



Comparative Analysis Between Economic Activity and Road Transport Safety – Insights from European Union Countries

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ABSTRACT

Road transport safety is a global concern, impacting public health, economic stability and quality of life. Understanding how economic growth and activity, represented by gross domestic product (GDP/capita), correlate with road safety outcomes is essential for crafting effective policies and interventions. This study investigates the complex relationship between gross domestic product (GDP/capita) and road safety in 27 European countries from 2005 to 2020. Using data on traffic fatalities per capita and vehicles, this research examines the influence of economic indicators on road safety outcomes, employing the original TRINCA model to frame the analysis within stages of economic development. The findings reveal that higher GDP levels are generally associated with improved road safety. However, the pace of these improvements varies significantly across European countries, reflecting diverse socio-economic contexts and regulatory frameworks. Cluster analysis classifies countries based on safety and economic performance, highlighting disparities in progress and opportunities for targeted interventions to prove the theoretical framework of the TRINCA model still exists. This study underscores the critical role of sustained economic growth and policy reform in achieving safer road systems.

KEYWORDS

personal safety; road transport safety; TRINCA model; mortality; fatality; gross domestic product (GDP).

1. INTRODUCTION

Road transport safety is a critical issue that profoundly impacts societies worldwide, attracting considerable attention across economics, transportation and traffic engineering. Amid the rapid economic growth observed in many countries, increasing pressure on road infrastructure and traffic systems has led to concerns about rising traffic accident rates and declining safety levels. Conversely, economic growth offers opportunities to enhance road safety through sustainable investments in infrastructure, enforcement of effective traffic laws and integration of modern transportation technology.

In this context, gross domestic product (GDP/capita) is a crucial indicator of economic performance and significantly influences road safety levels. The countries of the European Union exemplify how economic growth influences road safety outcomes, with notable shifts in GDP/capita and traffic fatality rates over recent decades. However, the relationship between economic growth and road safety is complex and varies across nations, reflecting differences in infrastructure development strategies, traffic regulations and resource allocation.

This study analyses data from 27 European countries, encompassing diverse geographical regions, including Denmark and Sweden in the north, the Netherlands and Germany in the west, Italy and Spain in the south, and Poland and Romania in the east. Data from 2005 to 2020 were used to investigate the temporal relationship between economic growth and road safety. Observations were taken at five-year intervals to minimise the influence of minor fluctuations and focus on broader trends, ensuring robust analysis of the interplay between economic and safety indicators.

Key metrics include GDP per capita, traffic fatalities per 100,000 inhabitants, and fatalities per 10,000 vehicles, providing a comprehensive view of the economic and safety dimensions. The TRINCA model will be employed to explore the stages of economic growth and their relationship with road safety. Additionally, cluster analysis will classify countries based on growth and safety performance, facilitating comparative analysis and insights.

The study aims to emphasise the economic determinants of road safety and provide evidence-based recommendations for future policies using the original TRINCA model and cluster analysis to investigate whether TRINCA model results are still valid for Europe. These findings will contribute to a more profound academic and practical understanding of the economic factors influencing transportation safety, offering valuable guidance to policymakers and urban planners in enhancing road safety and achieving sustainable development objectives.

2. LITERATURE REVIEW

Road transportation safety is a critical issue affecting societies worldwide. Due to the substantial financial and human costs associated with traffic accidents, the GDP/capita is a crucial metric of economic activity that represents the economic performance of nations and is thought to have a significant impact on determining road safety levels. Previous literature has shown a complicated link between road safety, transportation infrastructure investment and economic growth. The article in this section aims to review several previous studies on the relationship between road transportation safety and GDP/capita, focusing on influencing factors and future trends.

Many studies suggest that increased GDP/capita often leads to higher investments in transportation infrastructure and awareness campaigns and seminars to educate citizens about the risks and consequences of road accidents. These measures contribute significantly to reducing the number of accidents [1–4].

According to a previous study, the impact of improving transport varies amongst European nations, suggesting that the relationship between GDP/capita and transport safety is not fixed but depends on how resources are allocated [5]. The study titled *Transport Infrastructure Development, Public Performance and Long-Run Economic Growth: A Case Study for the EU-28 Countries* highlighted that countries with substantial investments in infrastructure have experienced notable improvements in traffic safety alongside increased economic growth. Additionally, it found that nations with higher economic growth tend to allocate more resources to enhance road conditions and develop transportation systems, effectively reducing road accidents.

