

Validity of the TRINCA Model (1988) in Current European Road Safety Assessment: A Comparative Study Using Recent Data

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Received: 20 November 2024, Accepted: 03 August 2025, Published online: 25 November 2025

Abstract

Road safety is a growing concern in Europe, with significant changes in traffic conditions, vehicle technology, and safety regulations over the past decades. The TRINCA model (1988) was historically effective in assessing road safety through two key indicators: Personal and Road Safety. However, its validity in the current context has become questionable due to evolving road safety measures. This study examines the applicability of the TRINCA model using recent data from 27 European countries for the years 2005, 2010, 2015, and 2020. Countries were divided into four geographical regions, and a *T*-test analysis was performed to compare the observed data against the model's predictions. The results reveal significant discrepancies, particularly after 2015, with *P*-values indicating statistically solid significance ($P \leq 0.05$ to $P \leq 0.001$). These findings suggest that the TRINCA model no longer accurately represents current road safety trends and highlights the need for an updated framework incorporating recent advancements in vehicle technology, infrastructure improvements, and updated traffic regulations.

Keywords

personals safety, road safety, TRINCA model, mortality, fatality

1 Introduction

In recent decades, the world, particularly European countries, has seen a growing focus on improving road safety and reducing traffic accidents, especially with increased vehicle numbers and higher mobility rates. According to the World Health Organization (WHO) (2023), road traffic accidents are among the leading causes of death worldwide. Nearly 1.19 million people lose their lives annually due to road traffic accidents.

Road safety and personal security remain priorities for traffic policies and academic research. Numerous models and indicators have been developed to assess the level of road safety, aiming to measure and analyze the risks associated with road travel. One notable model from the 1980s is the TRINCA model (1988) (Török, 2017; Trinca et al., 1988), which was widely employed to assess personal and road safety across various European nations (Török, 2015); this model utilizes two key indicators: Personal Safety

(number of fatalities per 100,000 inhabitants) and Road Safety (fatalities per 10,000 registered vehicles).

During its initial application, the model effectively aided in analyzing traffic safety and supporting policy development in the field. Researchers emphasized that the use of this model provided a clearer and more comprehensive understanding of traffic safety.

Török (2015) aimed to define the most important road safety challenges of Hungary. His methodology of the analysis highlights the interdependency of road safety and economy. However, with evolving traffic patterns and infrastructure improvements across Europe, there is a need to reevaluate the relevance of the TRINCA model with contemporary data. Factors like population growth, increased vehicle usage, and changing safety standards might affect the model's reliability. In this research, we intend to assess the applicability of the TRINCA model using updated data from 27 European

countries for the years 2005, 2010, 2015, and 2020. We categorized these countries into four geographical regions and performed a *T*-test to determine the model's validity.

This study aims to provide an unbiased evaluation of the TRINCA model and ascertain whether it remains effective or requires revision to align with modern data.

2 Literature review

2.1 Motor vehicle accidents: fatality trends and mortality trends

Car accidents are a significant cause of death and injuries in European countries. As reported by the World Health Organization in 2023, fatalities from road traffic accidents have declined by 5% since 2010, now amounting to 1.19 million deaths annually. However, road crashes remain a persistent global health issue, with pedestrians, cyclists, and other vulnerable road users continuing to face a high risk of fatal accidents (WHO 2023). Over the past decades, there have been fluctuations in the fatality rates from these accidents, driven by various factors. These include infrastructure improvements, traffic laws and policy changes, and vehicle design and safety system advancements (Farmer and Lund, 2006). In reviewing the literature on historical motor vehicle fatality trends, two contrasting patterns emerge: a significant increase in the total number of deaths and a simultaneous decline in the fatality rates per capita over time. As illustrated in Fig. 1, derived from data provided by the National Safety Council (NSC) (nsc Injury Facts, online) for the period from 1913 to 2022, there is a notable rise in the total number of annual motor vehicle-related deaths (green line), particularly during the mid-20th century. However, despite the increase in absolute death counts, the data also indicate a consistent decline in fatality rates per 100,000 population (blue line), especially after 1970.

