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HIGHWAY TRAFFIC ACCIDENTS PREDICTION USING ARTIFICIAL NEURAL NETWORK: A CASE STUDY OF FREEWAYS IN SPAIN

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Abstract: In recent years, Spain has witnessed a significant reduction in the accident rate, attributable to the improved behavior of road users. However, there remains a pressing need for enhancements in various areas. Notably, 2016 marked the first time in 13 years that the number of deaths increased by 7% compared to the previous year. This paper undertakes an analysis and prediction of road traffic accidents (RTAs) at severe accident locations on Spanish highways, employing Artificial Neural Networks (ANNs) with a Feedforward learning algorithm. This approach serves as a valuable decision-making tool for policymakers in infrastructure management, contributing to advancements in transportation safety research. The ANN, a potent technique with a track record of success in analyzing historical data to forecast future trends, is explored to predict the number of highway accidents in Spain. The paper proposes a method to select the most effective ANN model using accident data spanning from 2014 to 2017. The model incorporates variables such as highway sections, year, section length (km), annual average daily traffic (AADT), average horizontal curve radius, degree of vertical curvature, and traffic accidents with the percentage of heavy vehicles. In the development of the ANN model, the sigmoid activation function is employed in conjunction with the Levenberg-Marquardt algorithm, incorporating varying numbers of neurons. The results of the model indicate that the estimated traffic accidents, based on appropriate data, closely align with actual traffic accidents, making them suitable for forecasting traffic accidents in Spain. This underscores the potential of ANNs as a robust tool for analyzing and predicting traffic accidents and casualties.

INTRODUCTION

The number of traffic accidents in Spain have shown a great reduction in recent years as shown in Fig.1 mainly due to the improvement of the behavior of road users. According to , (DGT,2011-2013), this reduction is mainly due to the increase in the use of the helmet and the belt, the downward trend in the consumption of alcoholic beverages, better user behavior, improvement in infrastructure and the updating of the security systems of the vehicle fleet in spite of this, many areas such as the road and signaling conservation, reduction of speeding or distractions due to the use of mobile phones have still to be improved.

However, although the accident rate has been reduced in recent years, in 2016 for the first time since the last 13 years the number of deaths increased by 7% compared to the previous year (See Fig. 2). The cost in human lives of these traffic accidents justify the implementation of road safety policies as well as studies and methodologies that help to prevent accidents by identifying potential causes and identify the dark points were the infrastructure must be improved.

However, although the accident rate has decreased in recent years, in 2016 the Spanish General Direction of Traffic tries to further increase road safety. From the perspective of road owners and road safety managers, the understanding of the factors that contribute to a higher frequency of traffic accidents is of paramount importance. According to (Amos, L., Davies, D. and Fosdick, P.T., 2015), the tools included in the three Es (engineering, enforcement, and education) must be used to use to manage road safety. In fact, a good planification, a proper construction and a good maintenance of roads require in general the consideration of different fields influencing the occurrence of road accidents (e.g., human behavior, improvements in automotive manufacturing, weather among others).

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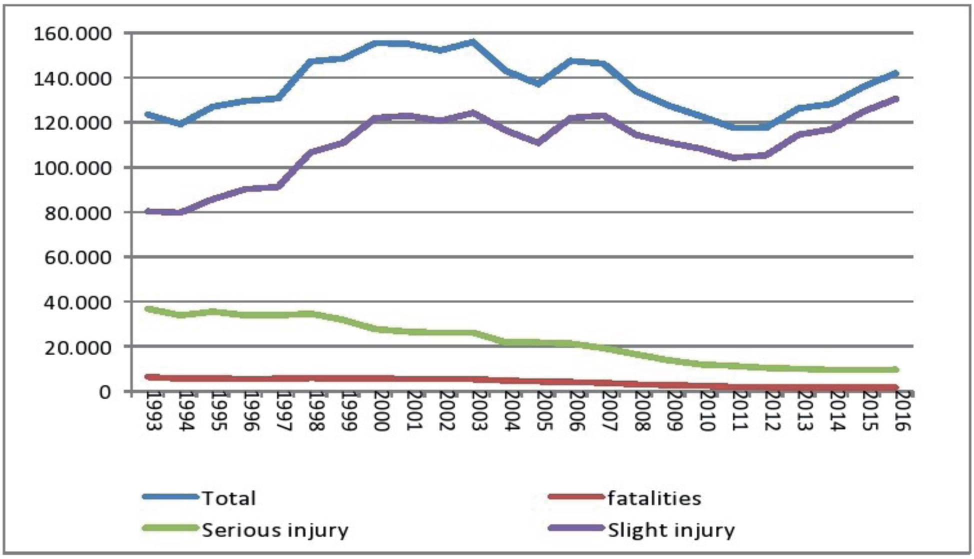