The World Health Organisation (WHO) reports that, beyond the human suffering caused by road traffic injuries, these incidents place a significant economic burden on victims and their families. This burden arises from the costs associated with medical treatment for the injured and the loss of productivity of those who are killed or permanently disabled. On a broader scale, road traffic injuries profoundly impact national economies, costing countries approximately 3% of their annual GDP [6].

Several studies have explored the relationship between GDP and road transport safety by investigating the economic and social factors influencing fatal accident rates. One such study, conducted by Sohaee and Bohluli [7], found that nations with higher GDP/capita tended to experience reduced fatal accident rates. This reduction was attributed to greater investments in transport infrastructure and enhancements in traffic management systems. The study highlighted that the link between GDP/capita and road transport safety is shaped by various factors, particularly government expenditure, which supports infrastructure development, creates job opportunities and facilitates the adoption of advanced traffic safety technologies. Additionally, the study addressed the influence of other economic variables, such as inflation and unemployment. It noted that unemployment could escalate accident rates due to the financial strain it places on individuals, while inflation impacts transportation costs, potentially altering driving behaviours in ways that compromise safety.

On the other hand, previous works of literature show that economic crises significantly affect investment in transport infrastructure and traffic safety. In a recent study, Navarro-Moreno et al. [8] examined the impact

of economic crises on road maintenance and transport safety in Europe, focusing on the global financial crisis of 2008. The study showed that spending on road maintenance in European Union countries decreased from 0.8% of GDP in 2008 to 0.5% in 2013, leading to an accumulation of unimplemented maintenance projects, especially in countries such as Germany, the Netherlands, Italy and Spain. The study also indicated that this decline in investment had a direct negative impact on road safety indicators, as efforts to improve road quality declined, leading to a slowdown in improving traffic fatality rates. The study also showed that the impact of road investment differed between high and low-income countries, as low-income countries benefited more from investment in new road construction, while high-income countries relied more on improving existing road maintenance. The study demonstrates the importance of maintaining stable investment in transport infrastructure, even during periods of economic volatility, to ensure continued improvements in traffic safety rates.

Multiple theoretical models have been developed to understand the relationship between economic growth and transport safety, such as the TRINCA model, which describes the relationship through three main stages [9]:

- Stage one: Rapid economic growth increases accidents due to insufficient infrastructure improvements;
- Stage two: Countries begin to achieve gradual safety improvements thanks to investments;
- Stage three: Significant safety improvements are realised due to sustainable investments and modern technologies.

The TRINCA model, which provides a thorough method by combining several indicators to determine safety levels, can be consulted to evaluate road transport safety. This model uses the fatality rate instead of only one measure, such as the mortality rate. Techno-economic factors (related to fatality rate) and socio-economic factors (related to mortality rate) are distinguished by the TRINCA model [10]. The distinct effects of many elements on road transportation safety are made clearer by this classification, which enables researchers and decision-makers to create more targeted and efficient interventions. With increasing interest in sustainability and modern technology, researchers expect innovations such as autonomous vehicles and intelligent transport technologies to enhance road safety significantly.

However, continued investment in infrastructure and the development of effective policies remain essential to ensure sustainable positive outcomes, as noted in the European Commission's report titled EU Road Safety Policy Framework published in 2021 [11].

Previous literature explores the complex relationship between economic growth and road transport safety, with studies suggesting that increased GDP/capita often leads to improvements in transport infrastructure, which contributes to reduced accident rates. However, the impact remains uneven across countries, with some countries facing significant challenges in achieving improvements in road safety due to insufficient investment or weak legislation.

3. METHODOLOGY

This chapter outlines the methodology for examining the relationship between economic growth and road safety in European countries. It describes the data used, which include GDP/capita and road safety indicators for 27 European countries from 2005 to 2020. It explains the tools and analyses applied, such as time series analysis for investigating trends and cluster analysis for categorising countries based on safety and economic growth indicators. Finally, the results will link to the TRINCA model to clarify the relationship between economic growth and road safety through various stages.

3.1 Data collecting

Data from 27 EU countries (2005–2020) are used for this research. The dataset includes economic indicators from Eurostat and the World Bank's traffic safety statistics. The countries represent Northern Europe (Sweden, Denmark, Finland), Western Europe (Germany, the Netherlands, France), Southern Europe (Spain, Italy, Greece) and Eastern Europe (Poland, Romania, Bulgaria). Key datasets in this study include:

- Gross domestic product (GDP/capita): The GDP per capita for each country serves as the primary indicator of economic growth. GDP data are collected annually to monitor economic development and evaluate each country's growth trajectory. The data are presented in chain-linked volumes (2010), measured in euros per capita ("Statistics | Eurostat", n.d.).
- Total population size for each country (2005, 2010, 2015, 2020).
- Number of passenger cars per 1,000 inhabitants (2005, 2010, 2015, 2020).