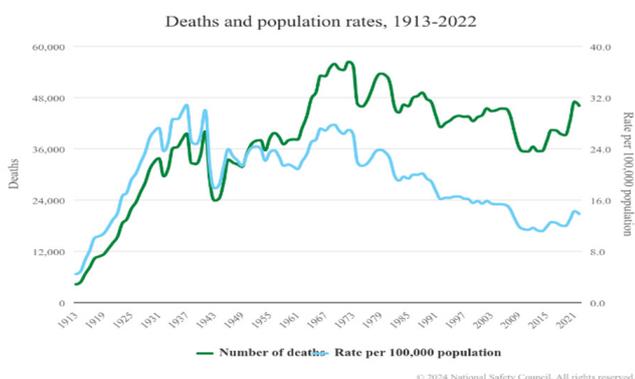


Fig. 1 Illustration of motor vehicle fatality trends from NSC data (1913–2022). The green line represents total deaths, while the blue line shows fatality rates per 100,000 population (nsc Injury Facts, online).

This divergence highlights the impact of advancements in traffic safety measures, vehicle design improvements, and stricter regulations to reduce risky driving behaviors.

2.2 Road transport safety and the TRINCA model

Road safety is a critical issue faced by communities globally, so its improvement is an essential goal for transportation authorities, as road traffic accidents (RTAs) result in approximately 50 million injuries and 1.2 million fatalities annually, causing significant human and material losses (Alirezai et al., 2017; Atubi and Gbadamosi, 2015; Wangdi et al., 2018). Numerous studies have investigated the factors contributing to road accidents, highlighting the complexity of this field due to the intricate relationships between various social and economic variables. Research efforts have often concentrated on road traffic fatalities (RTFs) in developed or high-income nations (Gaygisiz, 2010). Several scholars have also examined the impact of advancements in medical care and technology, such as Noland (2003), who attributed the decline in road traffic fatalities in developed countries to enhancements in healthcare services and technological innovations. A study by (Ali et al., 2019) revealed a decrease in RTFs linked to increased urbanization in regions such as Europe and America. To assess road transport safety, it is essential to refer to the TRINCA model, which offers a comprehensive approach by integrating multiple indicators to evaluate safety levels. Rather than relying solely on a single metric like the mortality rate, this model employs the fatality rate. The TRINCA model distinguishes between socio-economic factors (related to mortality rate) and techno-economic factors (related to fatality rate) (Al-lami and Torok, 2023; Török, 2017). This categorization helps clarify the separate effects of different factors on road transportation safety, enabling researchers and decision-makers to formulate more precise and effective interventions. Mortality Rate refers to the number of deaths relative to the population size. On the other hand, a notable contributor to the improvement in road safety metrics in recent years is the increasing integration of autonomous vehicle technologies. These technologies, designed to minimize human error (Alatawneh and Torok, 2024), play a pivotal role in reducing fatalities. A high mortality rate may suggest weaknesses in the healthcare system or insufficient awareness of traffic safety measures. Fatality rate, on the other hand, measures the number of deaths concerning the level of motorization. An increased fatality rate could indicate issues with the transportation infrastructure or inadequate enforcement of traffic

laws. This methodology is considered thorough because it examines a single dimension of safety and provides a more accurate overview by considering the influence of social and technical factors independently and as a whole (Trinca et al., 1988). A review of existing studies highlights a strong agreement on incorporating advanced technologies, improving infrastructure, and addressing social and economic elements when crafting road safety strategies.

3 Methodology

This study utilized a detailed approach to examine the relevance of the TRINCA model (1988) in analyzing road safety and mortality rates across 27 European countries for 2005, 2010, 2015, and 2020. The methodology comprised organized data gathering, time series analysis, statistical hypothesis testing, and supplementary calculations and visualizations conducted using Excel.