Fig.1. Number of Accidents (interurban and urban roads) in Spain. (DGT, 2017)

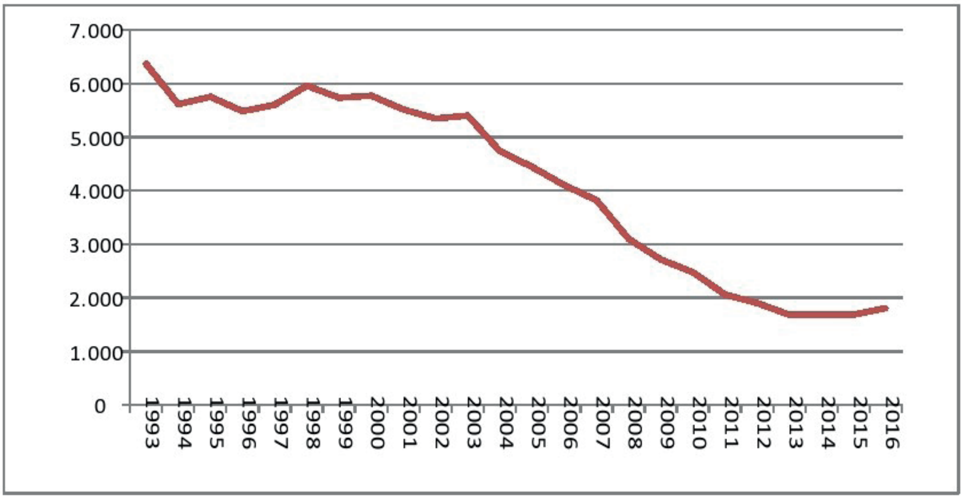

Fig.2. Number of fatalities (interurban and urban roads) in Spain. (DGT, 2017)

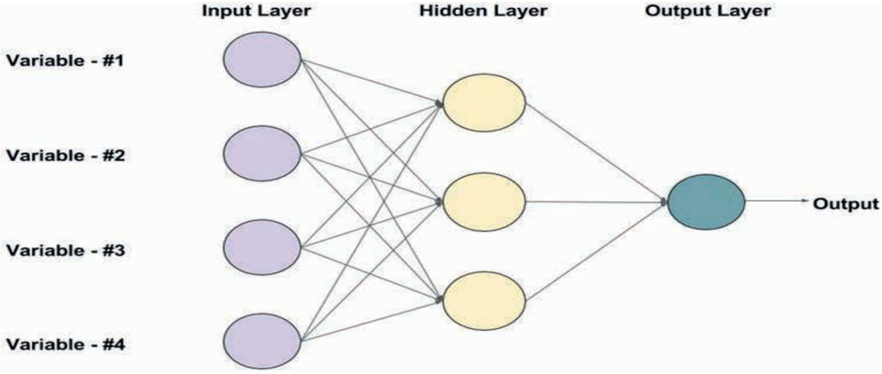

Fig.3. Typical layers in neural network

Many researchers have been worked in developing models for the prediction of traffic accidents in countries using various statistical techniques. However, the numerous variables and complex relationships between the characteristics of the various traffic elements require different analytical techniques than traditional ones. A recent approach to analyze these relationships is the artificial neural networks (ANN) that many scientists have proposed and used successfully as an alternative to conventional tools.

