TRAFFIC COLLISION TIME SERIES ANALYSIS (A CASE STUDY OF KARAJ–QAZVIN FREEWAY)

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ABSTRACT:

The application of Auto-correlation Function (ACF) and Partial Auto-correlation Function (PACF) in recent years has been improved in analyzing big traffic data, modelling traffic collisions and decreasing processing time in finding collision patterns. Accident prediction models for short and long time can help in designing and programming traffic plans and decreasing road accidents. Based on the above details, in this paper, the Karaj-Qazvin highway accident data (1097 samples) and its patterns from 2009 to 2013 have been analyzed using time series methods.
In the first step, using auto correlation function (ACF) and partial auto correlation function (PACF), the rank of time series model supposed to be autoregressive (AR) model and in the second stage, its coefficients were found. In order to extract the accident data, ArcGIS software was run. Furthermore, MATLAB software was used to find the model rank and its coefficients. In addition, Stata SE software was used for statistical analysis. The simulation results showed that on the weekly scale, based on the trend and periodic pattern of data, the model type and rank, ACF and PACF values, an accurate weekly hybrid model (time series and PACF) of an accident can be created. Based on simulation results, the investigated model predicts the number of accident using two prior week data with the Root Mean Square Error (RMSE) equal to three.

1. INTRODUCTION

The growing trend of traffic accidents is considered a serious public health problem in most countries of the world (World Health Organization, 2013 ; World Health Organization, 2004). Traumatic injuries are the primary cause of death, disability, hospitalization, as well as the economic loss worldwide (Peden, 2004). In some cases, the causes of accidents in some countries are proportional to the rapid economic growth, which include the rapid increase in the number of motor vehicles, increased exposure to hazardous factors such as speed and alcohol consumption, as well as inadequate traffic safety laws (Chisholm et al., 2012).
Accordingly, given the costly and unwanted cost of traffic accidents in developed and developing countries, it is quintessential to control the occurrence of such events. In Spain, for example, in 2008, the socio-economic costs of traffic accidents amounted to 0.04% of the gross domestic product (Alemany and Guillén, 2013). Moreover, the deaths from traffic accidents in Iran have declined in recent years, and in a study by Bahadorimonfared et al., about 19,000 deaths were reported in 2012 (Bahadorimonfared et al., 2013). According to statistics released by the Iranian Center for forensic examinations, the number of road accident victims in 2014 reached 16872 individuals, which is related to traffic accidents. Therefore, the deaths from traffic accidents in Iran are one of the most important priorities of the state health system (Naghavi et al., 2013). Despite the efforts made in the area of traffic accidents in Iran by Ministry of Health and Medical Education, the Police and the Ministry of Roads and Urban Development, we still see a lot of deaths and financial losses. Therefore, identifying the effective factors in traffic accidents and analyzing the severity of injuries could help reduce traffic accidents and losses.
Many studies have so far been conducted in Iran and the world on the factors affecting the deaths from traffic accidents. These studies have been in areas such as human behavior, road safety, vehicle safety, traffic management, all of which ultimately reflect the requirements for reviewing and drafting laws and regulations and their implementation. Any action in the area of traffic safety is enforceable by establishing a new law or enforcing a current law (Brsharma, 2006). Since 2007, losses due to traffic accidents on the roads in Iran have been declining (Bahadorimonfared et al., 2013). This decreasing trend is considerable when 15% of growth and increase in the production of vehicles is taken into account. On the other hand, it should be noted that middle-income countries are exposed to the greatest damage. One of the factors reducing the mortality rate from traffic accidents is the identification of human risk factors and prioritizing them to provide a general framework for reducing traffic accidents and resulting losses.
Accordingly, the main objective of this research was to investigate the traffic accidents and consequent traffic accidents using Karaj-Qazvin highway data (study area) and time series

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analyses based on spatial information system (hereafter, GIS). The novelty of this study is to provide a model of traffic collision data model with mean square error of incidents, using GIS on a weekly scale, taking into account the trend and period components, ACF and PACF in a combined method (time series and PACF). In the following sections, review of the related literature is examined. Then, the time series function model is explained. Then, the study area and the data used in this research are introduced. Next, the time series analysis and the determination of sample statistics will be explained. Finally, the conclusion of this study is presented.