3.1 Data collecting

The data used in this analysis were sourced from EUROSTAT, which offers comprehensive and reliable datasets on socio-economic indicators for EU member states. The dataset included the following variables:

- Total population size for each country (2005, 2010, 2015, 2020).
- Number of passenger cars per 1,000 inhabitants (2005, 2010, 2015, 2020).
- Total registered passenger cars (2005, 2010, 2015, 2020).
- Number of fatalities resulting from passenger car accidents. (2005, 2010, 2015, 2020). In addition, supplementary data were obtained from Our World in Data and the Hungarian Central Statistical Office, which provided additional insights and helped validate the dataset.

3.2 Calculation of safety indicators

To facilitate a standardized comparison across countries and regions, two primary safety indicators were computed:

- Personal safety (measured as fatalities per 100,000 population) (P.S):

$$P.S = \frac{\text{Fatalities from passenger cars}}{\text{Population}} \times 100000 \quad (1)$$

- Road Safety (measured as fatalities per 10,000 vehicles) (R.S):

$$R.S = \frac{\text{Fatalities from passenger cars}}{\text{Number of passenger cars}} \times 10000. \quad (2)$$

3.3 Time series analysis

The first step of the analysis focused on examining the temporal trends in road safety and mortality using time series data. Two distinct time series were constructed:

1. Social mortality rate (personal safety): This metric was measured as the number of fatalities per 100,000 inhabitants in each country for every year between 2005 and 2020. This indicator captures the overall risk to individuals within the population, providing insights into the effectiveness of national road safety measures and health policies to reduce road traffic deaths.
2. Road transport fatality rate (road safety): This metric was assessed as the number of fatalities per 10,000 motorized vehicles in each country, analyzed annually from 2005 to 2020. This indicator focuses on the risk per vehicle, measuring the safety level of road transport systems and the efficiency of vehicle safety standards over time. Figs. 2 and 3 illustrate the results of the time series analysis for both indicators. These visual representations provide a clear overview of the temporal development of the mortality and fatality rates across the European regions and highlight changes in road safety outcomes over the selected years. The trends observed in the time series analysis show distinct patterns across different regions. Over the years, a general decline in the social mortality rate was noticed, suggesting improved road safety and public health measures. Similarly, the road transport fatality rate exhibited a general decline over time, reflecting changes in traffic regulations, vehicle safety enhancements, and motorized vehicle ownership fluctuations, collectively contributing to improved road safety outcomes.

3.4 Theoretical model and geographical segmentation

Following the time series analysis, the study evaluated the applicability of the TRINCA model. Fig. 4 illustrates the theoretical relationship between personal and road safety, as proposed by Trinca et al. (1988). The model categorizes countries based on their safety levels, highlighting the expected trade-offs between improving road safety (reducing fatalities per vehicle) and maintaining high levels of personal safety (low fatalities per population).

The data were segmented based on the geographical classification used in the TRINCA model, dividing the countries into four main regions: Northern and Western Europe, Southern Europe, Central Southern Europe, and Central Europe. This segmentation allowed for a

