

Analysis traffic safety in Mongolia

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Abstract

This study examines the traffic safety (TS) situation in Mongolia from 2014 to 2023, analyzing trends, challenges, and potential solutions. Using Pearson correlation analysis and principal component analysis (PCA), a strong positive correlation was found between road accidents and injuries ($r=0.758$, $P<0.001$) and a weak correlation between accidents and fatalities ($r=0.305$, $P<0.05$). The significant regional differences were confirmed by the ETA coefficient (0.947), indicating a high spatial impact. A quadratic regression model revealed a nonlinear relationship between RS and GDP, suggesting that economic growth can reduce risks under certain conditions. The study highlights the need to improve infrastructure, increase public participation, and optimize policy and regulation to address challenges such as urbanization, rural road conditions, and seasonality. This study provides important information and solid suggestions for improving the MRT system, and will be a valuable resource for policymakers.

Keywords: Traffic safety, traffic accidents, Mongolia, statistical analysis, PCA

Introduction

Mongolia is a landlocked country in East Asia, covering 1.6 million square kilometers, making it the 19th largest country in the world. Its rugged steppes, high mountains, and deserts pose unique challenges to road infrastructure. The country's harsh inland climate, characterized by long, harsh winters and short summers, has a significant impact on road conditions and safety (White Paper on Road Traffic Safety in Mongolia, 2022). Mongolia experienced rapid urbanization between 2014 and 2023, with the number of cars increasing by 70%, with more than 1.2 million vehicles registered by 2023 (Statistics about traffic accidents in Mongolia, 2023). Most of these are concentrated in the capital, Ulaanbaatar, where about half of the population lives.

Urbanization and rising incomes have led to increased private car ownership, further increasing traffic congestion in urban centers. In rural areas, where 36% of the population lives, poor road conditions and unpaved roads are prevalent, increasing the risk of intercity traffic accidents (Tony Mathew, 2024) [3].

Political and legal developments have also influenced road safety trends. The government has implemented new traffic laws and adopted a national road safety strategy, which aims to reduce the number of road deaths by 25% by 2030 (Odgerel and Erdenechimeg, 2023). However, barriers to enforcement and limited public participation have limited the effectiveness of these initiatives. For example, only 60% of drivers regularly wear seat belts, and less than 50% of motorcyclists wear helmets (Katherine Guy and Rebecca Stapleton, 2024) [5].

Seasonality also poses challenges to road conditions. Icy roads in winter increase the number of accidents by 30%, while spring dust storms reduce visibility and increase the risk of collisions. These environmental, infrastructural, and behavioral challenges highlight the multifaceted challenges to road safety in Mongolia (Anand et.al., 2023).

This article examines these interrelated factors, provides a detailed analysis of road safety trends in Mongolia, and

suggests potential solutions to address the challenges.

1. Research Methodology: Data Sources and Description
The data used in this study contain the information necessary to determine the road safety trends in Mongolia and are composed of the following sources:

- **Statistics on road accidents, crimes, deaths, and injuries:** (This data was obtained from the Mongolian Traffic Police. It shows the number of road accidents recorded between 2014 and 2023 and their impact.)
- **Economic indicators:** (Indicators such as GDP per capita at the national level were obtained from the National Statistics Committee. It was used to determine *the impact of economic growth and the Traffic security.*)

Table 1: Situation of Mongolia by region

No	Region	Provinces that belong to the region
R1	West	Bayan-Ulgii, Gobi-Altai, Zavkhan, Uvs, Khovd
R2	Khangai	Arkhangai, Bayankhongor, Uvurkhangai, Bulgan, Orkhon, Khuvsgul
R3	Central	Darkhan-Uul, Selenge, Tuv, Govisumber, Dornogovi, Dundgovi, Umnugovi
R4	East	Dornod, Sukhbaatar, Khentii
R5	Ulaanbaatar	Capital Ulaanbaatar and its suburbs

Regional Classification

- The study divided Mongolia into five regions (Western, Khangai, Central, Eastern, and Ulaanbaatar) and analyzed the road conditions in each region.

Seasonal Characteristics and Natural Impacts

- The number and level of accidents caused by winter and spring road conditions were compared with natural phenomena.