A regression method to predict time series accidents associated to complex atmospheric and environmental phenomena is presented in this paper. We propose and discuss the development of a prediction model to estimate future traffic accidents in Spain using the ANN approach.

ARTIFICIAL NEURAL NETWORKS AND APPLICATIONS

Artificial Neural Network is a subdomain of Artificial Intelligence (AI) system which has been used recently to solve many varieties of civil engineering problems. A neural network is an information processing prototype and a data-modelling tool that represents complex relationships based on those existing in the human brain. ANNs are known to be universal function approaches and can exploit nonlinear relationships between variables. Neural networks are a class of flexible nonlinear regression, data reduction models, and nonlinear dynamical systems. They consist of many neurons, i.e., simple linear or nonlinear computing elements, interconnected in often complex ways and organized into layers see for example (Byerly, S., Maurer, L.R., Mantero, A., Naar, L., An, G. and Kaafarani, H.M., 2021).

The fundamental element of this model is the novel structure of the information processing system. It is composed of extremely interconnected processing elements termed neurons. Every neuron has a value, weight, and bias (constant) where the neuron's net input is the value of the neuron multiply by the weight plus the bias.

Layers are composed by an input layer which contains the data to be classified by the network (independent variables), one or more hidden layers which do the processing, and an output layer which contains the desired output (dependent variable). Every layer contains neurons connected to each additional neuron in the preceding layer by a connection that represents the weight. An example of an ANN with its several layers is shown in Fig. 3 (see Balkin, S.D. and Ord, J.K., 2000).

Other important component of ANNs is the activation functions, also called transfer functions, that define the mappings from inputs to hidden nodes and from hidden nodes to outputs, respectively (see Beale, Mark Hudson, Martin T. Hagan, and Howard B. Demuth,1992)."ANNs have been applied effectively in solving many civil engineering problems related to classification, prediction, and function approximation. In the transportation area, ANN has many applications and when applied to predict speed, for example, (Yang J W Mcfadden and Durrans, 2000). "Found it to offer predictive power superior to those of regression models. This is mainly because of their ability to model non-linearity, and flexibility with large complex data sets.

Auxiliary applications include the work of (Chiou, Y.C., 2006) who used the ANNs in classification of severity levels of accidents and reported several applications of ANN in the transportation field particularly in the traffic safety area. (F Shoukry, F.N., 2005) employed ANN to develop an expert system for the appraisal of two-car accidents. (Wenhui. 2009). applied the ANNs technique to estimate traffic safety in China, and (B X Xu, Chen, and Gan. 2009) researched the

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evaluation of safety in traffic accident scene based on ANN.

The study of (Yasin Çodur, Muhammed, and Ahmet Tortum. (2015). presents an accident prediction model of Erzurum's Highways in Turkey using artificial neural network (ANN) approaches, were many ANN models for predicting the number of accidents on highways were developed using 8 years with 7,780 complete accident reports of historical data (2005-2012).

In (Akhdar, Sharaf, Madhar Taamneh, and Salah Taamneh. ,2017) data from 5973 traffic accident records that happened in Abu Dhabi (2008 -2013) were used to develop an ANN model for predicting the degree of injury in road traffic accidents, which had a predictive performance of about 74.6 % using the test set.

In (García de Soto, Borja, Andreas Bumbacher, Markus Deublein, and Bryan T. Adey,2018). an approach was presented to build an accident risk prediction model that can be used as a policy decision tool in infrastructure monitoring. The method allows for appropriate handling of existing data of the study that it can be used to develop models using artificial neural networks (ANNs) and creates a systematic optimization process to determine the optimal architecture of the ANN model. The study was conducted using data from accident counts for Swiss national roads (2009 -2012). It was found that ANNs can be used as a viable method for predicting the frequency of road accidents. Since the accident counts are exceptional events, the data were categorized by a large proportion of zero observations.