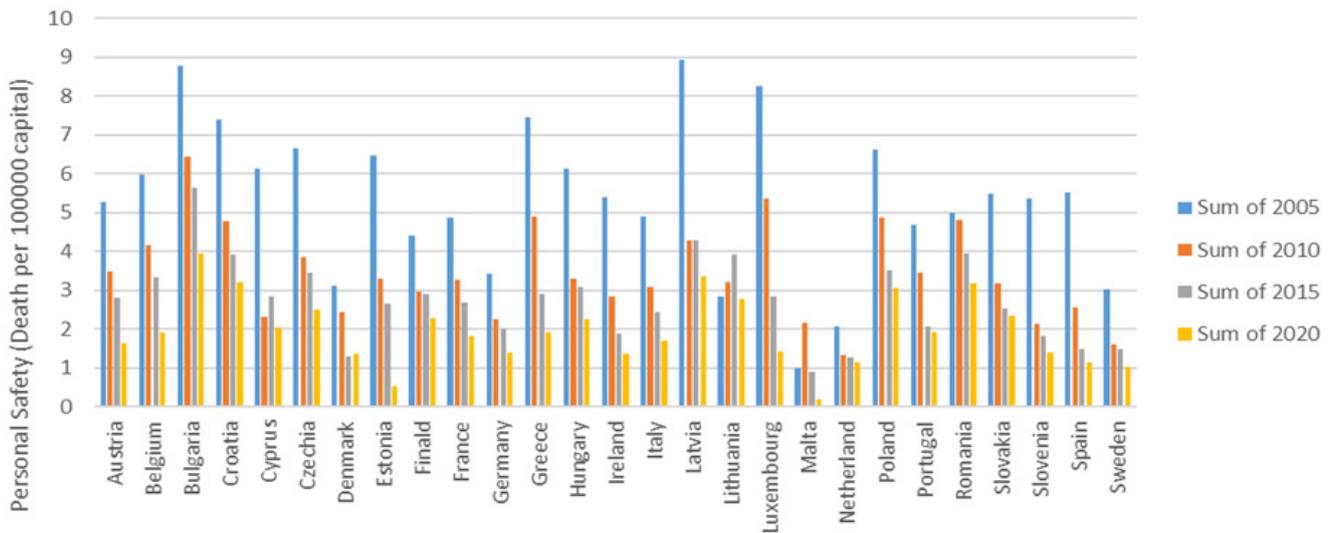


Fig. 2 Time series analysis of social mortality rate (2005-2020)

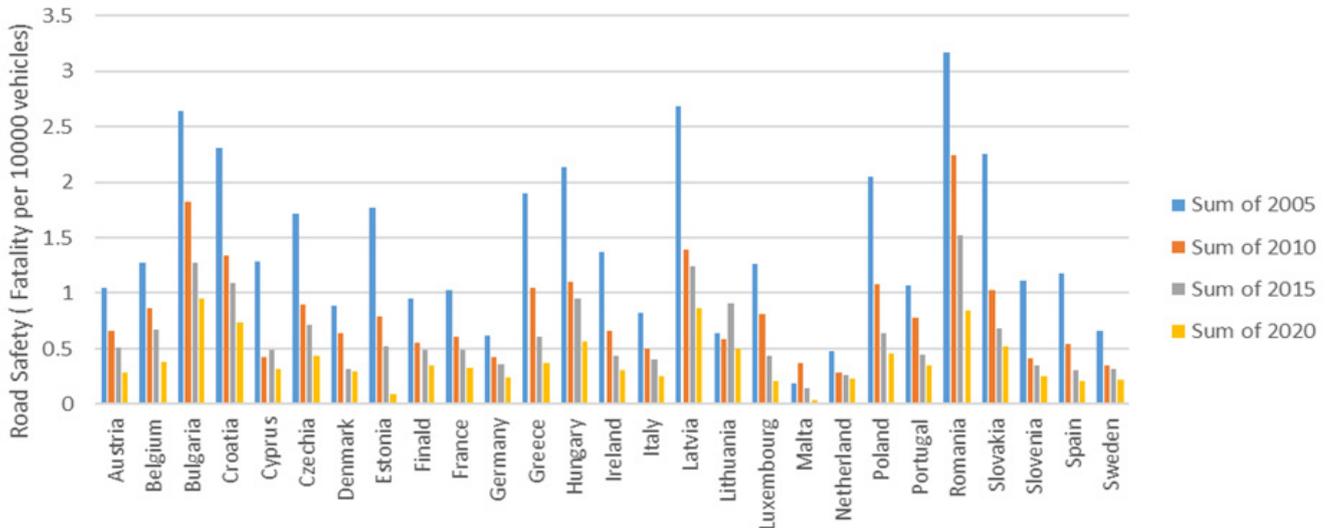


Fig. 3 Time series analysis of road transport fatality rate (2005-2020)

