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Comparing the Future Trend of the Number of Road Accidents in Non-Motorized Vehicles Using a Predictive Mathematical Method.

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Abstract **-** The article proposes an innovative approach to address the problem of traffic accidents involving non-motorized vehicles through the application of the predictive mathematical method Gray GM (1,1). The study is based on an analysis of historical accident data, considering variables such as location and characteristics of the road. The methodology used to apply the forecast model is described, highlighting the collection and preparation of data, the selection of relevant variables and the construction of the model. Real data was used to predict accident occurrence and underlying trends. The results of the study demonstrated the effectiveness of the proposed infrastructure model using the mathematical prediction model in non-motorized vehicle traffic accidents. Finally, it is concluded that the use of this predictive mathematical model contributes to the implementation of prevention strategies that would be effective in the future. Likewise, a new perspective could be provided to address road safety of non-motorized vehicles, highlighting the importance of anticipating and preventing accidents through the application of predictive mathematical models, which offers a significant contribution to improving safety. on public roads.

Keywords**:** Road safety, cycle path, forecast, bicycle, non-motorized.

1. Introduction

Road accidents leave 51.3 million people seriously injured worldwide, of which 2.5% die [1]. These figures are alarming for low- and medium-high-income countries, since these types of accidents are among the 10 main causes of death in their population. This is due to the lack of urban planning, as well as poor design in road infrastructure [2].

Currently, although road safety plans have been established, especially with bicycle lanes, 52% of the world's population believes that cycling is dangerous due to the lack of safety on its routes [3].

The research provides a new and important approach within the area of road safety focused on non-motorized vehicles that travel on bicycle lanes, since the use of the Gray GM Forecast (1,1) was implemented, which is a mathematical model that allows predicting the future trend of a variable expressed quantitatively and allows evaluating its behavior over time, to know the variability of the number of road accidents that would occur before and after the implementation of road safety measures in the studied area.

3. Tools

The mathematical prediction model under consideration was used because it has proven its effectiveness in various areas of science, such as technology, economics, energy consumption and other relevant fields. In recent years, expanded and modified Gray prediction models based on the GM (1,1) model have been developed and successfully applied thanks to the practicality and accuracy inherent in this methodology [4].

Among all the variables of the GM (1,1) model, we will use the original one, because this first-order model, focused on a single variable, is distinguished by its ability to generate highly accurate predictions even when a set of reduced data (four points). Its applicability is evident in its wide use, being considered one of the most prevalent techniques in this field [5].

4. Methodology

To achieve the development of this research, the following methodology indicated in Figure 1 was established, which shows the calculation process to follow for the development of the mathematical model [6].

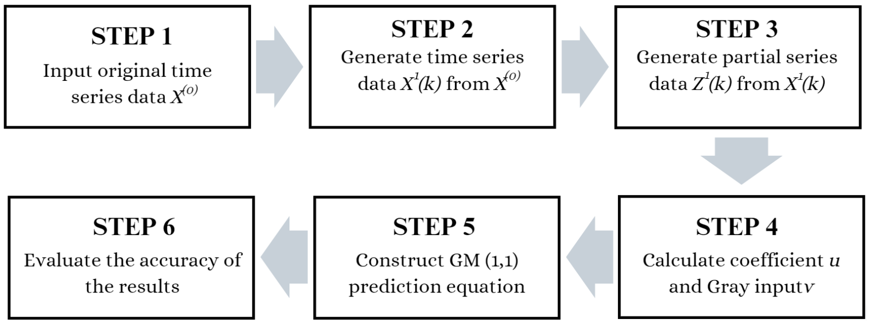

Fig. 1: Flowchart on the methodology used

As a first step, the original time series data are obtained $X^{(0)}$, shown in equation (1):

$$X^{(0)} = \left[X^{(0)}(1); X^{(0)}(2); \dots ; X^{(0)}(n)\right], n \geq 4 \tag{1}$$

