Research Paper: Estimating Accident-Related Traumatic Injury Rate by Future Studies Models in Semnan Province, Iran

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ABSTRACT

Background: Any accident is a disturbance in the balance between the human system, vehicle, road and environment. Future prediction of traumatic accidents is a valuable factor for managers to make strategic decisions in the areas of safety, health and transportation.

Materials and Methods: In this study, by using Grey Model (GM) (1.1), Rolling Grey Model (RGM), Fourier Grey Model (FGM) (1.1), survival modification model, ARIMA time series, harmonic pattern and statistical data, the number of traffic injuries referred to forensic medicine centers in Semnan Province between 2017 and 2020 were predicted based on the number of traffic injured in Semnan Province from March 2009 and March 2016 .

Results: The mean absolute error percentage for the GM (1.1), RGM (1), FGM (1.1), survival model, ARIMA and harmonic models were 0.994, 0.082, 0.091, 0.105, 0.05, 0.11, respectively, indicating a greater accuracy of the ARIMA method, compared to the other methods. The number of road traffic injuries in Semnan Province is decreasing and will reach 4052 in 2020.

Conclusion: ARIMA model is the best method of the future studies model for the number of injured patients referred to the forensic medicine centers in Semnan Province compared to other studied methods. Future studies model shows that the injuries caused by accidents in the province of Semnan are decreasing

1. Introduction

Road traffic accidents are among problems which threaten human health. Injuries caused by these events are so devastating that are sometimes referred to as a war on the road [1]. Road traffic accidents have increased by 13% in 18 developing countries of the world in the last decade, and various factors are involved in their occurrence [2]. Every year, accidents kill 24.1 million people globally and this number will rise to 9.1 million by 2020 if no effective action is taken. More than 90% of this mortality rate refers to low- and middle-income countries [3].

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According to the World Health Organization, in low-income and middle-income countries, age group of 15 to 30 years has the highest death rate due to traffic accidents. In these countries, more than 30% of deaths due to traffic accidents occur in the above-mentioned age group [3]. Car accident in Iran is considered as an important health problem and it is in second place of mortality cause with 14% of all deaths after cardiovascular diseases [4].

Car safety, driving culture, and road conditions are among the most important factors in preventing traffic accidents, and neglecting those increases direct and indirect costs and leads to the loss of active labor force either permanently or temporarily. Traumatic injuries caused by road accidents are categorized in the group of unintentional injuries, as major but neglected public health concerns [5]. Given the frequency of traffic accidents, their severe and fatal injuries as well as individual, social, and economic consequences in Iran, it is obvious that predicting relevant rates is a valuable factor for managers to make strategic decisions. Using solutions for road accidents and casualty reduction involves the analysis of accidents using futuristic models and the influence of various parameters in their occurrence, as well as efforts to improve traffic safety [6].

Models of future studies is widely used in road safety analysis and in identifying factors affecting road safety, identification and prioritization of road accident-ridden places, assessing the safety performance of the transportation network, assessing the safety of projects resulting from large-scale transport planning and determining the risk index to specify the safest route in the dynamic system of roads [7]. Sahebi et al. provided a prediction model for pedestrian traffic accident severity in outskirts roads. Their results show that violation of rules by pedestrians, time (accidents in the evening), place (accidents in plains), and the weight of the vehicle hitting the pedestrian were among the most important factors in the severity of the injuries. These parameters can be used for modeling and future studies of suburban road accidents [8].

Kazemi et al. provided future studies model of the number of accident casualties using the ARIMA pattern. Their results show that ARIMA time series has a high degree of prediction accuracy for road casualties [9]. Barba et al. combined ARIMA method and artificial neural network to improve the accuracy of futures studies model. Their results show that combining the two methods provides values with high accuracy of prediction [10]. Prediction is usually based on time series, but collecting data in a timely manner takes a lot of time and money [11].

Traditional predicting methods are usually on the basis of the using time series with a large number of data [12], but over the past few decades the researchers employed new methods with less data and more favorable results [13]. Using these methods is very necessary as they provide sufficient information for modeling by obtaining concise and comprehensive time series data. Grey system, harmonic pattern and ARIMA time series are examples of such methods. Grey system is a prediction method for future studies model of data with fewer time series [14]; ARIMA time series is designed based on Box-Jenkins Method for future studies model of various types of economic and social systems designed for health [15]; and harmonic pattern has an appropriate accuracy in future studies model by decomposing time series to sinus and cosine functions [16].