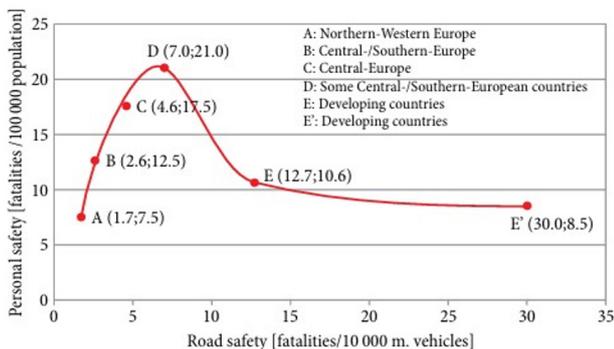


Fig. 4 Relationship between personal safety and road safety (Theoretical Model) (Trinca et al., 1988)

region-specific analysis, recognizing the differences in socio-economic factors and road safety policies that may affect outcomes.

3.5 Hypothesis testing using T-test

A rigorous statistical approach was adopted using the Student's *T*-test to evaluate the applicability of the TRINCA model across the selected European regions. This test was chosen due to its robustness in comparing observed data with theoretical expectations, allowing us to determine whether the TRINCA model accurately reflects current road safety indicators.

The hypotheses were structured as follows:

- Null Hypothesis (H0): No significant difference exists between the observed values of personal safety and road safety indicators and the expected values based on the TRINCA model predictions.
- Alternative Hypothesis (H1): A significant difference between the observed and expected values suggests that the TRINCA model may not be valid

for the current European context. The analysis was conducted for each geographical region, following the segmentation outlined in the TRINCA model. This regional approach allowed us to consider variations in socio-economic factors and road safety policies, providing a more nuanced examination of the model's validity. Normality is a key requirement for parametric statistical methods. The Shapiro-Wilk test and the Kolmogorov-Smirnov test were employed to assess the normality of the dataset. Both tests assume a null hypothesis that the data follows a normal distribution. The results showed that the P -values for all variables were greater than 0.05, indicating no statistically significant deviation from normality. This confirms that the dataset adheres to the assumption of normality, thus validating the use of the T -test for subsequent analysis. By structuring the analysis, we comprehensively evaluated the model's applicability while accounting for regional differences.

3.6 Statistical development of mortality and fatality rates

To complement the time series analysis and hypothesis testing, Fig. 5 presents the statistical development of mortality and fatality rates across the selected time points (2000, 2005, 2010, and 2020). Fig. 5 highlights the evolving trends and provides a comparative perspective on the changes observed in road safety indicators over the years.

4 Results and discussions

In this section, we present the results of the statistical analysis using the T -test to evaluate the applicability of the TRINCA model across different European regions from 2005 to 2020. The analysis focuses on two primary indicators: personal safety (fatalities per 100,000 population) and

road safety (fatalities per 10,000 vehicles). The results are categorized by region and year, followed by a comprehensive discussion of the observed trends and their implications:

1. Northern-Western Europe: The results for Northern-Western Europe show consistent rejection of the null hypothesis across all years (2005, 2010, 2015, and 2020). For each year, the P -value was less than 0.05, with $P < 0.05$ in 2005, $P < 0.01$ in 2010 and 2015, and $P < 0.001$ in 2020, indicating strong statistical significance. This suggests substantial differences between the current road safety data and the predictions of the TRINCA model. Despite the increasing number of vehicles, the decreasing trend in fatalities likely reflects advancements in road infrastructure, stricter regulations, and significant improvements in vehicle safety features. Furthermore, heightened public awareness and targeted safety initiatives may have contributed to these changes.
2. Central Southern Europe: The analysis of Central Southern Europe produced mixed results. In 2005, 2010, and 2015, the P -values were greater than 0.05 (specifically $P > 0.05$ for one-sided and $P > 0.10$ for two-sided tests), indicating no significant difference from the TRINCA model. This suggests that, during these years, the model was still somewhat reflective of the road safety conditions in this region. However, by 2020, the situation had changed, with a P -value of $P < 0.01$, leading to the rejection of the null hypothesis. This indicates a statistically significant deviation, likely due to recent changes in transportation policies and economic factors affecting road usage. It is crucial to note that the sample size in this analysis was limited to only two countries, which may reduce the power of the statistical conclusions and call for further investigation with a larger dataset.
3. Central Europe: In Central Europe, the T -test consistently rejected the null hypothesis across all analyzed years, with highly significant P -values of $P < 0.001$ throughout. These results indicate strong statistical differences from the TRINCA model predictions. The pronounced deviations may be attributed to rapid advancements in road infrastructure, more stringent traffic laws, and increased investments in vehicle safety technologies. These changes have likely improved overall road safety, rendering the TRINCA model outdated for this region.

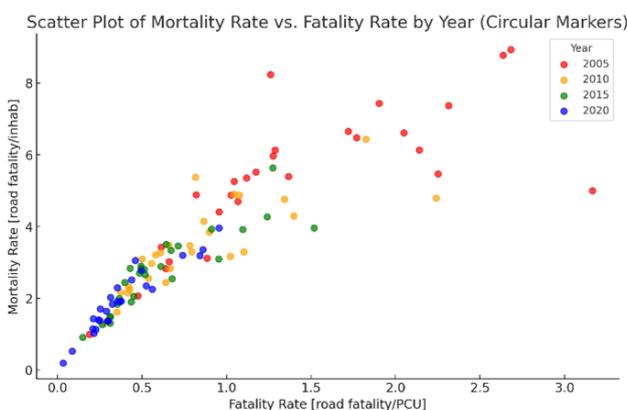


Fig. 5 Statistical development of mortality and fatality rates

4. Southern Europe: The Southern European countries displayed similar trends to those observed in Central Europe, with P -values consistently showing strong statistical significance: $P < 0.01$ in 2005 and $P < 0.001$ in 2010, 2015, and 2020. These results suggest substantial deviations from the TRINCA model across all metrics, reflecting notable improvements in road safety—the adoption of advanced driver-assistance systems (ADAS), and more effective public safety campaigns. The consistent rejection of the null hypothesis across all years implies that the model no longer captures the current realities of road safety in Southern Europe.
5. The analysis reveals a general trend of increasing discrepancies between the TRINCA model predictions and Europe's current road safety data, particularly after 2015. While Central Southern Europe showed alignment with the model in earlier years, all regions eventually exhibited significant deviations. The consistently low P -values provide strong statistical evidence suggesting that the TRINCA model is no longer applicable.
6. This highlights the need to either update the model or create a new framework that reflects the latest progress

in road safety practices, vehicle technology advancements, and infrastructure enhancements.

5 Conclusions

The results of this study suggest that the TRINCA model (1988), once a reliable tool for assessing road safety across European nations, no longer aligns well with current data. The T -test analysis showed statistically significant discrepancies, especially from 2015 onwards, indicating that the model fails to account for road infrastructure improvements, vehicle safety technology advancements, and recent changes in traffic regulations. While partial alignment was initially observed in Central Southern Europe, by 2020, significant deviations were found across all regions. This underscores the need to either update the TRINCA model or develop a new framework incorporating modern road safety standards, socio-economic shifts, and technological advancements. Future research should aim to incorporate more diverse data sources and broaden the analysis by including additional socio-economic factors, offering a comprehensive evaluation of road safety trends.

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