Road Traffic Safety in Mongolia: Trends, Challenges, and Solutions (2014–2023)

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Abstract: This study examines road traffic safety (RTS) in Mongolia from 2014 to 2023, analyzing trends, challenges, and potential solutions. Utilizing Pearson correlation and Principal Component Analysis (PCA), the study identifies strong positive correlations between traffic accidents and injuries ($r=0.758$, $P<0.001$), while weaker correlations exist between accidents and fatalities ($r=0.305$, $P<0.05$). Regional disparities play a significant role, with an ETA coefficient of 0.947, highlighting substantial spatial influences on RTS. Quadratic regression models demonstrate non-linear relationships between RTS and GDP, indicating that economic growth can reduce risks under specific conditions. Key challenges include rapid urbanization, poor rural road conditions, and seasonal hazards. The study underscores the importance of tailored policies, infrastructure improvement, and enhanced public awareness to mitigate traffic risks. It offers a comprehensive statistical analysis, providing actionable insights for policymakers aiming to improve road safety in Mongolia's unique socio-economic and geographical context.

Keywords: Road Traffic Safety, Traffic Accidents, Mongolia, Statistical Analysis, PCA

1. INTRODUCTION

Mongolia, a landlocked country in East Asia, spans 1.6 million square kilometers, ranking 19th globally in land area. Its vast steppes, high mountain ranges, and arid deserts present unique challenges to transportation infrastructure. The country’s extreme continental climate, characterized by harsh, prolonged winters and short summers, significantly impacts road conditions and safety (White Paper on Road Traffic Safety in Mongolia, 2022). Between 2014 and 2023, rapid urbanization resulted in a 70% increase in the number of vehicles, surpassing 1.2 million registered vehicles by 2023. Approximately half of these vehicles are concentrated in Ulaanbaatar, where nearly 50% of the population resides (Statistics about traffic accidents in Mongolia, 2023).

Urbanization and rising incomes have accelerated private vehicle ownership, intensifying traffic congestion in urban centers. In contrast, rural areas, home to 36% of the population, are characterized by underdeveloped road networks dominated by unpaved roads, increasing the risk of intercity traffic accidents (Tony Mathew, 2024).

Political and legislative developments have also influenced road traffic safety trends. The government has implemented new traffic laws and adopted a national road safety strategy aiming to reduce traffic fatalities by 25% by 2030 (Odgerel and Erdenechimeg, 2023). The national strategy provides a structured framework encompassing infrastructure improvement, public education, traffic law enforcement, and emergency response coordination. It is necessary to address Mongolia’s complex traffic safety landscape, where rapid urbanization, climatic extremes, and regional disparities demand an integrated and adaptive policy approach.

However, enforcement challenges and limited public engagement have impeded the effectiveness of these initiatives. For instance, only 60% of drivers consistently use seat belts, and helmet use among motorcyclists remains below 50% (Katherine Guy and Rebecca Stapleton, 2024).

Seasonal factors further exacerbate traffic risks. Icy roads during winter increase accidents by 30%, while spring dust storms reduce visibility, raising collision risks. These environmental, infrastructural, and behavioral challenges highlight the multifaceted nature of Mongolia's road traffic safety issues (Anand *et al*., 2023).

This study examines these interconnected factors, providing an in-depth analysis of Mongolia's road traffic safety trends and proposing feasible solutions to address pressing challenges.

2. RESEARCH METHODOLOGY

2.1 Data Sources and Description

The data used in this study were essential for identifying trends in road traffic safety in Mongolia and were derived from the following sources. To enhance the robustness of our findings, additional empirical studies on RTS in low- and middle-income countries were reviewed and incorporated, including Zhang (2024), Sarkar & Khanal (2023), and Heydari et al. (2019), which provide relevant methodologies and insights for contextual comparison.

a. Traffic Accident, Crime, Fatality, and Injury Statistics:
   - These data were obtained from the Traffic Police Department of Mongolia.
   - They encompass traffic accidents and their impacts recorded between 2014 and 2023.

b. Economic Indicators:
   - Indicators such as GDP per capita were sourced from the reports of the National Statistics Office of Mongolia.
   - These data were used to assess the impact of economic growth on road traffic safety.

c. Regional Classification:
   - For this study, Mongolia was divided into five regions (Western, Khangai, Central, Eastern, and Ulaanbaatar), with the road conditions in each region analyzed accordingly.

d. Seasonal Characteristics and Environmental Influences:
   - The frequency and severity of accidents during winter and spring were compared with natural phenomena affecting road conditions during these seasons.