2. LITERATURE REVIEW

Pollak, Peled, and Hakkert (2014) studied four Poisson statistical models for traffic accidents and estimated the best model for estimating the probabilities in terms of future risk recovery in road sections. In their study (2014), the contribution of each of the transport parameters and spatial parameters as the predictors of road accident rates was investigated (Pollak et al., 2014).

Using the Bayesian method, Zeng et al. (2017) calculated the severity of accidents with the correlation of the involved parameters and compared them with other methods (Zeng, et al., 2017).

Wang, Quddus and Ison (2013) made spatial and temporal analyses in England in the period 2003-2007 by developing a model of the negative binomial randomization model and Bayesian hierarchical classification and effecting speed (Wang, et al., 2013).

Zong, XU, and Zhang (2013) compared the two modeling techniques namely the base network and regression model. In the analysis of the severity of the events, they investigated three indicators of severity, the number of deaths, and the number of property damage, using the two methods and identified the main component of these factors and their effects (Zong et al., 2013).

Vahidnia, Vafaeinejad and Shafiei (2019) investigated for solving the problem in discrete spaces. Several experiments were conducted and perfectly acceptable convergence, accuracy, performance and stability were observed using this approach (Vahidnia et al., 2019).

Singh, Sachdeva and Pal (2016) studied road traffic accidents in five models during a period of 2 to 6 years on various sections of the eight national highways and the Indian Haryana (220 data) (Singh et al., 2016).

Aghakhani, Nasrabadi and Vafaeinejad (2018) Model performance was evaluated by using time series visual comparison plots and statistical indicators of Nash-Sutcliffe (NS) and the coefficient of determination (R2) (Aghakhani et al., 2018).

Saha et al. (2015), using the BRT method, made an attempt to find out the effect of each prediction variables on a two-stroke urban road accident and a 4-line road between urban areas for accident data from 2008 to 2012, in Florida. The results of the study showed that the BRT model with more branches had better results than BRT models with conventional branches (Saha et al., 2015).

Using Moving Average Autoregressive Probability models, Noobakht, Safari, and Sharifi (2016) modeled the time series of the daily position of the LLAS permanent station in the Southern California region for seven years. Singh, Sachdwa, and Pal in their research estimated geodetic parameters such as linear trend, annual and half-year volatility, as well as offsets simultaneously for the LLAS permanent station. In this study, auto correlation function and partial auto correlation function were used as study tools for identifying the time-series behavior of the daily position of the GPS station and it was possible to examine the dependency of daily data of the time series of the situation (Nobakht et al., 2016).

Ebrahimi et al. (2016) determined the factors affecting the production of urban waste such as population, urban growth, GDP index, and the relationship between them using the GEE model. Finally, the amount of waste produced by the city of Isfahan was predicted using the VENSIM software dynamic method and the time series method with ARMA technique (Ebrahimi et al., 2016).

Rasekh and Vafaeinezhad (2012) assigned the rescue of resources (Rescue Groups) to operational areas is of great importance to disaster managers. This paper presents a Decision support system based on Geographic Information System (GIS) and queuing theory in order to determine the resource allocation of an operational area (Rasekh and Vafaeinezhad, 2012).

In another study, using three self-explanatory approaches, the artificial moving average of the artificial neural network and the hybrid model of self-explanation of the seasonal moving average in combination with the post-propagation error algorithm were used to model and predict the drinking water consumption in the city of Rasht. In this regard, the monthly water consumption period of Rasht was used from 2001 to 2008. In the above method, a single root test method was used to create SARIMA pattern (Mousavi et al., 2016).

Fallahati, Barati and Jazairi (2016) investigated environmental temperature changes in the city of Arak using MINTAB software and Bartlett tests, first-degree autocorrelation, t Student, Mann-Kendall, Pearson correlation coefficient and nonparametric Spearman. After determining the type and range of the time series model, the prediction was made using the data of the first 40 years for the next 10 years with the estimation of the parameters of the AR model and the calculation of the residual values (Falahati et al., 2016).

Boroujerdian and Ebrahimi (2017) studied the speed variations in rainy and sunny weather conditions. They evaluated the results using the polynomial regression analysis and validation of the data through statistical tests. Traffic and rainfall data used in the research were for the last 6 months of 2012 (Boroujerdiyan and Ebrahimi, 2017).

Ainy et al. (2017) calculated the cost of injury and deaths caused by traffic accidents in 2013 using Bayesian analysis using the willingness to pay method. 782 people were selected and examined in this model (Ainy et al., 2017).