- Number of fatalities resulting from passenger car accidents. (2005, 2010, 2015, 2020).
Two leading safety indicators were calculated to enable a consistent comparison across nations and aggregated to regions such as North Europe, West Europe, South Europe and East Europe;
- Personal safety (measured as fatalities per 100,000 population) (P.S):

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

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

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

These data points were collected for the designated years (2005, 2010, 2015 and 2020) to observe trends and analyse the relationship between economic growth and road safety across different periods.

3.2 Time series analysis

This section analyses the road safety, personal safety and GDP/capita across 27 European countries in 2005, 2010, 2015 and 2020. The objective is to examine trends over time and correlations between economic growth and road safety improvements.

Road transport fatality rate (road safety): This indicator assesses vehicle safety regulations and road transport systems, focusing on the risk per vehicle. *Figure 1* shows a time series of road safety (fatalities per 10,000 vehicles) by country. In 2005, fatality rates were significantly higher in countries like Portugal, Latvia and Poland, reflecting serious road safety challenges. By 2020, most countries showed decreased fatality rates, indicating improved road safety. This trend is linked to economic growth, better infrastructure, enhanced vehicle safety technology and stricter traffic regulations. Austria, Germany and Sweden maintain low fatality rates, exemplifying their robust economic and infrastructure development.

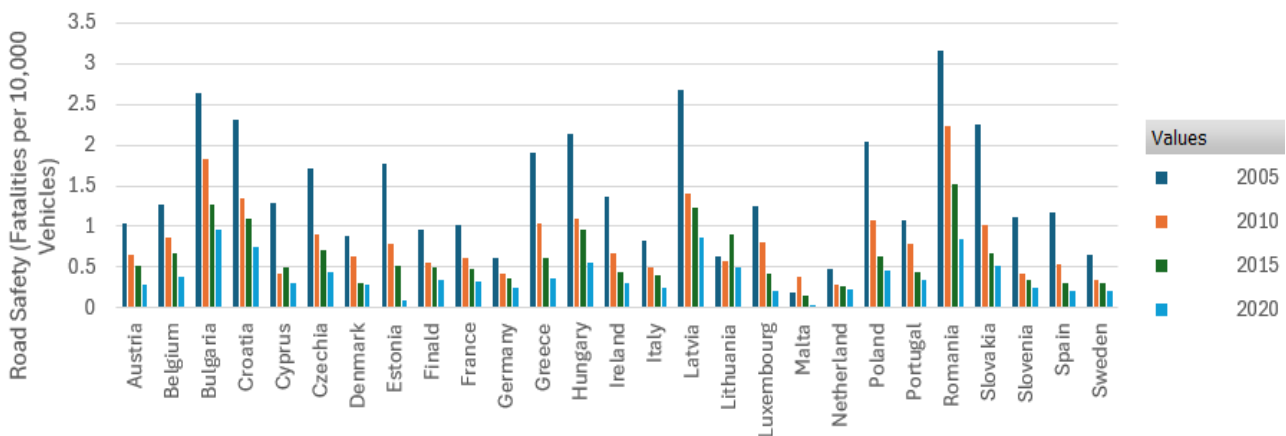


Figure 1 – Road safety (fatalities per 10,000 vehicles) by country (2005, 2010, 2015, 2020)

Social mortality rate (personal safety): This indicator evaluates the overall risk to individuals and provides insights into the effectiveness of national road safety initiatives and health policies to reduce traffic fatalities. *Figure 2* displays a time series of personal safety (fatalities per 100,000 population) by country (2005, 2010, 2015 and 2020). There is a gradual decrease in fatalities across most countries. In 2005, fatalities were higher in Bulgaria and Latvia, but these rates have significantly decreased over time in many European nations. Germany, France and the Netherlands have notably improved personal safety with reduced fatalities due to better infrastructure and road safety policies. Higher GDP/capita countries like Germany and Sweden continue to show improvement, while countries with limited economic growth, such as Romania and Bulgaria, progress more slowly.