2. Statistical analysis

Internationally proven methods and modern software were used for the statistical analysis of the study. Pearson

Correlation was used to determine the relationship between road accidents, deaths, and injuries, which is an effective method for calculating the relationship and direction between variables.

In addition, Principal Component Analysis (PCA) was implemented to comprehensively display the road accident index. Eigenvalues and Eigenvectors were calculated using PCA analysis, and road accident, death, and injury indicators were combined into an index. The calculations required for PCA were performed using Python and Microsoft Excel software. The “Analysis ToolPak” add-in for Excel and the Scikit-learn library for Python enabled this analysis to be carried out effectively.

In order to determine the spatial relationship between road accidents and regional indicators, the ETA coefficient was calculated and the impact of regions on the RTA was detected. To further investigate the relationship between economic indicators and the GNP, linear, quadratic, and logarithmic regression models were compared. R², Adjusted R², and RMSE were used to assess the fit of these models.

All research analyses used Python's Pandas, NumPy, and Matplotlib libraries for data processing, calculations, and visualization. For some detailed statistical analyses, SPSS or R software was used to verify the results. With the help of these methods and software, a deep analysis of the multifaceted problems of road safety in Mongolia was made possible, and realistic conclusions and solutions were drawn (Bayarsaikhan *et al.*, 2023) [7].

Results

Determination of the Road Safety Index

The data collected in this article are based on the statistics of road accidents, crimes, deaths and injuries recorded in

Mongolia. According to Pearson correlation analysis based on statistical data from 2014-2023, the correlation between the number of road accidents and deaths is r1=0.305 (P<0.05), which is a slight positive correlation between these indicators, which is statistically significant; the correlation between the number of road accidents and the number of injured is r2=0.758 (P<0.001), which is a very strong positive correlation, which is very significant; the correlation between the number of deaths and the number of injured is r3=0.542 (P<0.001), which is a moderate positive correlation, which is also significant, which suggests that further research is possible. It is seen that the above correlations represent different aspects of the RTA and are also interconnected. The number of road accidents, deaths, and injuries has been standardized and comprehensively developed.

To determine the indicators of the Traffic safety, PCA (Principal Component Analysis) analysis was performed (Shuwei Zhang, 2024; Pradip Sarkar Mandar Khanal, 2023; Shahram Heydari *et al.*, 2019) [8, 9, 10], and then Eigenvalue and Component Score Coefficients were determined using Excel. Excel does not have a direct function for PCA, but it can be calculated using the “Analysis ToolPak” tool. To do this, it was necessary to activate the “Analysis ToolPak” of Excel, prepare data suitable for PCA analysis, and standardize variables. To do this, the following formula was used.

After that, the covariance matrix was calculated using the Data analyses tool of Excel, and then the Eigenvalue and Eigenvector were determined using Python.

$$Z = \frac{x - \text{mean}}{\text{standard deviation}} \tag{1}$$

Table 2: Covariance matrix

Type	died	injured	traffic accident
died	13.06382		
injured	17.2205	77.18757	
traffic accident	164.5222	993.9927	22294.7

Table 3: Result of Eigenvalue болон Eigenvector

Eigenvalue	Eigenvector 1	Eigenvector 2	Eigenvector 3
22340.303966	-0.007396	-0.929550	-0.368623
7.930714	-0.044608	0.368573	-0.928528
36.717708	-0.998977	-0.009576	0.044191

Using these values, it is possible to perform Component Score Coefficients and other necessary calculations, and the Component Score Coefficients are calculated as follows:

Table 4: Component score coefficients

Component	died	injured	Traffic accident
1-р КОМПОНЕНТ	-0.000049	-0.006219	-0.002466
2-р КОМПОНЕНТ	-0.015840	0.130878	-0.329715
3-р КОМПОНЕНТ	-0.164861	-0.001580	0.007293

These coefficients are obtained by dividing the eigenvectors by the square root of the eigenvalue. In the future, the selection of the best-fitting component for calculating RTS (Road Traffic Safety) is based on the component that contains the most relevant information for the analysis. The following factors are considered when selecting it. Component 1 had the highest Eigenvalue and explained the most information affecting the indicators of road

accidents, deaths and injuries. Therefore, component 1 was considered the most suitable for use in calculating RTS. These coefficients are multiplied by the evaluation of each variable when calculating RTS and the sum is calculated.