Yang and Loo (2016) examined several ways of detecting hazardous spots on the road and obtained their spatial distribution using different land uses in Hong Kong (Yang and Loo, 2016).

In the study carried out by Yin and Shang (2016), a predictor of multivariate time series was discussed using an intelligent learning model with the nearest neighboring method and non-parametric regression model (Yin and Shang, 2016).

In addition to the above research, time series methods have been developed in the field of route, navigation, and road that demonstrate the functionality and flexibility of the time series as a modeling method in this area. For example, Vafaeinejad et al. (2009) pointed out that using the time series, the events of the aid chain were modeled in an earthquake event (Vafaeinejad et al., 2009).

In a completely different work with the previous research, Vafaeinejad (2018) used the time series to update on the moment of a dynamic GIS navigation system. The time series in this study was used to find the optimal path as a feature (Vafaeinejad, 2018).

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Vafaeinejad (2017) used the application of the time series for automotive vehicle guidance. Predicting future events and routing based on the current situation and predicting the future based on time series would make this system more efficient than similar methods (Vafaeinejad, 2017).
Bolouri et al. (2018) used the time series to predict and simulate fire events and then evolutionary algorithms (genetics and annealing) for optimal fire station location. In this research, time was the modeling variable and the minimization of the time to arrive at the accident site was the cost function variable of the evolutionary algorithms (Bolouri et al., 2018).
In this research, the time series analysis method (functional and statistical model analysis) by analyzing the classified data of the study area is based on the spatial information system for Karaj-Qazvin Provinces to investigate traffic accidents and resulting losses. It shows the time series behavior of classified data at different time scales daily, weekly and monthly using MATLAB software. In the weekly scale of time series analysis, the existence of trend and period components, the type and rank of model and ACF and PACF are investigated. Finally, we could use it to categorize the traffic accident data model. In addition, the partial-proximity correlation functions and the study of the components of trend and time on the weekly scale, which have not been observed with the form used in this study based on the search made in other studies, is the innovation of this research.

3. TIME SERIES

In recent years, competition for better prediction of values in time series has led to a variety of methods in this regard. Time series is one of the branches of statistics and probability in other disciplines such as economics, communications engineering, whose application is abundant. Time series analysis was theoretically and practically predicted and developed rapidly since George A.P Box and M. Jenkins started their work in the 1970s, named a time series analysis (Mbamalu and El-Hawary, 1993).
Time series are sets of observations arranged in time, such that a string of data is based on time t as x (1), x (2),. . . , x (t), and then the values of x (t + 1), x (t + 2), etc. must be obtained. Finding this time-dependent structure is the most important goal. Now a set of possible patterns is expressed for time series, which we call random processes.

3.1 Moving Average Processes

Suppose that $\{z_t\}$ is pure random process with a mean of zero and variance δ_z^2. In this case, $\{X_t\}$ is said to be moving average process of q, if

$$X_t = \beta_0 Z_t + \beta_1 Z_{t-1} + \beta_2 Z_{t-2} + ... + \beta_q Z_{t-q} \quad (1)$$

Where $\{\beta_i\}$ are fixed, we usually scale the Z. In which $\beta_0 = 1$ because they are Z_i independent, therefore: (2)

$$\begin{aligned}\gamma(k) &= Cov(X_t, X_{t+k}) \\ &= Cov(\beta_0 Z_t + ... + \beta_q Z_{t-q}, \beta_0 Z_{t+k} + ... + \beta_q Z_{t+k-q}) \\ &= \begin{cases} 0 & k > q \\ \sigma_z^2 \sum_{i=0}^{q-k} \beta_i \beta_{i+k} & k = 0,1,...,q \\ \gamma(-k) & k < 0 \end{cases}\end{aligned}$$

Because $\gamma(k)$ does not depend on t and the mean is constant, therefore, for all the values of $\{\beta_i\}$, the second-order stacking process, the auto correlation function of the moving average process is given as equation ۳ below (North, Pyle and Zhang, 2015).

$$\rho(k) = \begin{cases} 1 & k = 0 \\ \sum_{i=0}^{q-k} \beta_i \beta_{i+k} \Big/ \sum_{i=0}^{q} \beta_i^2 & k = 1,...q \\ 0 & k > q \\ \rho(-k) & k < 0 \end{cases} \quad (3)$$

If we look closely at these relations, we see that the auto covariance function is interrupted at a delay of q. Inclusion of the condition of inversion assures us that for each function of the auto covariance, there is a unique moving average process.