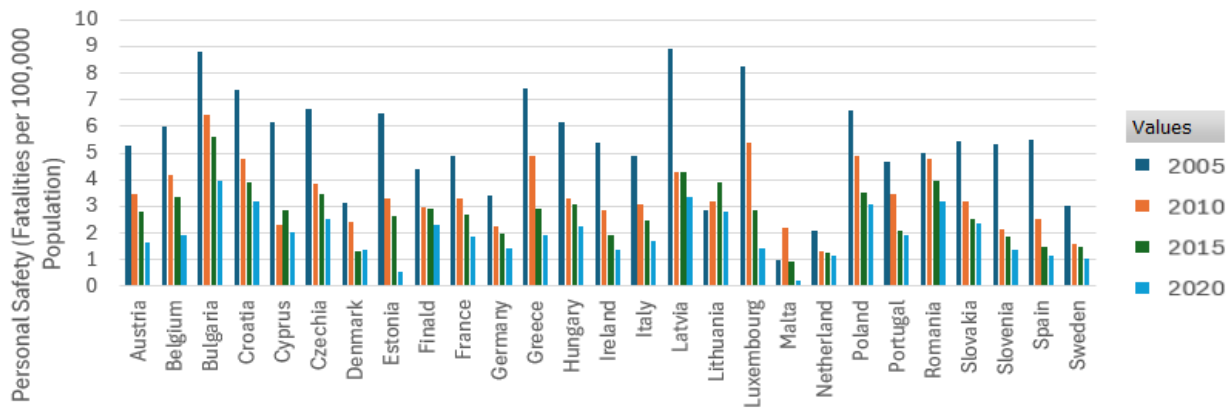


Figure 2 – Personal safety (fatalities per 100,000 population) by country (2005, 2010, 2015, 2020)

Gross domestic product (GDP/capita): Figure 3 presents a time series of GDP/capita by country for 2005, 2010, 2015 and 2020. These data are essential for analysing how economic growth correlates with improvements in road safety.

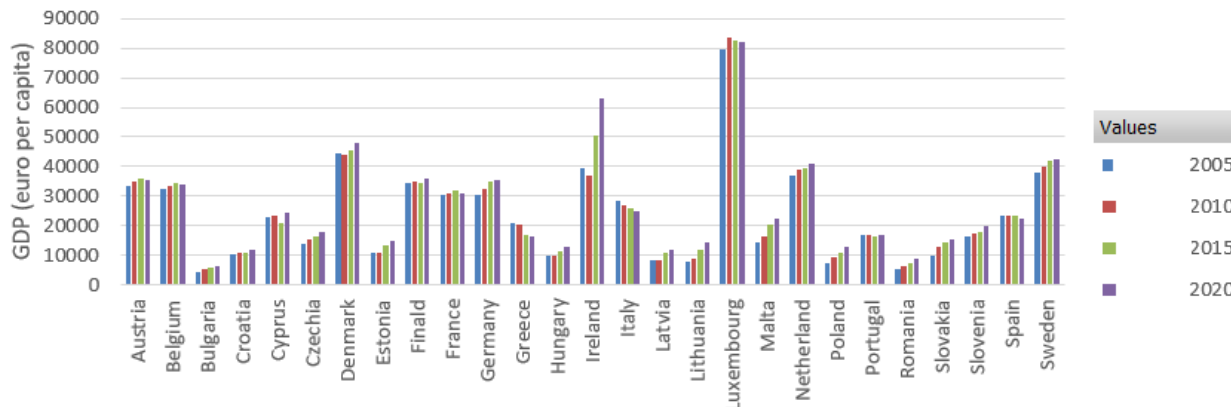


Figure 3 – Time series of GDP by country (2005, 2010, 2015, 2020; euros per capita)

3.3 The impact of economic activity on road safety and personal safety: an analytical overview

The EU nations’ GDP/capita-safety relationship is vital for understanding how economic growth impacts road accident fatalities. This analysis aims to determine if higher GDP/capita correlates with improved safety outcomes and the influence of economic factors on road safety policies. It uses data from 27 EU countries from 2005, 2010, 2015 and 2020 to explore this correlation and examine economic impacts on safety policies.

Figures 4 and 5 visually represent the relationship between GDP/capita and safety indicators, revealing trends. Figure 4 shows that road fatalities decrease as GDP/capita increases, indicating that wealthier nations invest more in road infrastructure and regulations, improving safety.