Where n denotes the total historical time period. Then we proceed to generate $X^{(1)}$ using the cumulative generation operation (AGO) to eliminate the uncertainties of the original data. Equation (2) shows the AGO equation:

$$X^{(1)} = \left[X^{(1)}(1); X^{(1)}(2); \dots ; X^{(1)}(n)\right], n \geq 4 \tag{2}$$

Where

$$\begin{cases} X^{(1)}(1) = X^{(0)}(1) \\ X^{(1)}(k) = \sum_{i=1}^{k} X^{(0)}(i) \end{cases}, \qquad k = 1,2, \dots , n.$$

We proceed to generate the partial data series $Z^{(1)}$ in equation (3):

$$Z^{(1)} = \left[Z^{(1)}(2); Z^{(1)}(3); \dots ; Z^{(1)}(n)\right], n \geq 4 \tag{3}$$

Where $Z^{(1)}(k)$ is the value of the mean sequence, as described in equation (4).

$$Z^{(1)}(k) = \frac{1}{2} \times \left[X^{(1)}(k) + X^{(1)}(k-1)\right], k = 2,3, \dots , n \tag{4}$$

Subsequently, equation (5) is constructed with the data from $X^{(0)}$ in equation (1).

$$\hat{X}^{(1)}(k+1) = (X^{(0)}(1) - \frac{v}{u})\, e^{-uk} + \frac{v}{u} \tag{5}$$

Where u denotes the development coefficient and v denotes the input of GM (1,1), respectively. Also, $\hat{X}^{(1)}(k+1)$ represents the value X of the forecast in the $k+1$ scenario. The value of the coefficients $[u, v]^T$ can be achieved using the ordinary least squares (OLS) method, as defined in equations (6) to (8).

$$\begin{bmatrix} u \\ v \end{bmatrix} = (H^T H)^{-1} H^T K \tag{6}$$

$$K = \begin{bmatrix} X^{(0)}(2) \\ X^{(0)}(3) \\ \cdots\cdots \\ \cdots\cdots \\ X^{(0)}(n) \end{bmatrix} \tag{7}$$

$$H = \begin{bmatrix} -Z^{(1)}(2) & 1 \\ -Z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -Z^{(1)}(n) & 1 \end{bmatrix} \tag{8}$$

Where $[u, v]^T$ is the parameter series, K is the data series, and H is the data matrix.
Of the values of $\hat{X}^{(1)}(k+1)$ in equation (5), $\hat{X}^{(0)}$ is established, which becomes the series predicted in equation (9):

$$\hat{X}^{(0)} = \left[\hat{X}^{(0)}(1); \hat{X}^{(0)}(2); \ldots; \hat{X}^{(0)}(n)\right] \tag{9}$$

Where $\hat{X}^{(0)}(1) = X^{(0)}(1)$.
Applying the inverse-accumulated generation operation, equation (10) is obtained as follows:

$$\hat{X}^{(0)}(k+1) = \left(X^{(0)}(1) - \frac{v}{u}\right) e^{-uk}(1 - e^{u}) \tag{10}$$

5. Results

By using the Gray GM model (1,1), it was possible to calculate the future trend of the accumulated number of accidents (the number includes fatal and non-fatal accidents) for the entire section studied, which covers approximately 800 meters. To carry out the predictive calculations, data provided by the National Police of Peru was used:

a. For a bike lane without road safety measures (current):

Table 1: Number of accidents in current bycicles lanes.

Year	*Accidents*	*Accumulated*
2019	14	14
2020	11	25
2021	13	38
2022	10	48

Based on the data presented earlier, the respective calculations were carried out to find the values of the prediction on the current bike path.

$$X^{(0)} = [14; 25; 38; 48]$$

$$X^{(1)} = [14; 39; 77; 125]$$

$$Z^{(1)} = [14; 26.5; 58; 101]$$

$$K = \begin{bmatrix} X^{(0)}(2) \\ X^{(0)}(3) \\ X^{(0)}(4) \end{bmatrix} = \begin{bmatrix} 25 \\ 38 \\ 48 \end{bmatrix}$$

$$H = \begin{bmatrix} -Z^{(1)}(2) & 1 \\ -Z^{(1)}(3) & 1 \\ -Z^{(1)}(4) & 1 \end{bmatrix} = \begin{bmatrix} -26.5 & 1 \\ -58 & 1 \\ -101 & 1 \end{bmatrix}$$

$$\begin{bmatrix} u \\ v \end{bmatrix} = (H^T H)^{-1} H^T K = \begin{bmatrix} -0.3042 \\ 18.188 \end{bmatrix}$$

All the values obtained are shown in Table 2 and illustrated in Figure 2.