Many of agencies especially government agencies are facing problems to identify the factors that contribute to the accidents that occurred on certain critical roads or highways. The measurements to prevent accident are maybe from the speed reduction, widening the roads, speed enforcement, or construct the road divider, or other else. These different types of factors can be identified to prevent the accident on the critical roads or highways for the future. It also can help many of agencies such as Police, Public Work Department, Road Transportation Department and local authorities in investigation process, planning process or in remedy process for the road after accident. It comes into a serious part when all the road users or agencies cannot know the exact measurement of how the accident can be occur. There are also many of prediction model that has been developed to analyze the accident variables but none of them can analyze all the variables. It also difficult for other users to implement or use the model that has been developed due to hardly understands and it uses complicated mathematical model.

It is important to conduct this study to get all the variables as many as possible in developing the accident prediction model and to propose an accident prediction with improvement of accident statistical model. Artificial Neural Networks (ANN) model is usually used for prediction cases. By using ANN model, these factors can be determined by collecting the input data from the critical road or highway. The input data can be process by the ANN applied software to get the predict result for the forecasting purposes for the road or highway. This ANN applied software is also easy and ready to use for any level of users which they can implement or analyze all the parameters and accident data for the future prediction.

All the problems stated above showed that it is important to study the accident factors especially on highway route which having the high number of accidents increment every year. ANN will be the analyzing tool which it is one of the highly performance tools in developing prediction model. This study will propose an appropriate accident prediction model which can be use by any users that can help them in providing the safety precautions and future work for safety issues especially for related agencies and for the road users in the future

As we stated at the end of the previous section, most previous studies have used statistical methods, such as Logistic Regression Model, Negative Binomial Model, Negative Binomial Model, and Linear Regression Model. These methods are subject to hard assumptions and limitations in application. In contrast, ANN has been shown to be useful and effective in many areas. In the field of traffic safety, some studies have applied ANN to predict of traffic accidents on highways, but few have a large dataset. Therefore, the aim of this paper is to propose and apply the potential of neural network analysis to develop a model in transportation engineering using MATHALB software. The ANN model has been successfully expressed in the number of traffic accidents compared with the original dataset. r provides a methodology to develop ANNs uses sensitivity analysis to determine the influence of the different inputs to the number of accidents. This is useful to infrastructure managers because ANNs developed this way will not only help identify areas of high risk in road networks but help determine how the different inputs affect their occurrence, hence giving infrastructure managers a support tool to help during the decision-making process and modification of influential parameters within their control.

METHODOLOGY

DATA COLLECTION AND CASE STUDY

The data collected on the number of accidents covered a period of four years from 2014 to 2017 and refer to the road network of all Spanish provinces. Data on traffic accidents were collected by (DGT, 2011-2013). Each accident contains several pieces of information such as date, location of accident, type of vehicle, gender of driver, age of driver, type of accident, day and time, number of fatalities, number of injured, number of vehicles involved and number of damaged vehicles. In addition to these data, geometric characteristics of the highway such as 85th percentile speed, Annual Average Daily Traffic AADT, radius of horizontal curve, and slope gradiant in each section were collected from (DGT, 2011-2013). After removing the missing and incorrect data, these data were categorized with the variables presented in Table 1, the choice of input variables was based on expert opinion and previous research (Çodur MY, 2012)

Modelling nonlinear systems is more challenging than linear systems. The disturbances that affect the system significantly complicate the modelling task. Scientists have been working on modelling nonlinear systems for years, and they have succeeded in teaching nonlinear system dynamics to artificial neural networks without the need for mathematical modeling (Komati, S. Narendra, and Parthasarathy Kannan,1990), (Narendra, Kumpati S., and Snehasis Mukhopadhyay,1997) ,(Singh, Pankaj, and M. C. Deo,2007)

To analyses traffic accidents on highways, it is necessary to select highways that have a wide variety of geometric and traffic characteristics The aim of this data collection is to divide these motorways into segments with homogeneous (i.e., with the same road and traffic characteristic). After examining several freeways in Spain, the road was divided into sections and their names as follows, A-1, A-2, A-3, and A-4 according to (DGT, 2017)**,** these freeways with median are the most suitable for this task.