$$\text{Variance Contribution Rate (VCR)} = \frac{\text{Eigenvalue}}{\text{Total Eigenvalue Sum}} \cdot 100 \tag{2}$$

Also, the variance contribution rate (more precisely, the amount of contribution or explanation rate) of the principal component can be determined from the results of Principal Component Analysis (PCA). The variance contribution rate is calculated using the following formula:

$$RTS = -0.000049 \cdot X_1 - 0.006219 \cdot X_2 - 0.002466 \cdot X_3 \tag{3}$$

From the PCA analysis data (calculated above), component 1 explains 99.4% of the total data.

Here,

X1: Number of people died in traffic accidents. **X2:** Number of people injured in traffic accidents.
X3: Total number of traffic accidents.
 These are taken from the data and put into the equation to calculate

the RTS index in that situation. Figure 1 shows the frequency distribution of the RTS index and the cumulative percentage of the RTS index in the regions of Mongolia from 2014 to 2023. The range of RTS distribution was very wide.

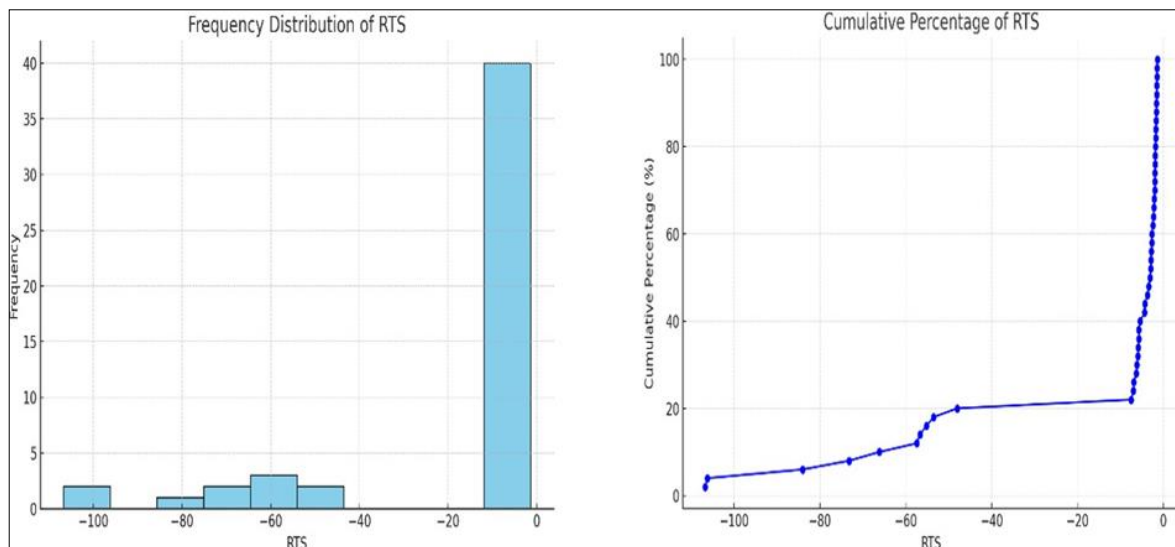


Fig 1: Chart showing the frequency distribution and cumulative percentage of RTS index in regions of Mongolia

The lowest RTS index value was -1.436 in the Eastern Region (R4) in 2016, while the highest value was -106.724 in the Ulaanbaatar Region (R5) in 2015. According to statistical data, about 90% of the data were between -20.0 ~ 0.0.

1. Time and space effects on the RTS

The changes in the RTS index of the regions of Mongolia from 2014 to 2023 are shown in Table 2. To analyze the

effects on RTS, the years 2014 to 2023 were taken as continuous variables (Joseph R., 2006; Khair Jadaan *et al.*, 2018) [12]. According to Pearson correlation analysis, the correlation coefficient between year and RTS index is $r=0.113$, P value 0.435. This is a weak correlation between years and the traffic security index, and this correlation is not statistically significant.

