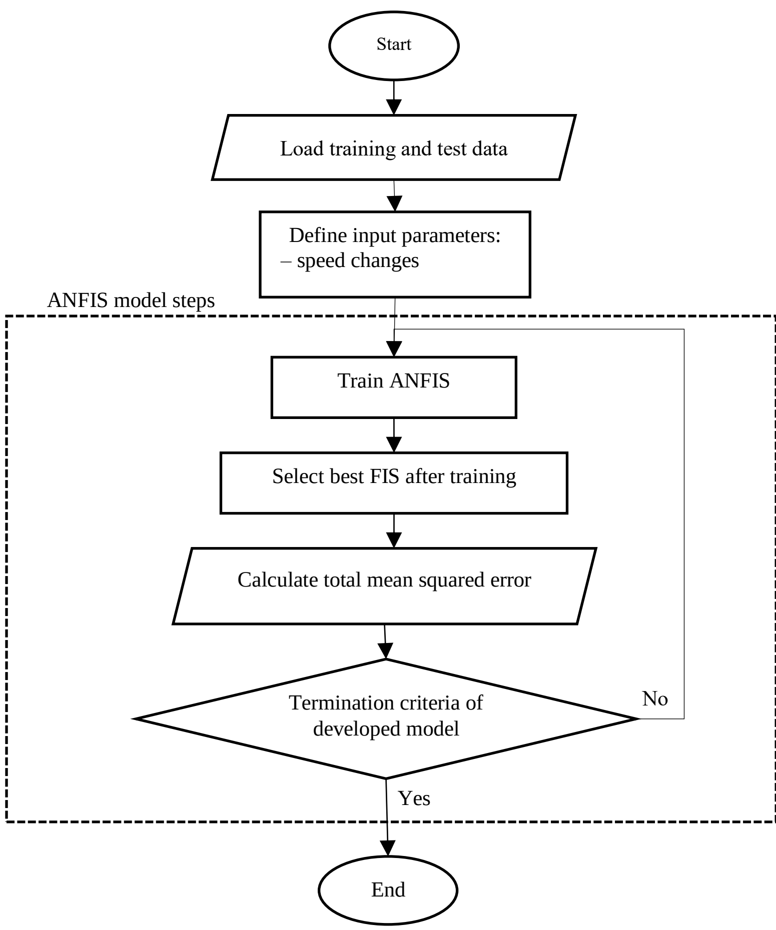

Fig. 5. Schematic view of research model.

4. Results

4.1, Statistical results

In this section, the statistical results of the research will be presented. Figures 6 and 7 show the average speed changes of drivers on the round-trip route in terms of time. The horizontal axis represents the time and the vertical axis represents the movement speed of the vehicle. In these diagrams, the transition sections before and after the tunnels are marked as dashed lines. The beginning of the transition range is determined based on the starting point of the vehicle deceleration and the end of the transition section after the tunnel is determined based on the point where the vehicle reaches the highest speed limit after the tunnel. The sections of the tunnel are also shown by gray hatching. In these areas, the driver reduced or increased the speed based on the geometric characteristics of the tunnel. In the both directions, the speed of the vehicles is significantly slower than that in other parts of the route. The speed of the vehicles increases significantly again after passing the tunnel.

4.2, Description of SPSS software results

The results show that the distance the drivers start to decelerate when they see the tunnel is much longer than the distance they increase speed after passing the tunnel. Also, the rate of speed the drivers reduce before entering the tunnel is greater than the rate of speed they increase. However, there is no warning sign in the movement direction of the drivers regarding the deceleration inside the tunnels.

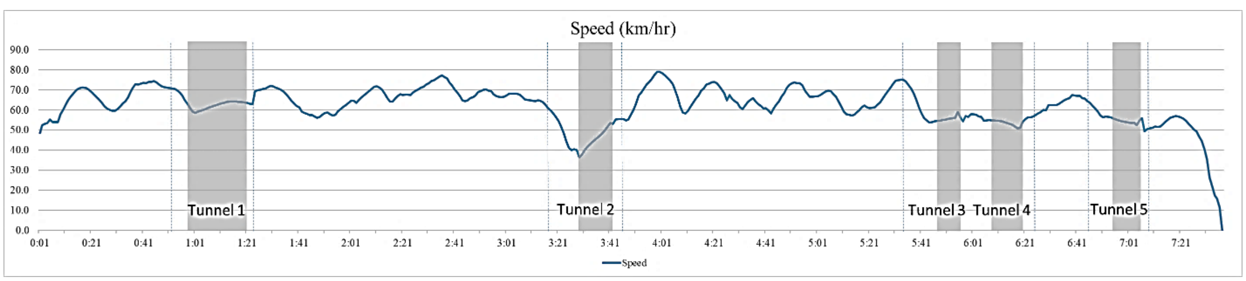

Fig. 6. Diagram of the average speed changes of drivers on the round-trip route in terms of time.