Table 1. Regional Classification of Mongolia

№	Region	Provinces Included
R1	Western	Bayan-Ulgii, Govi-Altai, Zavkhan, Uvs, Khovd
R2	Khangai	Arkhangai, Bayankhongor, Uvurkhangai, Bulgan, Orkhon, Khuvsgul
R3	Central	Darkhan-Uul, Selenge, Tuv, Govisumber, Dornogovi, Dundgovi, Umnugovi
R4	Eastern	Dornod, Sukhbaatar, Khentii
R5	Ulaanbaatar	Capital city Ulaanbaatar and its satellite towns

2.2 Statistical Analysis

The statistical analysis for this study employed internationally recognized methods and modern software tools. Pearson correlation analysis was utilized to assess the relationships among traffic accidents, fatalities, and injuries, providing an effective method to quantify the strength and direction of associations between variables. Pearson correlation was selected due to its effectiveness in quantifying linear relationships among accident-related variables. PCA was used to synthesize these correlated indicators into a single RTS index, aligning with approaches in recent studies (Shuwei Zhang, 2024; Pradip Sarkar, 2023), ensuring statistical robustness and comparability. To comprehensively represent the traffic accident index, Principal Component Analysis (PCA) was applied. PCA enabled the calculation of Eigenvalues and Eigenvectors, which were used to consolidate traffic accidents, fatalities, and injuries into an aggregated index. The necessary computations for PCA were conducted using Python and Microsoft Excel. Excel's "Analysis ToolPak" add-in and Python's Scikit-learn library facilitated the efficient implementation of this analysis.

The Eta coefficient was calculated to determine spatial correlations between traffic accidents and regional indicators, highlighting the influence of regional factors on road traffic safety (RTS). The relationship between economic indicators and RTS was further explored using linear, quadratic, and logarithmic regression models. Metrics such as R^2, Adjusted R^2, and RMSE were employed to evaluate the suitability of these models.

Python libraries, including Pandas, NumPy, and Matplotlib, were extensively utilized for data processing, computations, and visualizations. Additional statistical analyses were verified using SPSS or R software.

These methodologies and software tools enabled an in-depth analysis of Mongolia's multifaceted road traffic safety issues, providing actionable insights and robust solutions (Bayarsaikhan *et al.*, 2023).

3. RESULTS

3.1 Determining the Road Traffic Safety Index

The data analyzed in this study are based on statistics of registered traffic accidents, crimes, fatalities, and injuries in Mongolia. Using Pearson correlation analysis on data from 2014 to 2023, the following relationships were identified:

- The correlation between the number of traffic accidents and fatalities is $r_1=0.305$ ($P < 0.05$), indicating a weak positive correlation that is statistically significant.
- The correlation between the number of traffic accidents and injuries is $r_2=0.758$ ($P < 0.001$), demonstrating a strong positive and highly significant correlation n.
- The correlation between fatalities and injuries is $r3=0.542$ ($P < 0.001$), reflecting a moderate positive correlation that is also significant.

These findings suggest interconnected relationships among these variables, illustrating various aspects of road traffic safety (RTS). The data for traffic accidents, fatalities, and injuries were standardized to create a comprehensive index.