The highways selected with total of 655 km of freeway that connect around of Spain. These freeways are long enough to produce a satisfactory number of segments to develop the model. A-1, A-2, A-3, and A-4 were divided into 3, 4, 3, and 3 highway segments, respectively and defined by any change in the geometric and highway variables. So, each highway segment is uniform with respect to all the possible geometric and traffic features as Fig. 4. The highway sections are as follows:

Route A-1 that passes through Segovia, Burgos, Madrid (101 km).

Route A-2 that passes through Madrid, Zaragoza, Soria, Guadalajara (231 km).

Route A-3 that passes through Madrid, Cuenca, Valencia (163 km); and

Route A-4 that passes through Toledo, Sevilla, Córdoba (160 km).

DEVELOPMENT OF ANN MODELS

The proposed ANN models are multilayer feed forward ANNs (i.e., no loops in the network) with between two and ten neurons in a single hidden layer and the equal number of neurons in the output layer as the number of output variables. the number of neurons in the hidden layer (h_n) is different from 3 to 10, as advised by (A Blum,1992)

In the ANN model, independent variables are labeled as the input, and dependent variables are labeled as the output. Correlation analysis was performed to access the linear association between the variable. The results of the importance of variables relative to the number of accidents of the correlation analysis is shown in Table 2, the model results show that traffic volume (AADT) is the most important factor affecting the number of accidents on the highways with a high percentage (77%). The percentage of heavy traffic and the length of the section have almost the same effect as the second important parameter. The degree of horizontal curvature is the third most important factor, and the slope gradient % and percentage speed have little effect on the output factor.

As of the parameters applied in modelling, eight significant parameters were found based on those criteria. The following nonlinear model is proposed as follows:

$$y = f2\{[w2]f1\left[[w1]\begin{pmatrix} years \\ highway\ segments \\ section\ length \\ AADT \\ slope\ gradient \\ heavy\ vehicle\ traffic \\ horizontal\ curve \\ percentile\ speed \end{pmatrix} + [b1]\right] + [b2]\}y \tag{1}$$

Where: Y= the number of accidents, w1 and w2 are weight matrices and b1 and b2 are bias vectors.

Data sets were divided into three sets: the training set (70% of the total data), the validation set (15% of the total data) and the test set (15% of the total data), these phases were performed using MATLAB. Training algorithms do not use the validation or test sets to adjust network weights. The structural design of the ANN was as shown in Figure 5. A typical single-layer ANN (Fig.5) contains an input layer consisting of X number of input variables plus a bias, a hidden layer consisting of m number of neurons plus a bias and an output layer with the desired output. The neurons in the hidden and output layers are often referred to as processing neurons or processing elements. In addition to the normal neurons, there are also bias neurons (e.g., bias 1 and bias 2 in equation 1), which are used to help ensure that the model has a good fit with existing data. The connections between neurons in the ANNs are used to model the relationships between the neurons that is a change in the value of one neuron impacts the value of another neuron and, consequently, the value of the output. In addition to these elements, an ANN has an activation function.

The validation has been used to track the network's error performance, to identify the best network and to stop training if over-learning occurs. On the other hand, the test set was not used in training at all but is reserved to give an independent assessment

Variable	Variable Name	Code
X1	Year (2014-2017)	Categorical Value (2012-2013-2014-2015-2016-2017)
X2	Segment length (m)	Numerical Value
X3	Slope gradiant %	Numerical Value
X4	Radius of horizontal curve	Numerical Value
X5	AADT	Numerical Value
X6	Heavy vehicle %	Numerical Value
X7	85^{th} percentile speed (kph)	Numerical Value
X8	Highway Sections	Categorical Value (A-1, A-2, A-3, A-4)
X9	Freeway Segment	Categorial Value (A-1(Segovia, Burgos, Madrid), A-2(Madrid, Zaragoza, Soria, Guadalajara), A-3(Madrid, Cuenca, Valencia), A-4(Toledo, Sevilla, Córdoba))
Y	Number of Accidents	Numerical Value

Table 1. Input variables

(a) (b)

Fig. 4. Some section of Spain's freeway (a) for route A-3, (b) for route A-4

Variable name	Importance %
AADT	77 %
Segment length	53.4 %
Heavy vehicle percentage	50.3 %
Radius of horizontal curve	41 %
Slope gradiant	35.5 %
85^{th} percentile speed	22.7 %

Table 2. Importance of traffic accidents variables.