Table 2: Prediction in current bicycle lane (without road safety measures).

$k(year)$	$\hat{x}^1(k)$	$Value$	$\hat{x}^0(k)$	$Value$	$Rounding$
k = 0, (2019)	$\hat{x}^1(0)$	14	$\hat{x}^0(0)$	14.00	***14***
k = 1, (2020)	$\hat{x}^1(1)$	40.24	$\hat{x}^0(1)$	26.24	***27***
k = 2, (2021)	$\hat{x}^1(2)$	75.80	$\hat{x}^0(2)$	35.56	***36***
k = 3, (2022)	$\hat{x}^1(3)$	124.00	$\hat{x}^0(3)$	48.21	***49***
k = 4, (2023)	$\hat{x}^1(4)$	189.35	$\hat{x}^0(4)$	65.35	***66***
k = 5, (2024)	$\hat{x}^1(5)$	277.93	$\hat{x}^0(5)$	88.58	***89***
k = 6, (2025)	$\hat{x}^1(6)$	398.00	$\hat{x}^0(6)$	120.07	***121***
k = 7, (2026)	$\hat{x}^1(7)$	560.77	$x^0(7)$	162.76	***163***

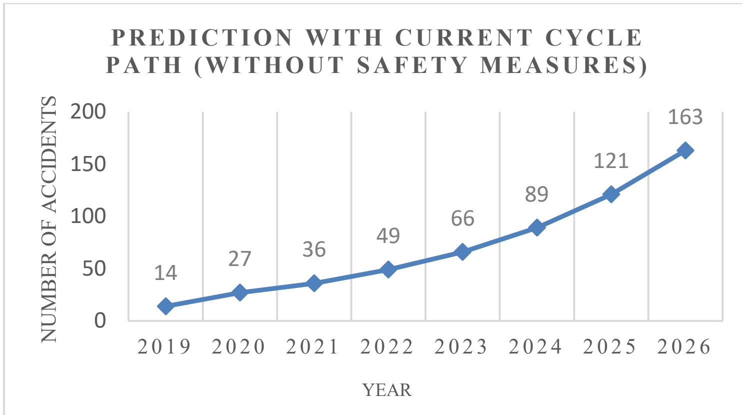

Fig. 2: Prediction with current bicycle lane (without safety measures).

Once this graph is obtained, the same procedure is carried out to obtain data in the study area under certain conditions that improve road safety. The results of the mathematical prediction method on the accumulated number of accidents that will occur within 4 years vary according to the type of proposed bike lane within the study area (the type of bike lane was determined based on the number of road accident reduction measures it presents). When analyzing the types of bike lanes within the studied section, the following considerations were obtained:

Table 3: Percentage reduction of road accidents involving non-motorized vehicles according to the type of bikeway.

Type of bicycle lane	*Reduction*
No security measures	0%
No bollards	23%
No bike boxes or speed bumps	15%
With all safety measures	30%

These percentages are determined based on studies carried out before and after the implementation of each measure.

Then, an approximate calculation of road accidents is carried out after the implementation of the measures mentioned in the previous table.

b. For a bicycle lane without bollards:

Table 4: Number of road accidents for a bicycle lane without bollards.

Year	***Accidents***	***Accumulated***
2019	11	11
2020	9	20
2021	10	30
2022	8	38

All the values obtained are shown in Figure 3.