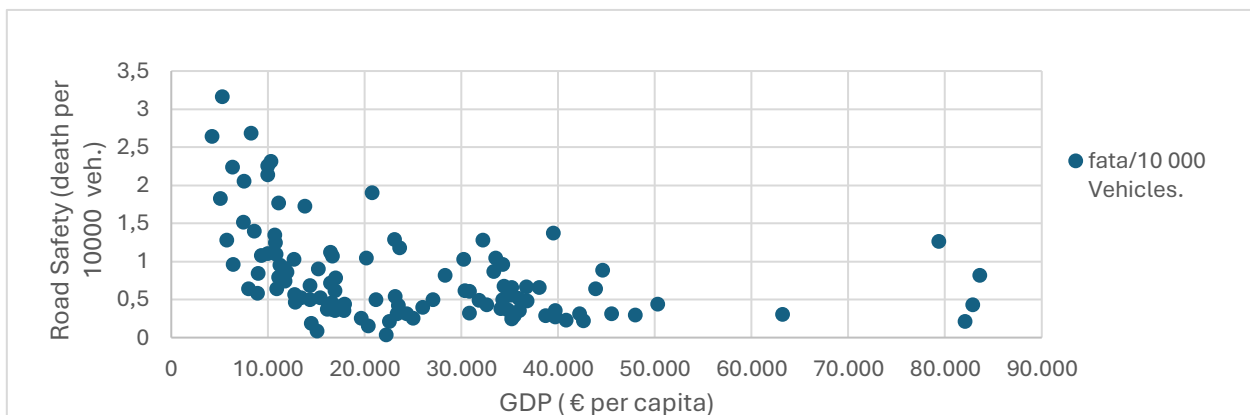


Figure 4 – The relationship between GDP/capita and road safety

The second chart in *Figure 5* depicts the relationship between economic activity and personal safety (fatalities per 100,000 population). It shows that as GDP/capita rises, personal safety improves, with higher GDP/capita countries experiencing fewer traffic-related deaths. However, the correlation between GDP/capita and personal safety is weaker than between GDP/capita and road safety.

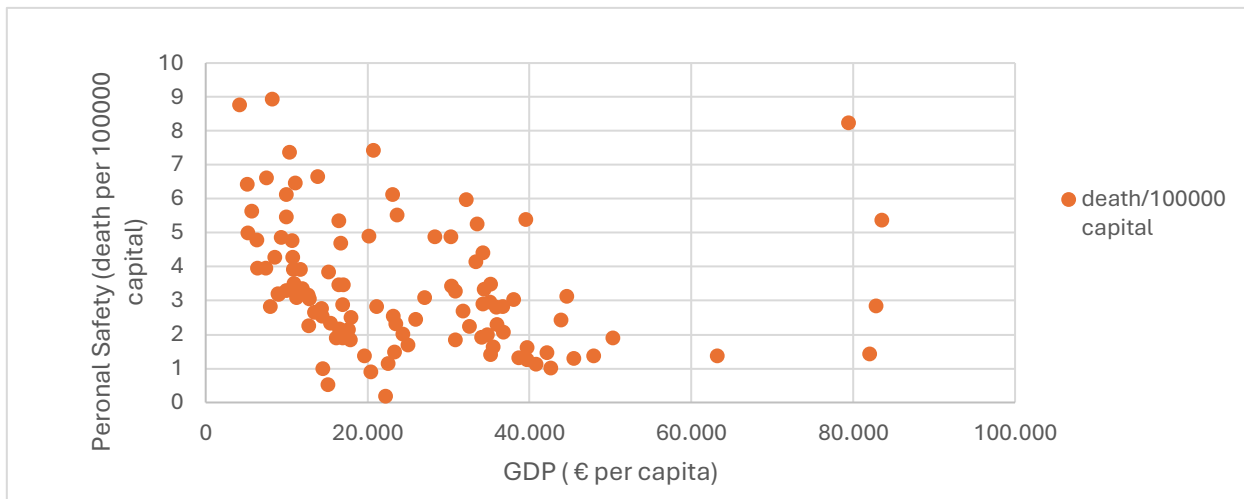


Figure 5 – Relationship between GDP/capita and personal safety

This suggests that while economic factors enhance personal safety, other elements like healthcare systems and social conditions influence outcomes. Economic growth is vital for improving road and personal safety, though its impact on personal safety is less direct than on road safety. Improved economic conditions lead to better infrastructure investment and policy enforcement, yet external factors are crucial to overall safety.

3.4 Theoretical model and cluster analysis for mortality rate and fatality rate

This study analysed the relationship between mortality and fatality rates to examine how economic growth influences road safety. The mortality rate reflects the societal impact of accidents, while the fatality rate indicates vehicle-related safety.

Data from 2005–2020 for 27 European countries was used to explore these indicators, divided by Northern, Central and Southern Europe. The following indicators were considered:

- Mortality rate (deaths per 100,000 population) per country over the years.
- Fatality rate (deaths per 10,000 vehicles) per country over the years.

A scatter plot was created to assess the relationship between mortality rate and fatality rate, segmented by regions of Europe and years, to clarify trends and identify outliers, as shown in *Figure 6*.