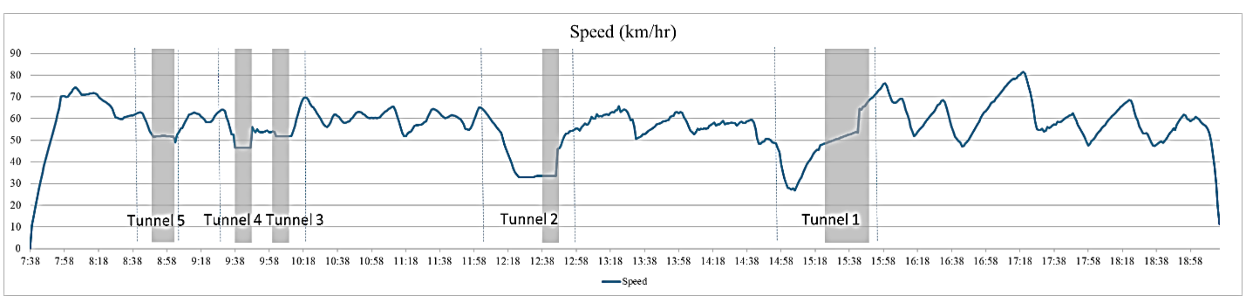

Fig. 7. Diagram of the average speed changes of drivers on the round-trip route in terms of time.

As a result, among the reasons for the significant reduction in the speed of drivers are entering a new environment, absence of shoulders, and sudden reduction of road width in the tunnels.

Table 3 shows the results of Pearson correlation analysis in SPSS software. As can be seen, a correlation matrix is provided for the two variables. According to Table 3, the correlation r between the two variables of the speed of entrance to tunnel and changes in vehicle speed before the tunnel is equal to -0.7, which is also statistically significant (p = 0.000). There is a double asterisk above the number -0.7, because this value is statistically significant at the 0.000 level. Due to the fact that the correlation coefficient is negative, it means that the correlation between the two variables is negative, that is, by decreasing the speed of entrance to the tunnel, the changes in the speed of entrance to the tunnel increases and vice versa. Based on the value of 0.7, it is concluded that the variables have a strong correlation.

4.3 ANFIS model results

Examining the performance of fuzzy inference system epochs in ANFIS to predict the speed of entrance to the tunnel according to the root mean square error (RMSE = 3.43) for the desired output variable, the type and number of optimal membership functions were determined for the input variables. The results show that the neuro-fuzzy network method has the ability to predict speed changes with a high accuracy based on the initial speed of entrance to the tunnel. Thus, the triangular function with 20 membership functions was selected as the optimal model for the output variable of the speed of entrance to the tunnel. To better evaluate and compare the performance of the prediction model of the speed of entrance to the tunnel, the diagram of best obtained output of the calculated RMSE is shown in Figure 8.

Table 3. The results of Pearson correlation analysis.

Variables	Speed of entrance to tunnel	
	r	p
Changes in vehicle speed before the tunnel	-0.7	0.000

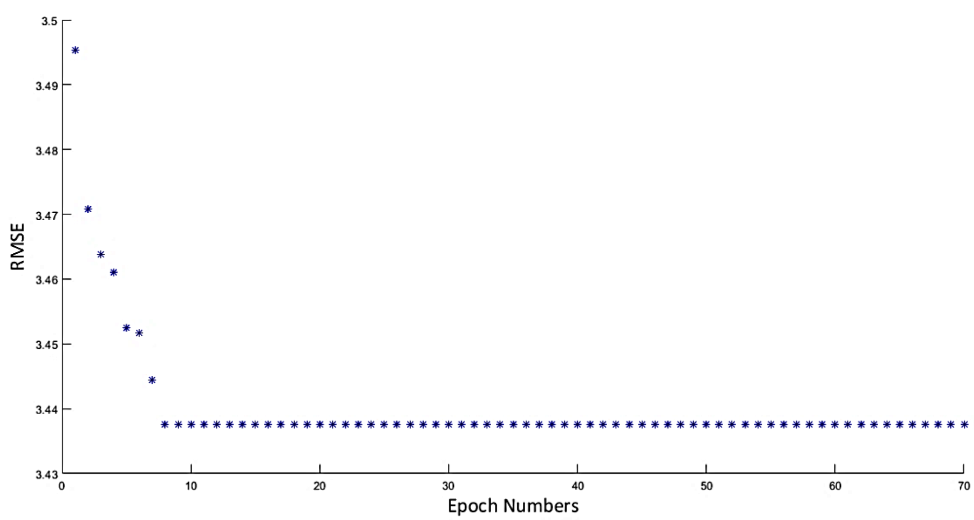

Fig. 8. Diagram of best obtained output of the calculated RMSE.

5. Conclusion

The purpose of this study was to investigate the driving performance in the area of tunnels. In this study, a length of 20 km from the beginning of the Sanandaj-Hamedan route was used, which has 5 two-lane round-trip tunnels. The speed of the vehicle is fully stored in the mentioned range.

Due to the negative value of correlation coefficient, there is a negative correlation between the two variables, meaning that with decreasing the speed of entrance to the tunnel, the change in the speed of entrance to the tunnel increases and vice versa. Based on the value of 0.7, it is concluded that the variables have a strong correlation. In this study, the speed of vehicles' entrance to the tunnel is modeled in the ANFIS toolbox of MATLAB software. According to the obtained results, the designed model with the presented root mean square error (RMSE = 3.43) is acceptable. The results show that the neuro-fuzzy network method has the ability to predict speed changes with a high accuracy based on the initial speed of entrance to the tunnel. The innovations of this research include the field measurement of vehicle speed in the tunnel area, calculation of speed changes in the mentioned area, and development of a model to determine the vehicle speed changes using the neuro-fuzzy network method based on the speed of entrance to tunnel. It is suggested to conduct a study in the future to compare the variables of this study with other variables affecting the drivers' behavior.

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