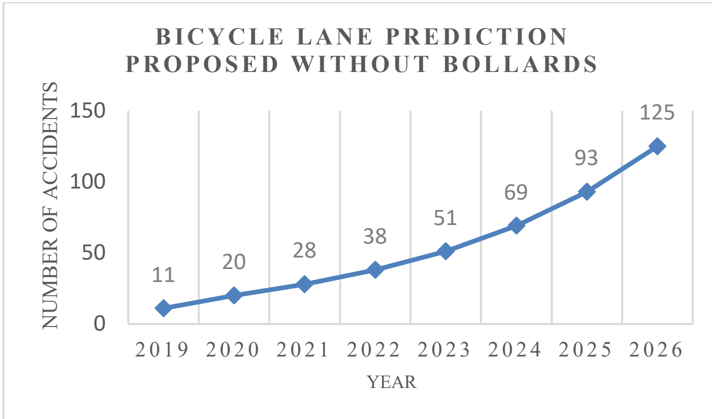

Fig. 3: Prediction on proposed cycle path without bollards.

c. For a bicycle lane without bike boxes or speed bumps:

Table 5: Number of road accidents for a bicycle lane without bike boxes or speed bumps.

Year	*Accidents*	*Accumulated*
2019	12	12
2020	9	21
2021	11	33
2022	10	43

All the values obtained are shown in Figure 4.

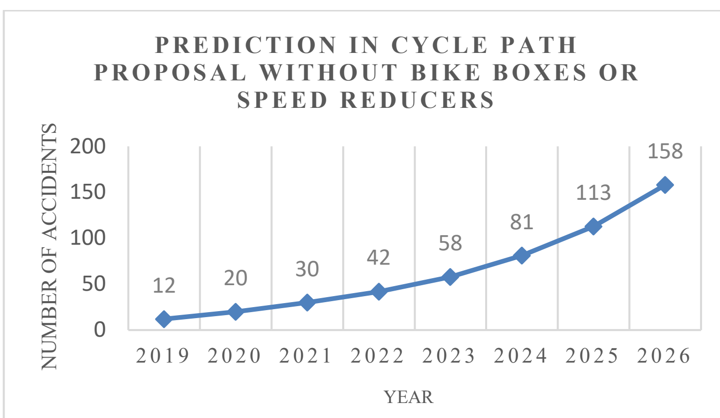

Fig. 4: Prediction on the proposed cycle path without bike boxes or speed bumps.

d. For a bicycle lane with bollards, speed bumps, signage and bike boxes:

Table 6: Number of road accidents for a bicycle lane with all safety measures.

Year	*Accidents*	*Accumulated*
2019	10	10
2020	8	18

2021	9	27
2022	7	34

Subsequently, the previously presented data was processed to determine the forecast of accidents (including fatal and non-fatal) that will occur in the studied area. With this, Figure 5 was developed.

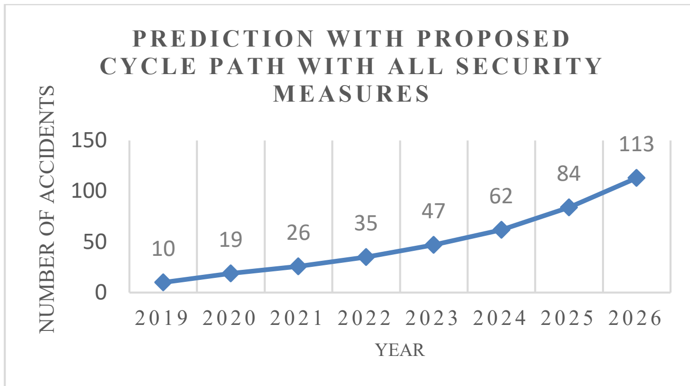

Fig. 5: Prediction with proposed cycle path with all security measures

Finally, a graph was obtained that connected each trend curve to make a comparison of how each type of bike lane affects the number of accidents involving non-motorized vehicles for the next 4 years.