Considering the use of futures study methods in many economic and social studies, they have also been used a few times to predict traffic casualties and accidents. To our knowledge, no study has been done on the prospecting and predicting accidents in Semnan Province, yet. Therefore, this study by using advanced methods of prediction, including four Grey Models (GM), ARIMA time series, and harmonic pattern tried to estimate the number of traffic injured individuals referred to the forensic medicine centers in Semnan Province. In addition to estimate the accuracy of methods, prediction is evaluated using precision-meter indicators.

2. Materials and Methods

This is a comparative retrospective study which intends to predict the future number of traffic accident victims in Semnan Province using statistical data received on a monthly basis from forensic medicine centers in Semnan Province from April 2009 to March 2015. The average percentage error value was used to compare the accuracy of prediction methods. The number of injured referred to the forensic medicine centers is shown in Figure 1.

To predict the number of traffic victims referred to the forensic medicine centers in Semnan province, four Grey models including the GM (1.1), Rolling Grey model, survival modification model, Grey model FGM (1.1), ARIMA time series, and the harmonic pattern were used in this study. Minitab was used to predict ARIMA time series, and Matlab for other prediction models. The Grey systems theory was introduced by Deng in 1982. The effectiveness of these methods in facing with uncertainty

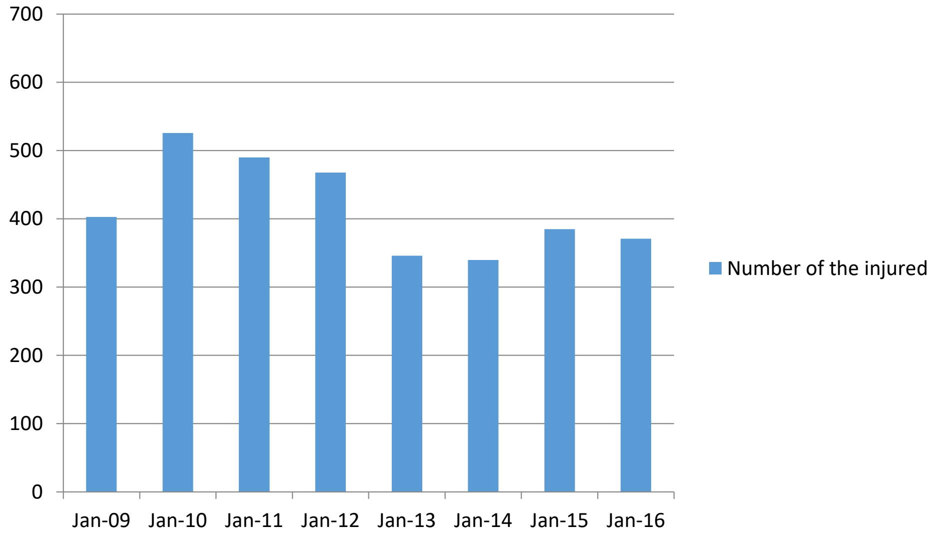

Figure 1. Number of victims suffered from accident trauma in Semnan Province

and information was proved inadequate. Grey system theory consists of five main sections, including grey forecast, grey relation, grey decision, grey planning and grey control. Grey prediction model can be considered as the core of grey theory.

The main application of grey theory under uncertainty conditions is data insufficiency and inadequacy. Deng introduced the model GM (m,n) as the main prediction model in the Grey theory. GM (m,n) model is a Grey model that n is the degree of differential equation extracted from the sequence of the Accumulating Generation Operation (AGO), and its sequence depends on the main sequence of the model and m represents the number of variables in the model, also (m-1) is an independent variable and its dependent variables and its linear differential equation are defined as follows [17]:

(1)

$$\frac{d^n x_1^{(1)}}{dt^n}+a_1\frac{d^{n-1}x_t^{(1)}}{dt^{n-1}}+\ldots+a_{n-1}\frac{d\,x_t^{(1)}}{dt}+a_n x_t^{(1)}=$$

$$b_1x_1^{(1)}(t)+b_2x_2^{(1)}(t)+\ldots+b_m x_{m-1}^{(1)}(t)$$

To smooth the random trajectory of the model's initial data for using in GM (1,1) models, these data are placed under the operation of the AGO. Actually, the most important and general procedure in the process of generating a grey sequence can be considered AGO operator [18]. In other words, this operator reveals the pattern of internal data order or the trend of the data series. x^1 is considered as the main sequence of data:

$$(2)\ x^{(0)}=\left(x^{(0)}(1),x^{(0)}(2),\ldots,x^{(0)}(n)\right)$$

And after the performance of the AGO operator, the sequence of x is calculated by Equation (3):

$$(3)\ x^{(0)}(k)=x^{(0)}(k)=\sum_{k=1}^{1}x^{(0)}(k),\sum_{k=1}^{2}x^{(0)}(k)\ldots,\sum_{k=1}^{n}x^{(0)}(k)$$

Differential equation used in grey model is different from other differential equations. Other differential equations are used for continuous and differential concepts, while the grey system is able to use discrete data sequence to build the model. This is while the concepts are neither differential nor continuous. In addition, ordinary differential equations are used in infinite information environments. The grey sequences belong to the finite information space. The GM model (1.1) in the grey theory can be defined as follows [18].

$$(4)\ \sum_{i=0}^{h}a_i\frac{d^{(i)}x_1^{(1)}}{dt^i}=\sum_{j=2}^{N}b_jx_j^{(1)}$$

If h=1 and N=2.

$$(5)\ \frac{d\,x_1^{(1)}}{dt}=a_1x_1^{(1)}=b_2\Rightarrow\frac{d\,x_1^{(1)}}{dt}+a_1x_1^{(1)}=b$$

Consequently, the differential equation GM (1,1) is obtained as Equation (6).

$$(6)\ x^{(0)}(k)+az^{(1)}(k)=b_2\Rightarrow x^{(0)}(k)+az^{(1)}(k)=b$$

A is the coefficient of development (improvement) and b is the grey input coefficient or grey control parameter

[14]. Whitened equation of grey differential can be generated by two quantities:

$$(7)\ \frac{dt^{(1)}(t)}{dt} + az^{(1)} = b$$

The relationship between the grey differential equation and its whitened equation are presented as equations (8) and (9) [19].

$$(8)\ x^{(0)}(k) = x^{(1)}(k) - x^{(1)}(k-1) \approx \frac{dx^{(1)}(t)}{dt}$$

$$(9)\ z^{(1)}(k) = x^{(1)}(t)$$

In order to obtain a and b values, the original data sequence and the value of $z^{(1)}(t)$ should be placed in the grey differential equation and, thus, n-1 linear equation is obtained. For the production of az $^{(1)}$(n) the sequence of in Equation (10) is computed:

(10)

$$z^{(1)}(k) = \left(z^{(1)}(2), \ldots, z^{(1)}(n)\right)$$
$$z^{(1)}(k) = ax^{(1)}(k) + (1-\alpha)x^{(1)}(k-1)\ , \alpha \in (0,1)$$

Investigators usually consider α value equal to 0.5, so the order of sequence can be considered as the mean sequence of series. Of course, determining the application of different values for α has been the subject of the many studies. Determining the director for the sequence has also led to the provision of improved Grey models. Chen and Chang showed in their article that:

$$(11)\ \frac{dx_1^{(1)}}{dt} = \lim_{\Delta t \to 0} \frac{x_1^{(1)}(t+\Delta t) - x_1^{(1)}(t)}{\Delta t}$$

$$(12)\ \frac{d\,x_1^{(1)}t}{dt} = x^{(1)}(t+1) - x^{(1)}(t) = x^{(0)}(t+1)\ \ , \Delta t \to 1$$

Linear equations can be transformed into a matrix form:

$$BW = Y$$

$$(13)\quad Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix} ;\ B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} ;\ W = \begin{bmatrix} a \\ b \end{bmatrix}$$