3.2 Autoregressive Processes

Suppose ξ_t (term of error) is a pure random or mean zero and variance δ_z^2, then $\{X_t\}$ process is a p-rank autoregressive process if: (4)

$$X_t = \alpha_1 X_{t-1} + \alpha_2 X_{t-2} + ... + \alpha_p X_{t-p} + \xi_t$$

In this case, since X_t is not fitted on independent variables, but is estimated on past values of X_t, it is therefore called auto-regressive. We present an autoregressive p order, AR (P).
In this model, the value of X_t is a linear combination of the most recent p of its past, plus a turmoil sentence (term of error) that prescribes anything new at time t, which is not expressed by the previous values, in this way we assume that $_t$ ζ is independent of X_{t-1} and X_{t-2} ,. . . .. Note that ζ_t has white noise characteristics. This process can also be calculated by using the backward operator (Frunza, 2016).

3.3 Compound Patterns

An important class of patterns for time series is those that are composed of a combination of AR and MA processes.
A composite auto regressive-moving mean process, including P sentences AR and q sentences MA is called (p, q) order.
(5)

$$X_t = \alpha_1 X_{t-1} + \alpha_2 X_{t-2} + \ldots + \alpha_p X_{t-p} + \xi_t + \beta_1 \xi_{t-1} + \ldots . + \beta_q \xi_{t-q}$$

In this process, the terminology ξ is a pure random process (white noise).
The importance of ARMA processes lies in the fact that often a static time series can be expressed with an ARMA pattern, which has fewer parameters than the MA or AR process alone.

3.4 Integrated Patterns

In practice, most time series are non-static. In order to fit static patterns, removing resources that cause non-static is essential. If the time series is non-stationary, then we will divide the series until it becomes static.
For non-seasonal data, usually the first-order difference is sufficient to reach the apparent standpoint, so that the new series $\{y_i\}$ is formed from series $\{X_j\}$ with $Y_t = X_{t+1} - Xt = \nabla X_{t+1}$. The first-order differentiation is widely used in economics. Sometimes the second-order differential is required for which the operator T^2 is used (Grami, 2016).
Therefore, if we replace X_t with $\nabla^d X_t$ in the equation, then we have a pattern that can express some non-static series. Such a pattern is called an "integrated pattern," because the static pattern that is matched to the differentiated data must be summed up to fit a pattern for non-static data. If we write: $W_t = \nabla^d X_t$
The overall moving average of the integrated autoregressive is as follows: (6)

$$W_t = \alpha_1 W_{t-1} + \alpha_2 W_{t-2} + \ldots + \alpha_p W_{t-p} + \xi_t + \beta_1 \xi_{t-1} + \ldots + \beta_q \xi_{t-q}$$

This process of ARIMA, which indicates the d-order of the data fragmentation, is called (p, d, q) order. In practice, the value of d is often considered one (Grami, 2016).

4. CASE STUDY

Tehran-Karaj Highway is a three-way freeway per path. The purpose of this highway is to connect Tehran and its western suburbs and the overcrowded population of Tehran in the western suburbs. This freeway is experiencing its fifty-one anniversary on December 20, 2017. It reaches Qazvin Province, and then branches off, one to Rasht and the other to Takestan and Zanjan (Shown in Figure 1).

4.1 Required Information

In this study, traffic accident data was investigated on one of the major contributing axis of Iran in Karaj-Qazvin axis from 2009 to 2013 using time series analysis (1097 records). This information is based on the traffic collision days released by Iran Road Maintenance and Transportation Organization. Until now, the updated information of this research has not been available.

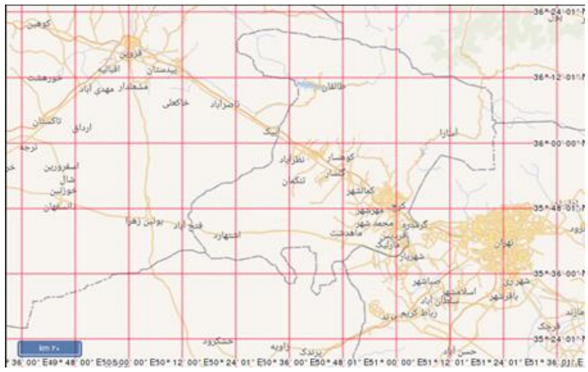

Figure 1. Location of the Karaj-Qazvin Freeway

Using the MATLAB software, data collected on a daily basis (Sunday, Monday, Tuesday, Wednesday, Thursday, Friday and Saturday) were plotted based on the average number of accidents as shown in Figure 2.