Table 5: Mean and Standard Deviation of RTS (2014-2023)

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
mean	-17.399	-23.996	-24.593	-19.462	-15.781	-13.815	-11.714	-14.170	-13.194	-13.812
std	31.266	46.284	45.730	36.142	28.239	24.430	20.307	23.838	22.619	23.218

Spatial Impact on Traffic Safety

The regional RTS index of Mongolia is shown in Table 6. To analyze the impact on the RTS index, region was taken as a variable (Maryam Tavakkoli *et al.*, 2022) [13]. The eta coefficient test showed that $ETA=0.947$, $ETA2=0.896$, indicating a significant relationship between region and RTS, and 89% of RTS can be predicted from regions. To calculate the ETA coefficient, the overall mean of all RTS values was calculated and the average value of RTS values for each Region was found. After that, the Eta square was calculated by calculating the size of the difference between groups (SS_between) and calculating the total size of the difference (SS_total).

Table 6: Mean and Standard Deviation of RTS by Region

Region	R1	R2	R3	R4	R5	Mongolia
mean	-1.856	-3.431	-6.131	-1.820	-70.731	-16.794
std	0.251	0.967	0.914	0.331	21.572	28.818

The relationship between the economy and RTS
 The impact of economic development on RTS was complex. To further explore the relationship between the two, three univariate regression models were constructed, with GDP per capita as the independent variable and the corresponding value of RTS as the dependent variable. The results are shown in Table 6.

Table 7: Data for single-element regression models

Model	R ²	Adjusted R ²	RMSE	Equation
Linear	0.540	0.531	19.338	$y=-0.466-2.189 \cdot 10^{-6} \cdot x$
Quadratic	0.717	0.705	15.170	$y=11.567-5.711 \cdot 10^{-6} \cdot x + 9.651 \cdot 10^{-14} \cdot x^2$
Logarithmic	0.613	0.605	17.751	$y=333.942-2.297 \cdot 10 \log x$

A table containing the R², Adjusted R², and RMSE values for the Linear, Quadratic, and Logarithmic models between

RTS and GDP is presented. Comparing the three models, the Quadratic model has the highest R², Adjusted R² values,

and the lowest RMSE value. This indicates that the relationship between RTS and GDP is the strongest. The three models are shown in Figure 3.

RTS and GDP are indirectly related to each other to some extent. The quadratic model more accurately reflects the

impact of GDP growth on RTS. It is possible that GDP and RTS are inversely related: when GDP increases, RTS decreases.

This suggests that the risks of a particular RTS decrease as economic development improves.