Now, using the least squares method, we can write:

$$(14)\ W = \begin{bmatrix} a \\ b \end{bmatrix} = (B^T B)^{-1} B^T Y$$

By specifying a and b values, the whitened Equation (15) can be solved as:

$$(15)\ \frac{dx^{(1)}(t)}{dt} + ax^{(1)}(t) = b$$

The following results are obtained from the solution:

$$(16)\ \frac{dx^{(1)}(t)}{dt} = -a\left(x^{(1)}(t) - \frac{b}{a}\right)$$

$$(17)\ \frac{d\left(x^{(1)}(t) - \frac{b}{a}\right)}{dt} = -a\left(x^{(1)}(t) - \frac{b}{a}\right)$$

Now if and t=1, then the formula is given in the description of Equation (18):

$$x^{(1)}(t) = x^{(0)}(t)\ ,\ \ x^{(1)}(t) = -\frac{b}{a} = \omega$$

$$(18)\ \hat{x}^{(1)}(n+1) = \left(x^{(0)}(t) - \frac{b}{a}\right)e^{-n} + \frac{b}{a}$$

As seen in the model formulating, instead of using the original sequence of data, the sequence produced by AGO operator is used; therefore, it is necessary to reintroduce a new operator. This operator is IAGO: inverse accumulating generation operation. Using the operator listed, we can write:

$$(19)\ x^{(0)}(i) = x^{(1)}(i) - x^{(1)}(i-1)\ \ x^{(0)}(1) = x^{(1)}(1)$$

Now, the formula for model prediction of GM (m,n) using the listed operator, equals to:

$$(20)\ \hat{x}^{(0)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right)e^{-k}\ (1-e^{a})\quad k = 1,2,\ldots.$$

The basis of RGM (1,1) is to use more recent data to calculate prediction values. The main difference between this model and the common model of GM (1,1) is the replacement of the latest data, removing the oldest data, and calculating the required sequence to build the prediction model [18].

The performance of this model is as follows: By entering new data, the oldest data from the data sequence is deleted, and therefore, the number of data in the main sequence of the prediction model is always fixed. For example, if the initial sequence consists of five data such as ($x^{(0)}(1)$, x(2), (2), $x^{(0)}(3)$, $x^{(0)}(4)$, $x^{(0)}(5)$) the preceding sequence is used to predict . Data replacement process in the sequences will continue to replace all the original sequence data. Fourier Grey Model (FGM) (1.1) model is based on GM (1.1) model and the difference is the use of the first value of the initial sequence in the produced prediction.

The ARIMA time series prediction method is based on the studies of Box and Jenkins. In the Box and Jenkins analysis, single-variable time series prediction occurs with statistical modeling. A static time series can be modeled with different methods. One of the most popular modeling in econometrics is based on the methodology of Box and Jenkins and relying on historical values of the time series and stochastic error sentences. This type of modeling known as ARIMA modeling has been widely used by researchers and its general condition for ARIMA (p, d, q) is in the form of Equation (21).

(21) $Z_t=\sum^{p}_{i=1}\phi_t z_{t-i}+\sum^{q}_{i=i}\theta_t a_{t-i}+a_t$

Therefore, the most important issue in this method is determining the number of intervals for accident injured statistics and detecting the random variable structure in the model. In this case, we used a standard and common method in this field, that is, the Box and Jenkins methodology. In this method, the number of interruptions and random variable structure is determined on the basis of self-correlation functions and partial self-correlation between model errors.

Decomposition of a time series to its components leads to a deeper understanding of the structure and the variable oscillatory behavior in time. Spectral analysis method is used in econometrics studies such as the separation of the process and the cyclic components from each other. The purpose of the spectral analysis method is decomposition of a time series to sinus and cosine functions with specific wavelength.

In the case of time series variables, spectral analysis method is used to understand seasonal fluctuations with different periods of time. Basic assumption of time series harmonic analysis is that a time series can be written as a function combined of cycles having the oscillating filed as follows:

(22) $Z_t=\alpha_0+\alpha_1 Sin(\frac{2\pi t}{p})+\beta_1 cos(\frac{2\pi t}{p})$

In the above Equation, Z indicates data of time series under study, P is the duration of the assumed cycle, α_1 and β_1 are harmonic coefficients with the oscillating field and t is the time trend.