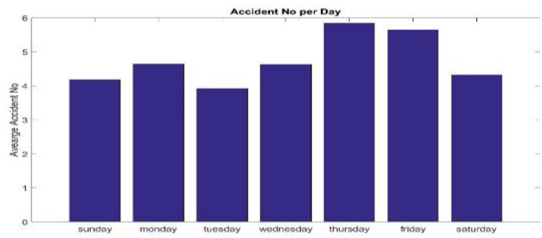

Figure 2. Number of collisions on a daily scale

4.2 Data Classification

Using the MATLAB software, the data in the study area was classified based on a spatial information system in 1097 records of the given data.
Investigation and analysis of the predicted traffic accident model have been performed on two weekly scales (Figure 3), including 155 weeks and monthly scale (Figure 4), including 35 months.

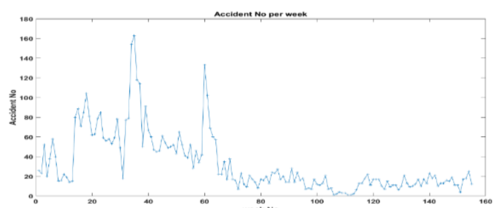

Figure 3. Number of collisions on a weekly scale

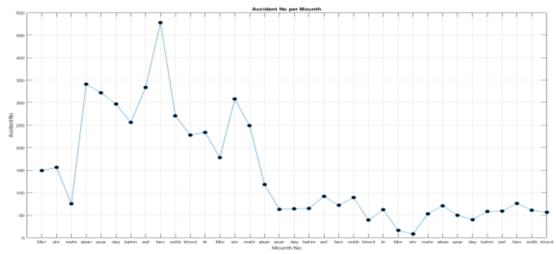

Figure 4. Number of collisions on a monthly scale

In Figures 3 and 4, the data are studied on a weekly and monthly scale, which shows the norm of the data from the 70th week (Figure 5).

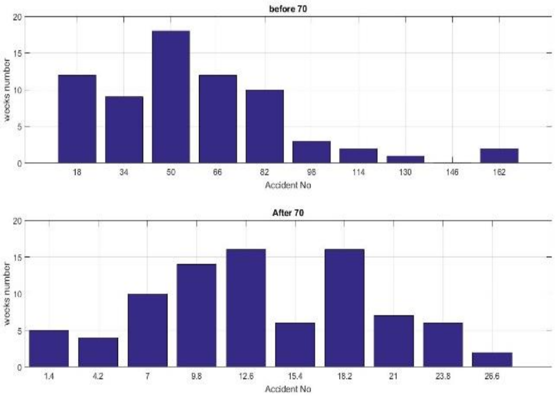

Figure 5. Number of collisions on a weekly scale (before and after the 70th week)

5. RESULTS AND DISCUSSIONS

5.1 Analysis of the time series and determination of the sample statistics

The first step in analyzing time series is to draw data. First, the data of the studied area based on the spatial information system of the time series from the 70th week were drawn up in accordance with Figure 6 and the number of sample statistics was obtained.

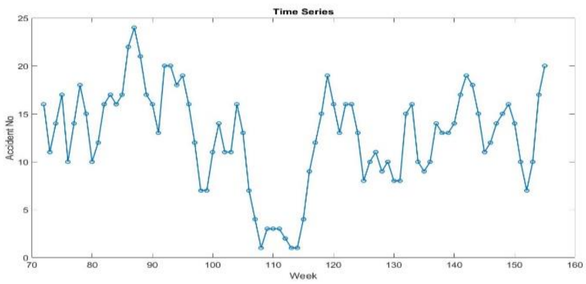

Figure 6. Time series related to the number of collisions since the 70th week

After drawing the time series curve, in the first stage, the values of the data statistics were determined (Loucks, et al. 2005).

5.2 Investigation of the trend and period components

The second step in the analysis of time series is to determine the trend component in the time series and to remove it to make the data static. After the data is made static, the appropriate models are fitted. The software adjusts a line to the data to determine the trend component.