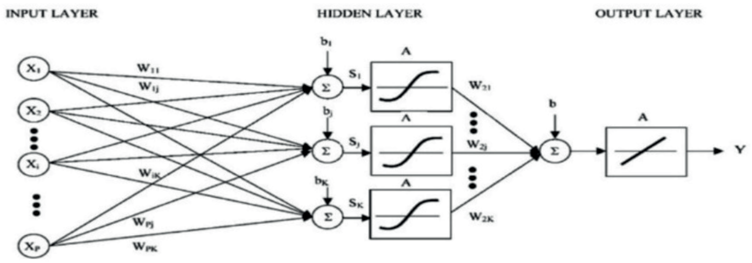

Fig.5. Structural design of the ANN (Mosa AL-Akhras,2019)

Model No.	Number of hidden neurons(h_n)in one hidden layer	Correlation Coefficient (r)
1	2	0.9668
2	3	0.9930
3	4	0.9772
4	5	0.9639
5	6	0.9900
6	7	0.9950
7	8	0.9871
8	**9**	**0.9992**
9	10	0.9927

Table 3. ANN models alternatives with different number of neurons

Segment Name	Actual (input)	Predicted(output)	Residual
Segovia(A-1)	9	40.783	-31.783
Burgos (A-1)	36	28.390	7.609
Madrid(A-1)	735	735	0
Madrid(A-2)	704	704	$-2.27e\text{-}^{13}$
Zaragoza(A-2)	325	325	$5.68e^{-14}$
Soria(A-2)	38	38	$-1.27e^{-13}$
Guadalajara(A-2)	183	183	$-5.68e^{-14}$
Madrid(A-3)	543	534.093	8.906
Cuenca(A-3)	42	42	$2.842e^{-14}$
Valencia(A-3)	481	481	0
Toledo(A-4)	209	209	$-8.526e^{-14}$
Sevilla(A-4)	62	53.445	8.554
Córdoba(A-4)	228	228	$-5.68e^{-14}$

Table 4. Actual and predicted number of accidents by ANN for four years (2014-2017) for model 8.

	Actual	Output
Mean	276.538	277.054
Standard deviation	247.245	258.917
Minimum	9	28.39
Maximum	735	735
R- Squared	0.9992	
MSE	93.887	
RMSE	9.689	