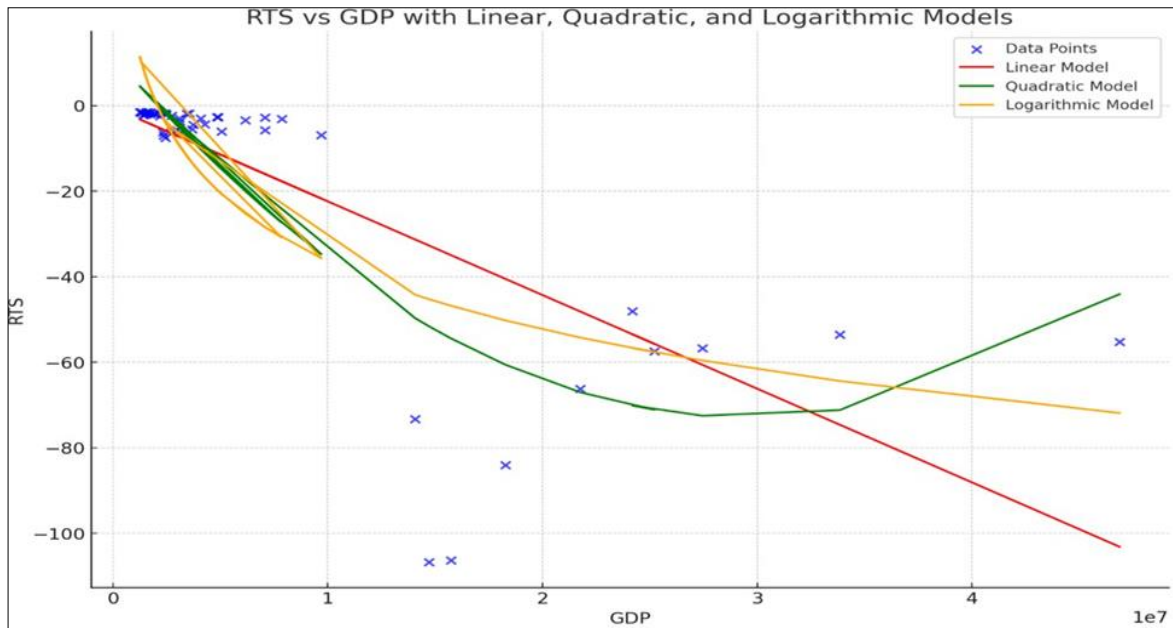


Figure 2: RTS vs GDP with Linear, Quadratic, and Logarithmic Models

Discussion

Economic development limits the improvement of road safety, a challenge faced by all developing countries.

Figure 3 shows the growth rate of road accidents and casualties in Mongolia from 2014 to 2023.

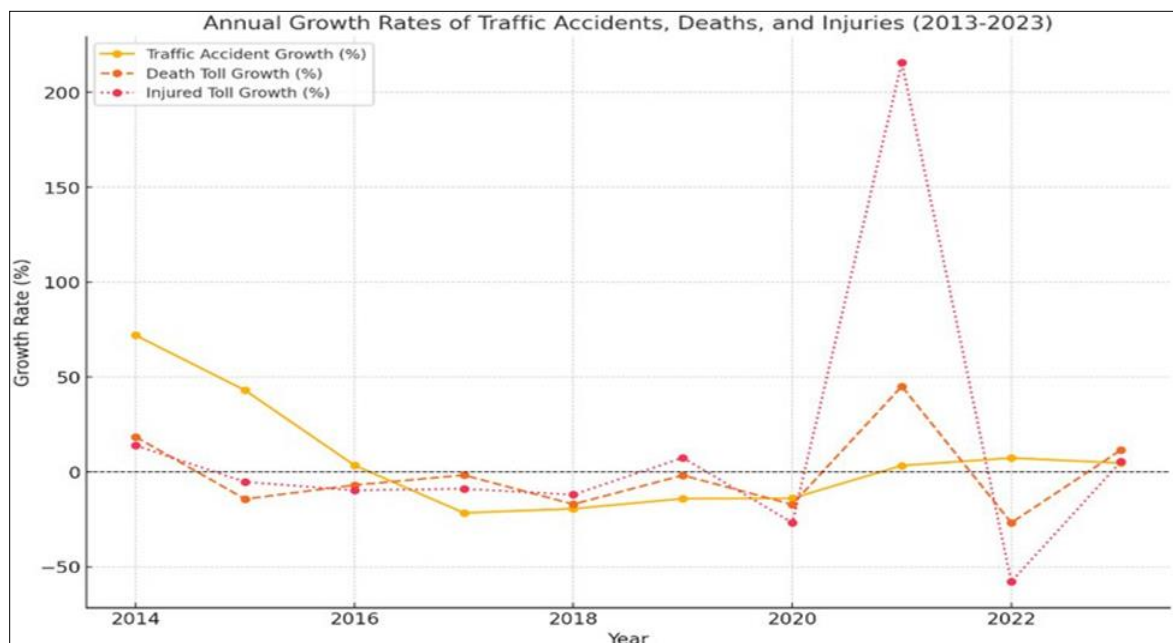


Fig 3: Annual Growth Rates of Traffic Accidents, Deaths, and Injuries

Annual Growth Rates of Traffic Accidents, Deaths, and Injuries The above graph shows that since 2013, the number of road accidents has increased dramatically in some years (for example, ~72% increase in 2014), and in subsequent years, the increase has tended to decrease. The number of road accidents decreased between 2017 and 2018 (~- 21.7%, -19.5%), which may be due to the effectiveness of control

measures. However, deaths increased slightly in 2014 (~18.4%), but have been decreasing since 2015. The decrease in deaths has been relatively stable since 2017 (~-1.8%, -17.1%). The number of injuries increased by ~13.9% in 2014, but has been decreasing steadily since 2015. The decrease from year to year is relatively stable and is likely related to the number of accidents. Traffic accidents

have shown the largest increase and decrease, while deaths and injuries have a slightly stable tendency to decrease. This may be an effective policy to reduce the number of accidents, but it is noteworthy that there has been an increase in certain years.