The slope of this line is equal to the trend component. Obviously, if the slope of this line is zero and the line is horizontal, the data lacks trend component and is therefore static (Chatfield, 2016). By examining the data, it was clear that the data has a downward trend.

The equation of the fitted line is as follows: (7)

$$y = -0.028x + 16$$

This equation is an approximate non-static model. Therefore, it is not necessary to convert the existing time series to the static series.

Based on the current trend, the data over time can be reduced as shown in Figure 6, which indicates that the number of accidents has experienced very little downward trend over time.

There is no periodic mode in this series, because there is no obvious duplicate pattern in Figure 7.

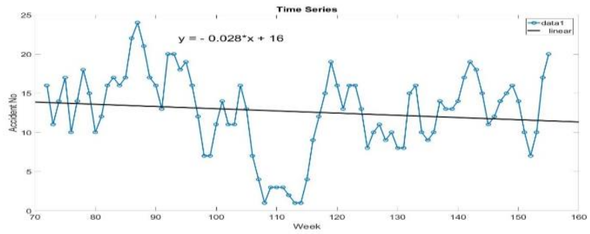

Figure 7. Time series related to the number of collisions on a weekly scale

5.3 Results

To determine and identify the type and rank of the model, it should first be judged on the ACF charts and partial ACF. Typically, AR, MA and ARMA models are selectable. The reason for the widespread use of these models can be related to their ability to create a correlation between the values of the present time and the earlier times, as well as the simplicity of the structure of these models.

5.3.1 Investigation of ACF and partial ACF: A method for expressing time dependence in the structure of a time series is the definition of the ACF. The relation of ACF with delay k is shown in Equation 8: (8)

$$\rho_K = \frac{\sum_{i=1}^{n-k}(z_i - \bar{z})(z_{i+k} - \bar{z})}{\sum_{i=1}^{n}(z_i - \bar{z})^2} \qquad -1 \le \rho_K \le 1$$

ρ_K : The value of ACF of time series with delay k

z_i, z_{i+k} : Values of variables or time series data at time i and time delay k

$\bar{z}$: The mean value of the variables

Another method for naming the time dependence in the structure of a time series is the definition of a partial ACF if the partial ACF is part of the time series with K delay. The relation of the partial ACF is shown in the form of equation 9:

(9)

$$\phi_K(k) = \frac{\rho_k - \sum_{i=1}^{k-1}\phi_i(k-1)\rho_{k-1}}{1 - \sum_{i=1}^{k-1}\phi_i(k-1)\rho_i}$$

ϕ_K : The value of ACF of time series with k delay

In Figures 8 and 9, the ACF and PACF charts for delayed data for trending data are shown for 50 times delay, respectively.

The interpretation of the correlation and auto-correlation graphs (Figures 8 and 9) is illustrated below.

A) If the ACF has a downward or exponential pattern, it indicates that the model is non-static and there is the need for a re-differentiation or change in the differentiation or perhaps conversion. The ARMA model (p, q) is converted to ARIMA (p, d, q).

B) If the downward ACF to zero and the PACF has a meaningful interruption at the beginning of the function, then it shows that the model has an autoregressive model of order p, AR (p), P depends on the number of significant lags.

C) If the PACF has a downward trend to zero and the ACF has meaningful interruptions at the beginning of the function, it shows the moving average pattern with the order q, MA (q).

D) If both the ACF and the PACF have a downward trend towards zero, they represent the ARMA compound pattern (p, q).

E) If the ACF and PACF functions have both an alternating process, they can represent a seasonal pattern.