3. Results

Estimated values for traffic injuries between 2017 and 2020 were obtained using four Grey models of GM (1,1), RGM (1,1), FGM (1,1), as well as the survival changes, as shown in Table 1. Grey models were implemented in Excel. First, the relevant data for 15 consecutive months were used. For model performance parameters with 15-time series data, a was equal to 0.001726 and b equal to 98.0412. Considering α equals to 0.5 and the values obtained for a and b, the structure of the prediction series model was completely introduced step-by-step in the research methodology section and the survival series start with the second data.

Prediction series are specified for the future, i.e. 2017 to 2020. Estimated values for the coming years is obtained from the sum of the estimated values for 12 months. Mean Absolute Percentage Error (MAPE) is an indicator for measuring the accuracy of the prediction method and whatever the percentage is closer to 0, it indicates the precision of the prediction method. To predict ARIMA time series, statistics information must be static. Data on the number of injuries is being static after two times the differencing. Their second magnitude difference is shown in Figure 2.

Analysis and evaluation of self-correlation function and partial self-correlation shows that ARIMA is the most suitable model for the number of traffic injuries referenced to Semnan Province (4, 2, 4). This means that the time series of the number of injuries should differentiate two times to be stationary (d=1) and then modeled using an ARMA process (4, 4). To estimate the coefficients of the model, the least squares method was used, but we resort to nonlinear methods when the model was nonlinear in terms of parameters. Model coefficients for ARIMA model (4, 2, 4) were obtained in the form of the following equations.

(23) $Z_t=0.26Z_{t-2}/Z_{t-1}+42.63Z_{t-3}-0.47Z_{t-4}+a_t-2.173a_{t-1}+1.293a_{t-2}+0.34a_{t-3}-0.42a_{t-4}$

Among the time series models of ARIMA, Equation 34 will have the most accurate prediction among the number of injured traffic and the results are presented in Table 2.

Table 3 presents the results of the prediction through the harmonic pattern, in which the order of the pattern demonstrates P values, the order of 8 for the injured indicates using the result of dividing 360 by 4, i.e. the cycle in the prediction is 90 degrees. By obtaining α and β

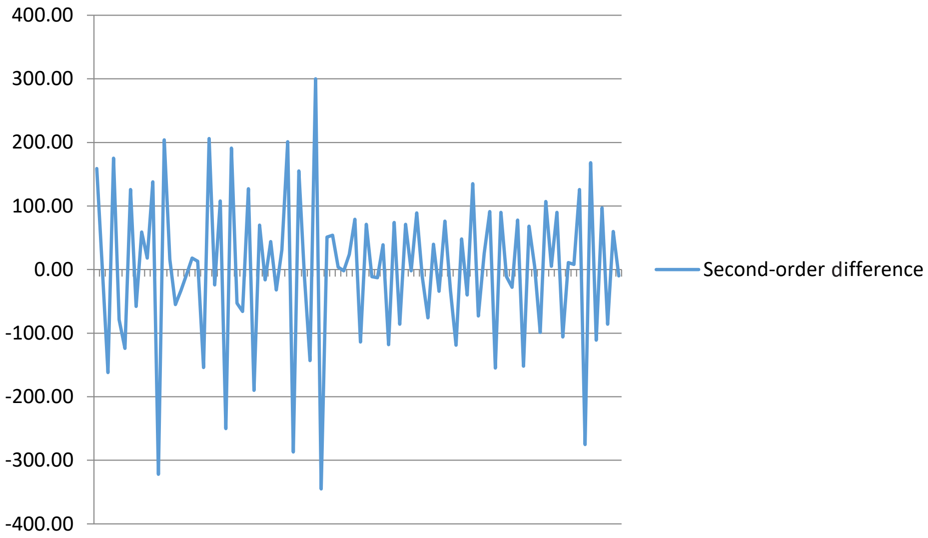

Figure 2. Second-order difference between traffic casualties in Semnan Province

and assuming order 4, in Equation 22, prediction values were obtained between 2017 and 2020.

4. Discussion

Annually, a large number of people in Iran lose their lives in traffic accidents or suffer from financial or individual losses. Reviewing and predicting the behavior of transportation systems is a valuable factor available for managers, experts, and researchers for making decisions in this regard. Using statistics of traumatized traffic casualties referring to the forensic medicine centers in Semnan Province, the number of injured was predicted for 2017 to 2020.