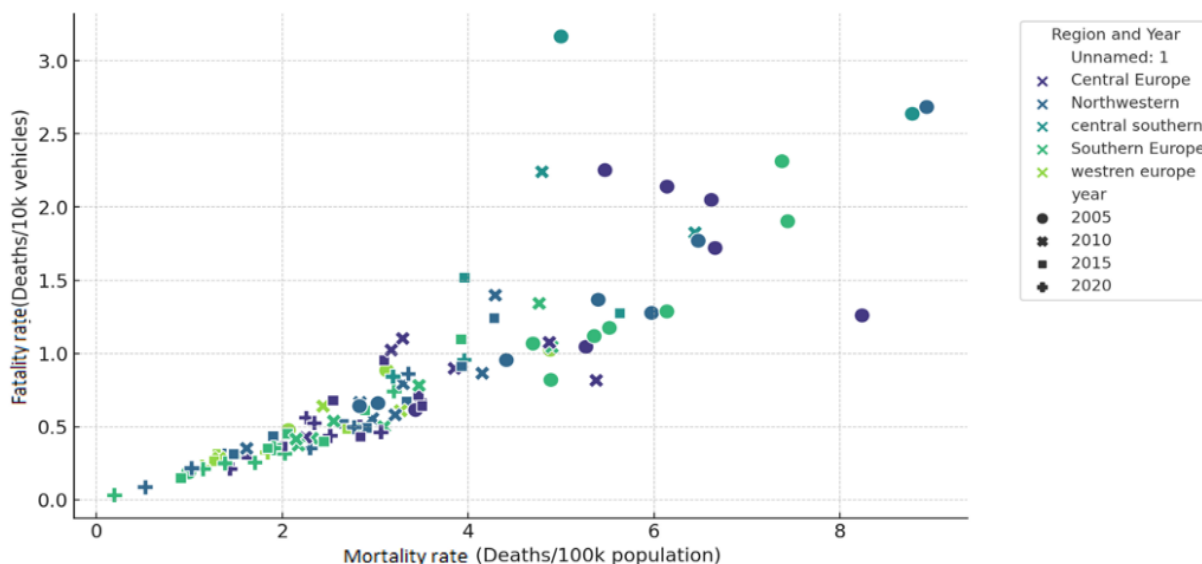


Figure 6 – Relationship between personal safety (mortality rate) and road safety (fatality rate) by region and time

The scatter plot shows a positive correlation between mortality rate and fatality rate. Generally, countries with higher fatality rates tend to have higher mortality rates, indicating that those facing more vehicle-related deaths experience a greater impact on population health.

Regional differences reveal trends in this relationship. Central Europe exhibits a balanced correlation, with improved safety measures reducing both rates. Southern and North-western Europe present significant variations, with some countries improving vehicle safety while others struggle with road safety issues. Western Europe generally has a lower fatality rate despite moderate mortality rates, likely due to better road safety technologies and infrastructure investments.

From 2005 to 2020, most countries improved both rates as road safety standards advanced and road infrastructures were upgraded. Cluster analysis followed the relationship examination of mortality and fatality rates. This analysis categorised countries based on road safety and personal safety indicators to identify patterns linking economic performance with road safety outcomes.

Figure 7 illustrates the scatter plot demonstrating the relationship between mortality rate (deaths per 100,000 people) and fatality rate (deaths per 10,000 vehicles) across regions (North, West, South and East Europe) and years, highlighting the positive correlation in different European regions.