Conclusion

This study aims to examine traffic safety in Mongolia between 2014 and 2023 and identify challenges and solutions. The main findings of the study are as follows:

1. Relationship between road accidents and the number of deaths and injuries

- A strong positive relationship ($r=0.758$, $P<0.001$) was found between traffic accidents and injuries, indicating that injuries increase with the increase in traffic accidents.
- A weak relationship ($r=0.305$, $P<0.05$) was observed between deaths and accidents, highlighting the need to pay attention to accident conditions.

2. Regional differences

- The ETA coefficient ($ETA=0.947$) indicates a strong influence of regions on the RTS (Traffic Safety Index). This highlights the need for regionally appropriate policies and measures.

3. Impact of economic development

- Economic growth can have a positive impact on RTS, but the regression models confirmed that this relationship is not linear. The quadratic model had the highest R^2 (0.717), which explains the relationship between economic growth and RTS more accurately.

4. Areas for improvement

- Challenges arising from factors such as urbanization, the number of private cars, and road conditions need to be addressed.
- It is important to improve traffic rules and increase public awareness of safety.

5. Recommendations

- Improve infrastructure and strengthen control over the implementation of traffic rules.
- Implement policies based on regional characteristics.
- Increase public participation and improve preventive measures.

This study provides important information and conclusions to improve traffic safety in Mongolia and will be a valuable source for future policy development.

References

1. Ministry of Roads and Transport Development. White Paper on Road Traffic Safety in Mongolia. Ministry of Roads and Transport Development, 2022.
2. General Police Department Road Police Agency. Statistics about traffic accidents in Mongolia. General Police Department Road Police Agency, 2023, 9–93. (in Mongolian)
3. Mathew T. TRL software, Advancing Road Safety in Mongolia: Implementing a Comprehensive Crash Data Management System iMAAP. Road Safety, 2024.
4. Ulziikhutag O, Eldev-Ochir E. AIRI Road Safety in Mongolia – ESCAP National Workshop on Inclusive Transport and Innovation, Ulaanbaatar, Mongolia. AIRI, 2023.

5. Guy K, Stapleton R. Mongolia Road Safety Management. Asian Development Bank, 2024.
6. Ganbaatar A, Thiruchelvam M, Lu L. Mongolia: Institutional Strengthening for Road Safety. Asian Development Bank, 2023.
7. Bayarsaikhan B, Ganjargal O, Lhagvasuren B. An Analysis of Road Safety Trends in Mongolia. Proceedings of the Eastern Asia Society for Transportation Studies, 2023, 14.
8. Zhang S. Road Traffic Safety in Developing Countries: Taking China as an Example. Iranian Journal of Public Health, 2024;53(2):356–366. doi:10.18502/ijph.v53i2.14920
9. Sarkar P, Khanal M. Road Safety in Developing Countries. Journal of Civil & Environmental Engineering, 2023, 4(2). doi:10.4172/2165-784X.S3-001
10. Heydari S, Hickford A, McIlroy R, Turner J, Bachani AM. Road Safety in Low-Income Countries: State of Knowledge and Future Directions. Sustainability, 2019;11(22):6249. <https://doi.org/10.3390/su11226249>
11. Morris JR. Improving Road Safety in Developing Countries, 2006, 32.
12. Jadaan K, Al-Braizat E, Al-Rafayah S, Gammoh H. Traffic Safety in Developed and Developing Countries: A Comparative Analysis. Journal of Traffic and Logistics Engineering, 2018;6(1):1–5. doi:10.18178/jtle.6.1.1-5
13. Tavakkoli M, Torkashvand-Khah Z, Fink G, Takian A, Kuenzli N, de Savigny D, *et al.* Evidence from the Decade of Action for Road Safety: A Systematic Review of the Effectiveness of Interventions in Low and Middle-Income Countries. Public Health Reviews, 2022, 43. <https://doi.org/10.3389/phrs.2022.1604499>