Predicting the number of injured in the future provide human resources in forensic medicine valuable information for responding to injured people and also taking police preventive measures. The advanced prediction methods including the four Grey methods of GM (1,1), RGM (1,1), FGM (1,1), and survival changes model as well as ARIMA time series methods and the harmonic pattern were used. Mean percentage error of these methods were 0.094, 0.082, 0.091, 0.510, 0.05, 0.11, respectively indicating the greater accuracy of the ARIMA method, compared to the other studied methods. In a study conducted in China, road traffic injuries from 1951 to 2003 were put under the time series analysis with the Box-Jenkins technique and the statistics from

Table 1. Estimated values using Grey models for the number of traffic jams in the coming years of Semnan Province

Grey Models	2017	2018	2019	2020	MAPE
GM (1,1)	4001	3956	3941	3932	0.094
RGM (1,1)	4125	4075	4009	3987	0.082
FGM (1,1)	4196	4154	4026	4003	0.091
Changes model	4125	4072	3945	3875	0.105

Table 2. Prediction of the number of traumatic injuries referred to the forensic medicine centers using ARIMA time series

Predicted Variable	2017	2018	2019	2020	MAPE
The number of traffic injured referred	4160	4085	4063	4052	0.05

Table 3. Estimating the number of traumatic injuries referred to the forensic medicine centers in Semnan

Predicted Variable	P-Order	2017	2018	2019	2020	MAPE
The number of traffic injured referred	4	4151	4026	3975	3875	0.11

the ARIMA model showed that prediction for 2003 was very close to reality [20].

In the process of predicting the number of accidents, other methods are also used in addition to the Jenkins Boxing methodology. A study that predicted the number of accidents using Grey systems, suggested values from increasing number of accidents and also acceptable Grey system accuracy in prediction [21]. Prediction values of the traffic injured referred to forensic medicine centers in Semnan Province using the ARIMA method for the years 2017 to 2020 were 4160, 4085, 4063 and 4052, respectively which represents a diminishing move of the number of injuries in Semnan Province.

Omidi et al. in a study to predict the occurrence of accidents in transportation systems, showed that the number of road traffic injuries in the province of Khuzestan is decreasing [22]. Due to the high accuracy of the ARIMA method, researchers and organizations are recommended to use this method to predict the number of traffic injuries referring to forensic medicine centers. Reduced number of casualties in Semnan indicates the effectiveness of traffic police measures in this province.

The amount of casualties and the number of accidents can be decreased by training, better control and setting appropriate traffic rules. The most important point to prevent accident occurrence, consist of observance of driving directions and regulations, and avoiding driving offenses, because the introduction of any accident is definitely committing a violation and driving offense only occurs when driving laws and regulations are ignored. Examples of observing driving laws and regulations is fastening seatbelt while driving.

Although fastening the seatbelt is annoying for some people, it plays a very important role in reducing road accident casualties. Fastening the seatbelt must be taken seriously not only by the drivers, but also by passengers both adults and children, especially in out-of-town roads. Obligatory seatbelt fastening from a legal point of view is set and implemented to this end. One of the best ways to reduce accidents is defensive driving.

It does not mean that the driver is able to control the negligence of other drivers. Defensive driver can predict possible road accidents and use the best way to react and prevent accidents. One of the reasons for accident occurrence is inaccurateness and distraction of drivers during driving that the police should make drivers aware of the dangers of distraction while driving, by warning and educating them through the media and driving schools.

5. Conclusion

ARIMA (4,2,4) model has more power and precision compared to other advanced single-variable future study models. In measuring the accuracy of the methods related to Grey systems, the RGM method works better than others and the output is the values with a higher coefficient of confidence. Harmonic pattern is not a suitable method for the future studies model of traffic casualties, given the fitting of the models by the mean absolute percentage error. Future studies model of the obtained values indicates a reduction in injuries caused by accidents trauma in Semnan Province.

It is suggested that a software be designed based on the Box-Jenkins method, in order to accelerate obtaining information about accidents in the future studies. Also in future studies, various provinces can be evaluated and ranked in terms of the number of accident casualties.

Ethical Considerations

Compliance with ethical guidelines

The authors of this article have followed all ethical principles.

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Conflict of interest

The authors certify that they have no affiliation with or involvement in any organization or entity with any financial interest, or non- financial interest in the subject matter or materials dismissed in this manuscript.

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