Table 5. Summery of Result and information criteria of the model

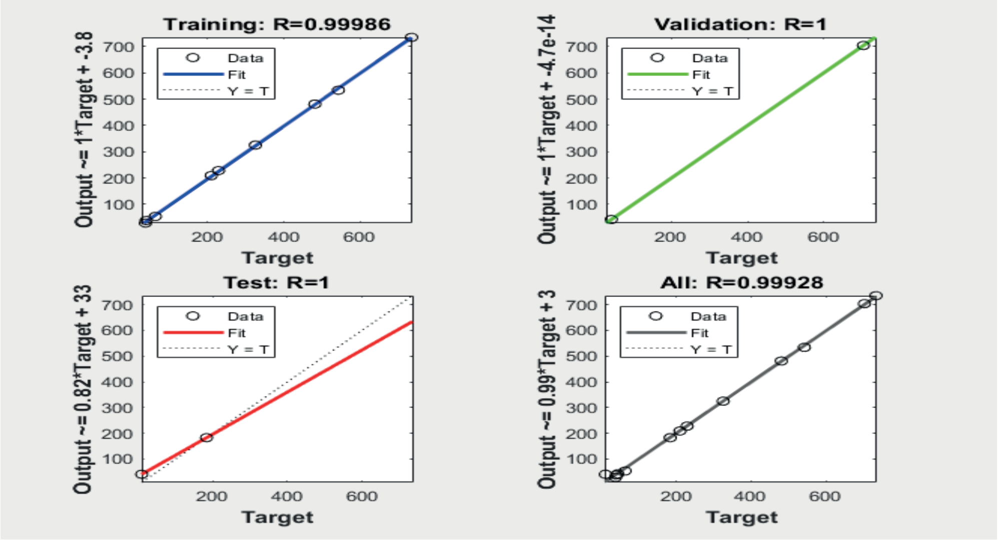

Fig.6. Model Number 8 Output

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of the network's performance when an entire network design procedure is completed. Lastly, we have selected the Tan-sigmoid for the input hidden layer. The main reason why we use sigmoid function is because it exists between (0 to 1). Therefore, it is especially used for models where we must predict the probability as an output. The logistic sigmoid function can cause a neural network to get stuck at the training time, and a linear transfer function for the output hidden layer because it a simple feedforward neural network with three layers the input, hidden and output layer as showed in Figure 5.

ASSESSMENT OF ANN MODEL

The coefficients of determination (R^2), mean square error (MSE) and the root mean square error (RMSE) are the criteria used in this paper to estimate the performance of the ANN model. They are defined as follows:

$$MSE = \frac{\sum_{i=1}^{n} (actual - forecasted)^2}{n} \quad (2)$$

$$RMSE = \sqrt{\frac{MSE}{n}} \quad (3)$$

RESULTS

The ANN allow the development of different alternatives by changing the number of hidden neurons in the hidden layers. Nine alternative models with different numbers of hidden layers were considered and Table 3 summarizes the results. Model 8 was proved to be the best model with the highest coefficient of determination (R^2 =0.9992). A comparison between the actual and the predicted number of accidents using Model 8 yielded the results shown in Table 4. The results were very satisfactory, with relatively small residuals, especially in recent years when more reliable databases are available due to the use of more advanced data collection techniques.

To determine the performance of the model ANN, the comparison of the model prediction performance between the actual and output results is examined using the residual difference between the actual accident count and the predicted accident count for each highway (residual) in Table 4. The conclusion summary includes minimum, maximum, mean, and standard deviation for the target, output and R-squared parameters of the tested network given in Table 5. R^2 is used to measure the degree of fit. For a perfect fit, R^2 would be approximately equal to 1, for a very good fit it will be close to 1 and for a poor fit it would be close to 0. In the model ANN, R^2 is 0.9992. considering the low values of the MSE, RMSE and high values of R^2 in ANN, the dominance of the model is clear. In the model ANN, the values of MSE and RMSE s are 93.887 and 9.689 respectively. This shows that the ANN model is a suitable method for the analysis of road traffic accidents.

In the analysis, the ANN model number 8 output R-Squared for training set validation and test set as shown in Figure 6. where there are four shape for training sets ,validation ,test as well as all sets together

CONCLUSION

This study focuses on analyzing factors contributing to accidents and aims to develop an Artificial Neural Network (ANN) model capable of predicting accidents. Implementation of this tool by traffic and transportation authorities has the potential to enhance highway safety and mitigate injuries. The database for this analysis incorporates geometric characteristics of highway sections and traffic accident reports spanning the years 2014 to 2017.

Utilizing ANN as a forecasting tool, the study demonstrates its flexibility and ability to evaluate various aspects of traffic accidents. Notably, the ANN model accurately predicted the number of accidents on routes passing through Madrid (A-2), matching the actual count of 735 with a residual value of 0. This underscores the efficacy of ANN as a reliable technique for accident prediction.

The assessment of the ANN model reveals low Root Mean Square Error (RMSE) values and high R2 values, indicating the model's superiority. Correlation analysis highlights the significance of traffic volume (AADT), with a substantial 77% impact on the number of accidents on highways. These findings provide valuable insights for policymakers, transportation system designers, and researchers.

The study emphasizes the need for a multidimensional perspective in evaluating problems related to traffic safety. Rather than focusing solely on specific factors, such as incremental changes, planners should consider a variety of geometric and traffic characteristics. Additionally, researchers can leverage advanced techniques like neural networks to analyze and understand the complexities associated with these variables.

DATA AVAILABILITY

Data used to support the findings of this study are available from the corresponding author upon request.

CONFLICTS OF INTEREST

Authors declare that there are no conflicts of interest regarding the publication of this paper.

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