To determine the RTS index, Principal Component Analysis (PCA) was conducted (Shuwei Zhang, 2024; Pradip Sarkar Mandar Khanal, 2023; Shahram Heydari *et al.*, 2019). PCA calculations, including Eigenvalues and Component Score Coefficients, were performed using Microsoft Excel. The theoretical justification for applying PCA lies in its ability to reduce dimensionality and extract the most informative component representing RTS variation. Prior studies (Zhang, 2024; Heydari et al., 2019) have also applied PCA in traffic safety assessments, validating its interpretability and utility for index construction. Although Excel lacks a direct PCA function, these computations were made possible by activating the "Analysis ToolPak" add-in. This required preparing the data for PCA, standardizing the variables, and applying the following formula. Before applying PCA, variables were standardized to have zero mean and unit variance to eliminate scale effects. The RTS index was constructed by selecting the first principal component, which accounted for 99.4% of the variance. This component's score coefficients were used to calculate the RTS index through a linear combination of standardized fatalities, injuries, and accident counts.

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

Subsequently, the covariance matrix was calculated using Excel's Data Analysis tool, and the Eigenvalues and Eigenvectors were determined using Python.

Table 2. Covariance Matrix

	Fatalities	Injuries	Total Traffic Accidents (TTA)
Fatalities	13.06382		
Injuries	17.2205	77.18757	
TTA	164.5222	993.9927	22294.7

Table 3. Results of Eigenvalues and Eigenvectors

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, the Component Score Coefficients and other necessary calculations were determined. The Component Score Coefficients were calculated as follows:

Table 4. Component Score Coefficients

Component	Fatalities	Injuries	Total Traffic Accidents (TTA)
Component 1	-0.000049	-0.006219	-0.002466
Component 2	-0.015840	0.130878	-0.329715
Component 3	-0.164861	-0.001580	0.007293

These coefficients were derived by dividing the eigenvectors by the square root of the eigenvalues. To calculate the Road Traffic Safety (RTS) index, the most suitable component was selected based on the one containing the most significant and relevant information for the analysis. The first component, with the highest eigenvalue, was found to explain the largest proportion of variance in traffic accidents, fatalities, and injuries. Therefore, the first component was deemed the most appropriate for calculating the RTS index. These coefficients were used in the RTS calculation by multiplying them with the corresponding variable values and summing the results.

Additionally, the variance contribution rate of the principal component was determined from the results of the Principal Component Analysis (PCA). This contribution rate, which represents the proportion of variance explained by the component, can be calculated using the following formula.

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

The PCA analysis data (calculated above) show that the first component explains 99.4% of the total variance in the dataset.

$$RTS = -0.000049 \cdot X_1 - 0.006219 \cdot X_2 - 0.002466 \cdot X_3 \quad (3)$$

where,

X_1 : the number of fatalities caused by traffic accidents,
X_2 : the number of injuries caused by traffic accidents,
X_3 : the total number of traffic accidents.

By extracting these values from the dataset and applying them to the equation, the RTS index can be calculated under the given conditions. Figure 1 depicts the frequency distribution of the RTS index across Mongolia's regions from 2014 to 2023, as well as the cumulative percentage of the RTS index. The range of RTS distribution was significantly broad.

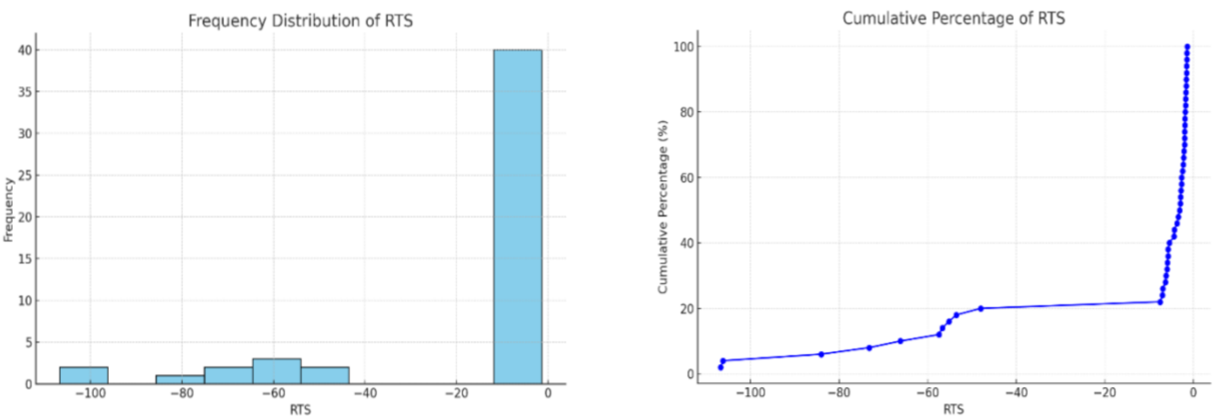

Figure 1. Graph Showing the Frequency Distribution and Cumulative Percentage of the RTS Index Across Regions in Mongolia