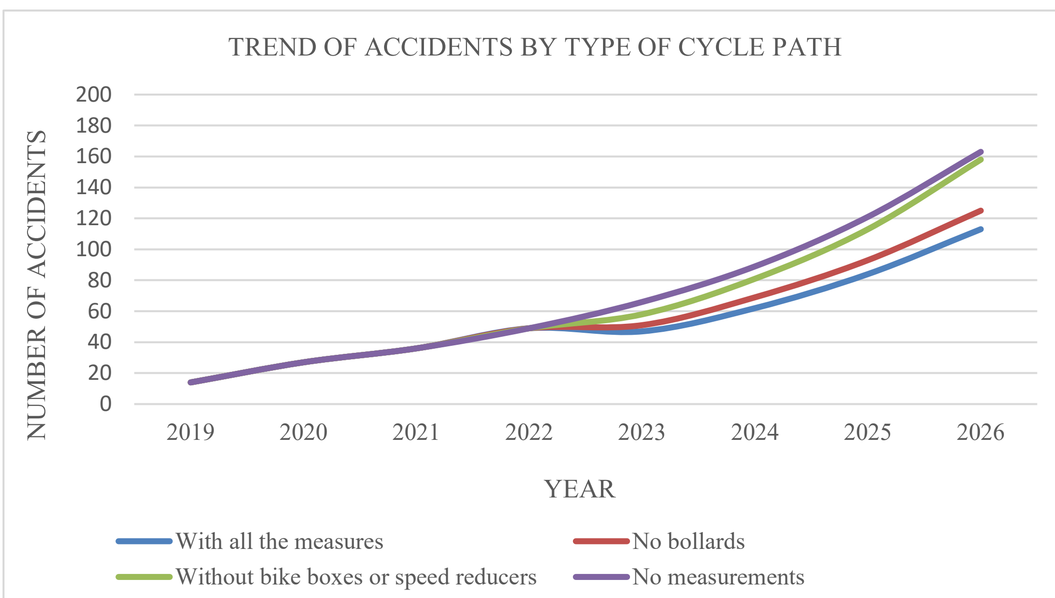

Fig. 6: Comparison of trends according to type of cycle path.

This final graph indicates which road safety measure turned out to be the most optimal in reducing the trend of accidents involving non-motorized vehicles in the future.

6. Validation

Predictive accuracy values can be measured using the mean absolute percentage error (MAPE), which is called $\propto$ the formula is presented as follows:

$$\propto = \frac{1}{n}\sum\left(\frac{X^{(0)}(k) - \hat{X}^{(0)}(k)}{X^{(0)}(k)}\right) \times 100\% \tag{11}$$

Where

$$\begin{cases} \propto \leq 10\% : \mathit{High\ Accuracy}, 10\% < \propto \leq 20\% : \mathit{Good} \\ 20\% < \propto \leq 50\% : \mathit{Reasonable}, \propto > 50\% : \mathit{Inaccurate} \end{cases}$$

This formula is used to obtain validation of the mathematical model and identify how accurate our prediction was. For our predictions the following results were obtained:

Mathematical model for cycle path without safety measure:

$\propto = 5.1\ (\mathit{High\ Accuracy})$

Mathematical model for cycle path without bollards:

$\propto = 2.2\ (\mathit{High\ Accuracy})$

Mathematical model for a cycle path without bike boxes or speed bumps:

$\propto = 5.4\ (\mathit{High\ Accuracy})$

Mathematical model for a cycle path that has all the safety measures:

$\propto = 4.1\ (\mathit{High\ Accuracy})$

7. Conclusion

When implementing the road safety strategies for non-motorized vehicles of our proposal, it was noted that the trend in the number of accidents for this type of transportation, through the use of the Gray forecast, decreases between 9% to 29.9% for the years 2023 until 2026. The predictive method used has proven to be effective in reducing the number of road accidents due to the high precision in its results. This highlights the importance of employing data and analytics-driven approaches to address road safety issues. Furthermore, it validates the choice of using a predictive model instead of more traditional methods to plan the choice of road safety measures. The quality and relevance of the data used to feed the predictive model are essential, since the availability of accurate and up-to-date data contributed significantly to the success of the method. The predictive model proved to be adaptable to changes in the conditions studied, this confirms the flexibility of the model and the ease of adapting to various quantitative problems that require predicting its long-term behavior.

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