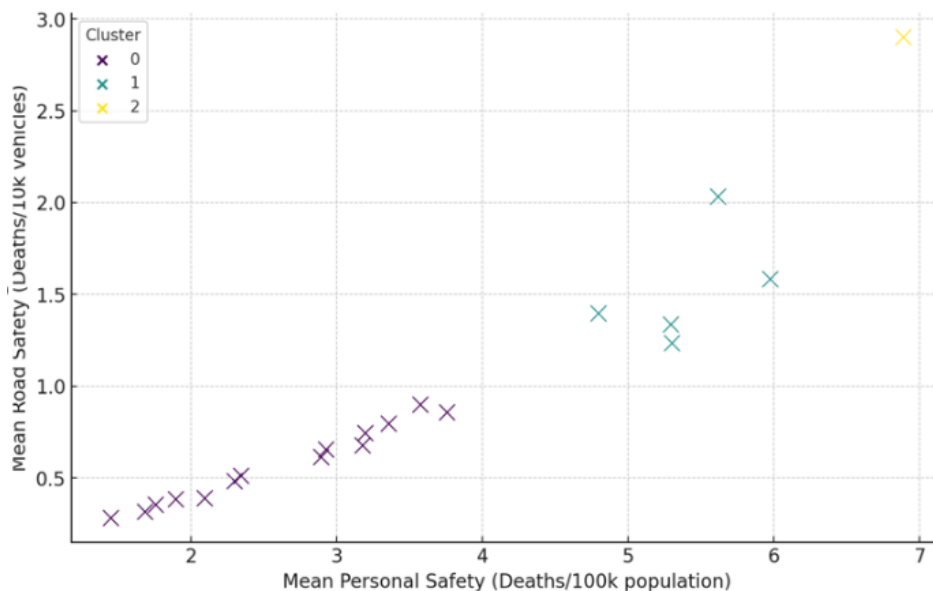


Figure 7 – The relationship between mortality rate (personal safety) and fatality rate (road safety)

Personal and road safety served as key indicators for the cluster analysis. Data were standardised to mitigate the impact of value differences, ensuring variable scales did not bias the study. The K-means clustering algorithm divided countries into clusters based on safety rate similarities.

Countries were split into three clusters: Cluster 0 had high economic growth and safety, with lower fatality rates; Cluster 1 consisted of transitioning countries showing partial safety improvements, and Cluster 2 included those facing significant road safety challenges.

Cluster 0 indicated that advanced economies had strong safety measures and lower fatality rates, Cluster 1 showed improvements in transitional countries, while Cluster 2 highlighted significant challenges needing urgent action.

The TRINCA model explains the link between personal and road safety rates, identifying three key stages connected to the clusters. Figure 8 illustrates the relationship between road safety (fatalities per 10,000 vehicles) and personal safety (fatalities per 100,000 population). Figure 8 shows the results of the original TRINCA model; meanwhile, Figure 7 shows the results for EU countries only as a result of our investigation.

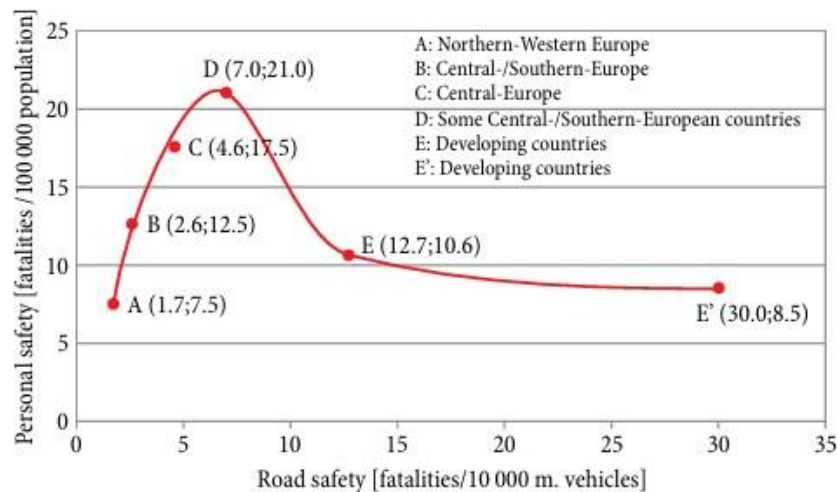


Figure 8 – Relationship between personal safety and road safety (theoretical model, TRINCA et al. 1988)

The model's stages are as follows:

- Stage E' to E: Countries experience early development phases, where economic growth increases fatalities due to a lack of infrastructure and weak regulations.
- Stage E to D: Countries show road safety improvements, driven by infrastructure and technology investments, leading to fewer accidents.
- Stage D to A: Nations in this stable phase see sustained investment in infrastructure and road safety technologies, resulting in improved road safety.

Our study focuses on stages A to D, excluding developing countries in the D to E' phase. This allows us to concentrate on nations with significant progress in economic growth and road safety.

4. RESULTS AND DISCUSSIONS

4.1 Temporal data analysis

The temporal analysis results significantly improved personal and road safety across the studied periods. For example, fatalities per 100,000 population and 10,000 vehicles consistently declined from 2005 to 2020, reflecting improvements in infrastructure and traffic safety policies across most European countries. This suggests that effective policies have contributed to improving road safety over time.