The lowest RTS index value was observed in the Eastern region (R4) in 2016, with a value of -1.436, while the highest value was recorded in the Ulaanbaatar region (R5) in 2015, reaching -106.724. Statistical data indicate that approximately 90% of the values fell within the range of -20.0 to 0.0.

4. TEMPORAL AND SPATIAL EFFECTS ON RTS

4.1 Temporal Effects on RTS

The changes in the RTS index across Mongolia's regions from 2014 to 2023 are presented in Table 2. To analyze the temporal effects on RTS, the years 2014–2023 were treated as a continuous variable (Joseph R., 2006; Khair Jadaan *et al.*, 2018). Pearson correlation analysis revealed a correlation coefficient of r=0.113r = 0.113 and a p-value of 0.435 between years and the RTS index. This indicates a weak correlation between the two variables, which 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

4.2 Spatial Effects on RTS

The RTS index for Mongolia's regions is presented in Table 6. To analyze the spatial effects on RTS, regions were treated as a variable (Maryam Tavakkoli *et al.*, 2022). The Eta coefficient test showed ETA=0.947 and ETA^2=0.896, indicating a significant correlation between regions and RTS. This suggests that 89% of the variation in RTS can be predicted based on regions.

To calculate the Eta coefficient, the overall mean of all RTS values was determined, followed by calculating the mean RTS values for each region. The variation between groups ($SS_{between}$) and the total variation (SS_{total}) was computed to derive the Eta squared value.

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

5. RELATIONSHIP BETWEEN ECONOMIC DEVELOPMENT AND RTS

The impact of economic development on RTS was found to be complex. To further investigate this relationship, three single-element regression models were developed, with GDP per capita as the independent variable and the corresponding RTS values as the dependent variable. The results are presented in Table 7.

Table 7. Information on 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 summarizing the R^2, Adjusted R^2, and RMSE values for the linear, quadratic, and logarithmic regression models between RTS and GDP has been developed and presented. Among the three models, the quadratic model demonstrates the highest R^2 and Adjusted R^2 values, along with the lowest RMSE, indicating the strongest correlation between RTS and GDP. We acknowledge the reviewer's suggestion and agree that using disaggregated indicators such as the number of fatalities, injuries, and crashes as separate dependent variables could enhance interpretability. However, the RTS index was constructed to capture the multidimensional nature of traffic safety performance in a compact form, facilitating regional and temporal comparisons. Future studies may explore simultaneous equation models to further analyze these relationships individually. The comparison of the three models is illustrated in Figure 3.