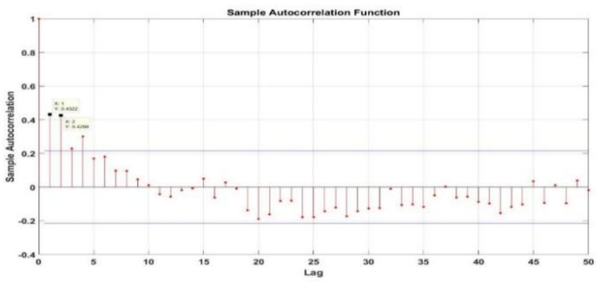

Figure 8. ACF chart

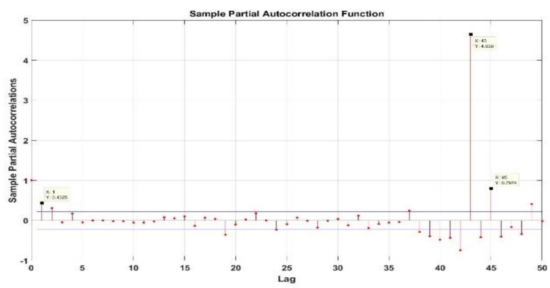

Figure 9. PACF chart

Weeks	Data up to two weeks ago (Model Input)		Real Data	Model Data	Error
98	7	8	7	7	0
109	2	4	3	3	0
110	4	3	3	3	0
127	15	9	11	11	0
134	13	9	10	10	0
139	10	17	13	13	0
88	27	17	20	21	1
95	24	16	18	19	1
100	7	17	12	11	1
112	3	1	1	2	1
113	1	1	2	1	1
120	22	11	17	16	1
122	17	17	17	16	1
126	7	15	9	10	1

5.3.2 Examination and evaluation of model type: According to the ACF and PACF charts, in the two functions, the data are considered as Eq. 18 for the prediction of the model. The prediction model, available data, models, and data are depicted in Figure 10.

$$y = +0.426 y_{t-2} + 0.432 y_{t-1} + y_0 \qquad (10)$$

In addition, for estimating the second-order index, the mean square error is used. The relations are defined as follows.

$$RMSE = \sqrt{\frac{1}{T} \sum (\dot{P}_F - \dot{P})^2} \qquad (11)$$

T: The number of predefined periods

$\dot{P}_F , \dot{P}$: The real and predicted values

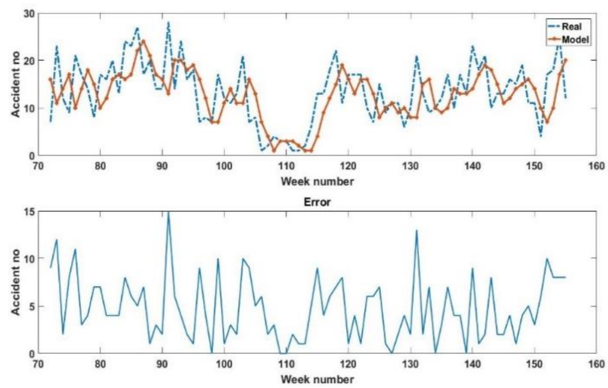

Figure 10. The above diagram: model prediction and available data; below diagram: error between model and data

On the weekly scale, time series analysis, the existence of the trend and period components, the type and rank of the model, and ACF and PACF are investigated and the model of traffic accident data model in a compound method (time series and PACF) are predicted using GIS based on two previous weeks. Based on this method, the root mean square error of events (total error 397, average 5, minimum zero, maximum 15), the simulated results in the short term could estimate incident rate. Fourteen samples of this predicted information are presented as an ascending error as described in Table 1.

Table 1. Model response, data up to two weeks ago (model input), and the actual number of accidents with weekly scale errors for some weeks

6. CONCLUSIONS AND RECOMMENDATIONS

The issue of road traffic safety is one of the most important issues, especially in recent years and for the years ahead due to the progressive growth of population and traffic jams. Despite its tremendous importance, there are few studies in this field and its importance has been neglected. The results of such studies can be directly applied to the operational section to improve the safety of transport. In this work, 1097 traffic collisions were selected first in Karaj-Qazvin highway, and then, by analyzing the data of the study area using GIS, a combined model was proposed based on the use of the data of two prior weeks. In the proposed approach, firstly, the model data were studied in general. Based on time series analysis, the trend component was determined in the time series and its elimination to make the data static. Moreover, the appropriate models were fit. For determining and identifying the type and rank of the model, first, ACF charts and PACF were selected and based on the form of the charts, second-order was selected. Given the results, the proposed method could estimate the accident rate with the average square error of three accidents (total error 397 over the entire time interval, mean error of 5 events, minimum zero and maximum error of 15 events) in the short period. Therefore, the suggestions that can be given in the light of the results obtained from this study are as follows:

- Comparison of the predicted time series model in this study with fuzzy neural network, and wavelet analysis with each other using GIS to increase the predicted accuracy of each incident in the most optimal form.
- Prioritization of the pseudo-accidental points of the road for safety.
- Identification of risk factors, their relationship and the severity of their impact on traffic collisions with the help of descriptive studies can accelerate and facilitate the planning and implementation of appropriate policies to reduce injuries and traffic accidents.

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