4.2 Cluster analysis

The European countries were divided into three clusters using cluster analysis based on temporal and geographical indicators. The results of this process revealed the following clusters:

- Cluster 0 (gradual development): Represents countries that have gradually improved safety rates due to continuous investments in infrastructure and increased awareness of safety policies. Central Europe and North-Western countries were classified within this cluster in most years, especially in 2020.
- Cluster 1 (transitional stage): Countries in this cluster have shown slower progress in road safety but still need further improvements. Many countries in Southern Europe (such as Greece, Croatia and Italy) represent this cluster, with some countries in Central Southern Europe appearing during 2005.
- Cluster 2 (significant challenges): Countries in this group face major challenges in improving road safety due to limited investment or weak legislation. In 2020, Western European countries, such as France and Denmark, were classified within this cluster.

Central Europe showed improvement in 2020, reflecting significant investments in road safety and economic advancements. Southern Europe in 2005 faced considerable safety challenges, but over time, some countries began to improve. Western Europe witnessed significant improvements after 2005, while North-Western Europe remained more stable.

The analysis shows that countries with low mortality and fatality rates generally have a high GDP/capita. This aligns with the hypothesis presented by the TRINCA model, which suggests a relationship between economic growth and road safety rates.

- Countries with high GDP/capita: Countries with high GDP/capita, such as those in Western Europe and Central Europe, tend to fall into Cluster 0 or 1. These clusters show improvements in safety rates over time. These countries typically have significant investments in road infrastructure, modern safety technologies and strict enforcement of traffic laws. This results in lower mortality and fatality rates than in countries with less developed economies.
- Countries with lower GDP/capita: Conversely, countries with lower GDP/capita, like many in Eastern Europe and Southern Europe, tend to fall into Cluster 2. These clusters face significant challenges in improving road safety. These countries are often in the E' to E stages of the original TRINCA model, where limited economic growth leads to higher mortality and fatality rates due to weaker infrastructure and insufficient investments in safety measures.

5. CONCLUSIONS

This study employed temporal and cluster analyses to investigate the relationship between economic growth and road transport safety across various European nations. The outcomes were examined utilising the TRINCA model, which correlates road safety enhancements with different economic growth stages. The results underscore the disparities in road safety improvements throughout Europe and offer valuable insights into how economic development impacts road safety outcomes.

The time-series analysis conducted from 2005 to 2020 revealed a clear downward trend in personal and road safety, suggesting significant improvements in road safety across European countries. These improvements reflect the effectiveness of policies that enhance road safety through infrastructure development, the adoption of new technologies and stricter enforcement of road safety regulations. However, the pace of improvement varied across regions, indicating the necessity of adopting region-specific strategies to address unique challenges. The cluster analysis grouped countries into three categories based on their road safety and economic growth characteristics. Cluster 0 consisted of countries that demonstrated steady improvements in both road safety indicators, while Cluster 1 represented countries in a transitional phase, showing moderate improvements but still requiring further investment and reform. Cluster 2 comprised countries facing significant challenges in improving road safety due to inadequate infrastructure and weak safety regulations. This classification underscores the varying levels of road safety across countries, highlighting the need for tailored approaches to address the challenges faced by each group. By linking the cluster results to the TRINCA model, it became evident that countries in Cluster 2 are in the D to C stage, where economic growth often leads to higher fatalities due to underdeveloped road safety systems.

In contrast, Cluster 1 and Cluster 0 countries are transitioning through the C to B and B to A stages, where road safety improvements are more significant due to sustained economic growth and investments in safety policies and infrastructure. In conclusion, this study highlights the critical role of economic growth in enhancing road safety. It presents a transparent methodology for analysing and linking the relationship between GDP/capita and road transport safety.

However, it also emphasises the disparities between countries, where higher GDP/capita nations tend to experience lower fatality rates. Addressing these inequalities will require targeted investments, policy reforms and international collaboration to establish safer and more sustainable road systems across Europe. As economic growth remains a key driver of road safety, it is essential to focus efforts on ensuring that growth translates into safer and more efficient transport systems for everyone.

5.1 Limitations and future research

This study acknowledges several limitations. Firstly, while the analysis includes 27 European countries for 15 years, the availability and consistency of data varied slightly among these countries, which may have affected the comparability of certain indicators. Secondly, although the TRINCA model is valuable, it might not fully account for country-specific socio-economic or cultural factors affecting road safety. Additionally, various explanatory variables, population density, road quality and enforcement levels, were excluded due to data limitations, which could have provided further insights into the relationship between GDP/capita and road safety.

Future research could build upon this study by integrating more extensive explanatory variables and exploring non-linear modelling methodologies, including machine learning approaches. Comparative studies extending beyond Europe, or case studies focusing on nations with either high or low performance, may also

contribute to a more profound understanding of the contextual factors that influence road safety outcomes concerning economic development.

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