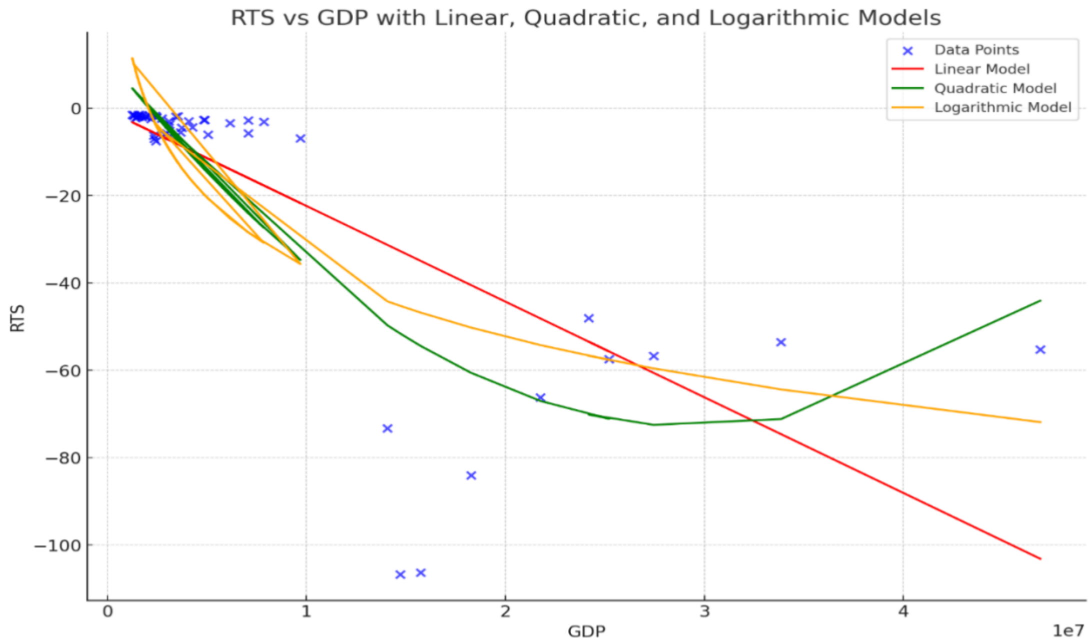

Figure 2. RTS vs GDP with Linear, Quadratic, and Logarithmic Models

The relationship between RTS and GDP appears to be indirect. The quadratic model provides a more detailed representation of how GDP growth impacts RTS. There is a likelihood of an inverse relationship between GDP and RTS, where an increase in GDP may lead to a decrease in RTS. This suggests that as economic development improves, certain RTS risks may be reduced.

6. DISCUSSION

Economic development poses challenges to improving road traffic safety (RTS), a common issue faced by all developing countries. Figure 4 illustrates the growth rates of traffic accidents and casualties in Mongolia from 2014 to 2023.

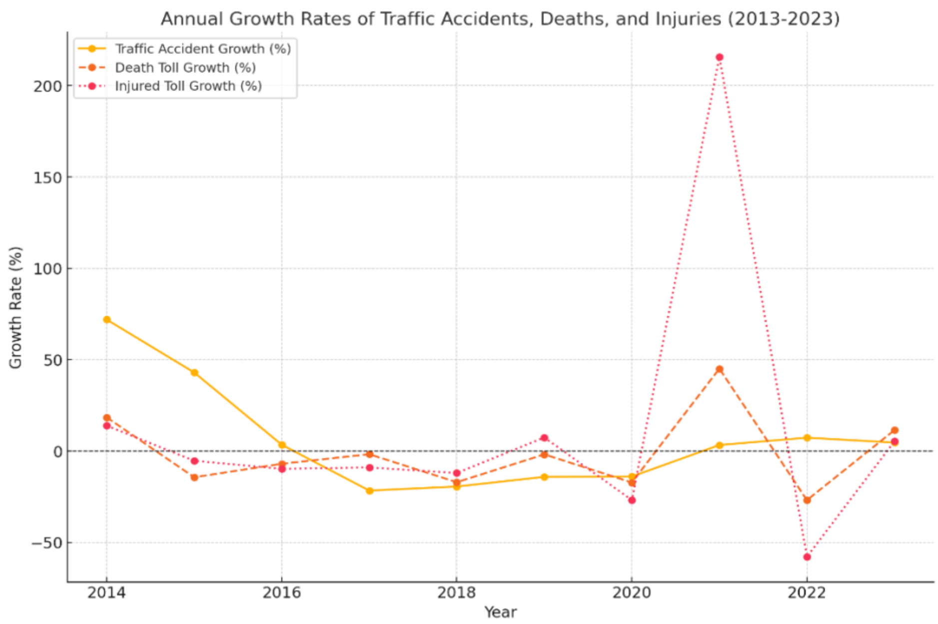

Figure 3. Annual Growth Rates of Traffic Accidents, Deaths, and Injuries

The graph shows that since 2013, the number of traffic accidents has significantly increased in some years (e.g., a -21.7%, -19.5%), suggesting that control measures may have been effective. Fatalities slightly increased in 2014 (-1.8%, -17.1%). The number of injuries increased by ~13.9% in 2014 but has consistently decreased since 2015. These reductions appear to correlate with the decline in the number of accidents. Traffic accidents demonstrated the most pronounced fluctuations in both increases and decreases, whereas fatalities and injuries have shown a more stable downward trend. This indicates that policies aimed at reducing accidents may have been effective; however, the occasional spikes highlight areas requiring further attention and intervention.

7. CONCLUSION

This study examined road traffic safety (RTS) in Mongolia from 2014 to 2023, aiming to identify challenges and propose solutions. The following conclusions were drawn from the key findings:

a. Correlation Between Traffic Accidents, Fatalities, and Injuries:
   - A strong positive correlation was observed between traffic accidents and injuries ($r=0.758$, $P<0.001$), indicating that an increase in accidents leads to more injuries.
   - A weak positive correlation between fatalities and accidents ($r=0.305$, $P<0.05$) highlights the need for targeted attention to accident conditions.

b. Regional Disparities:
   - The Eta coefficient (ETA=0.947) demonstrates a strong regional influence on RTS, emphasizing the need for region-specific policies and interventions.

c. Impact of Economic Development:
   - Economic growth can positively influence RTS, but this relationship is non-linear, as evidenced by regression models. The quadratic model, with the highest R^2 (0.717), provides a more detailed explanation of the relationship between economic growth and RTS.

d. Areas for Improvement:
    - Challenges related to urbanization, private vehicle ownership, and road conditions require immediate attention.
    - Enhancing road traffic rules and raising public awareness about safety are crucial.

e. Recommendations:
    - Improve infrastructure and strengthen the enforcement of traffic regulations.
    - Develop region-specific policies tailored to local conditions.
    - Increase public engagement and enhance preventative measures.

This study provides critical insights and actionable recommendations for improving road traffic safety in Mongolia, serving as a valuable resource for future policy development.

REFERENCES

White Paper on Road Traffic Safety in Mongolia (2022) Ministry of Roads and Transport Development, Mongolia.

Statistics about traffic accidents in Mongolia (2023) General Police Department Road Police Agency, 9-93. (in Mongolian)

Tony Mathew (2024) *Advancing Road Safety in Mongolia: Implementing a Comprehensive Crash Data Management System*, TRL software, iMAAP, Road Safety.

Odgerel Ulziikhutag, Erdenechimeg Eldev-Ochir (2023) *Road Safety in Mongolia – ESCAP*, National Workshop on Inclusive Transport and Innovation, AIRI, Ulaanbaatar, Mongolia

Katherine Guy, Rebecca Stapleton (2024) Mongolia Road Safety Management, ADB.

Anand Ganbaatar, Mookiah Thiruchelvam, Lin Lu (2023) Mongolia: Institutional Strengthening for Road Safety, Asian Development Bank (ADB).

Bayarsaikhan, B., Ganjargal, O., Lhagvasuren B. (2023) *An Analysis of Road Safety Trends in Mongolia*, Proceedings of the Eastern Asia Society for Transportation Studies, Vol.14.

Shuwei Zhang (2024) *Road Traffic Safety in Developing Countries: Taking China as an example*, Iran J Public Health. 53(2):356–366.

Pradip Sarkar Mandar Khanal (2023) *Road Safety in Developing Countries*, Journal of Civil & Environmental Engineering 04(02).

Shahram Heydari, Adrian Hickford, Rich McIlroy, Jeff Turner, and Abdulgafoor M. Bachani (2019) *Road Safety in Low-Income Countries: State of Knowledge and Future Directions*, 11(22), 6249.

Joseph R. Morris (2006) *Improving Road Safety in Developing Countries*, 32p

Khair Jadaan, Ethar Al-Braizat, Sajeda Al-Rafayah, Hala Gammoh (2018) *Traffic Safety in Developed and Developing Countries: A Comparative Analysis*, University of Jordan, Journal of Traffic and Logistics Engineering.

Maryam Tavakkoli, Zahra Torkashvand-Khah, Günther Fink, Amirhossein Takian, Nino Kuenzli, Don de Savigny, Daniel Cobos Muñoz (2022) *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 Rev, Volume 43.