Evaluating the Efficacy of Periodic Technical Inspections (PTI) on Road Safety and Economic Outcomes in Türkiye:

A Comprehensive Analysis from 1990 to 2022

Study by

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Explanatory Note

Given that commas and full stops are used in different ways in different European countries for the decimal point and for separating groups of three numbers in large numbers, it is crucial to define and use a consistent style throughout the paper.

The style adopted for this paper is:

- A full stop (.) is used for the decimal point.
- A comma (.) is used to separate groups of three numbers in numbers with four or more digits.

Table of Contents

List of Figures

List of Tables

Abbreviation

ACF	Auto Correlation Function
GDP	Gross Domestic Product
I	Intercept
N	Number of observations
PSEM	Pure socio-economic models
PTI	Periodic technical inspection
PTMS	Pure time series models
PTPM	Pure traffic parameter models
RSS	Residuals Sum Squared
S	Slope
TL	Turkish Lira
TI	Technical Inspection
TIs	Technical Inspections
WACC	Growth rate of road accidents

1 Executive Summary

The main objective of this study is to prove whether the introduction of PTI in Türkiye in 2008 was a structural change to the number of road accidents. That means the general question is how effectively PTI increases traffic safety. First, we discuss the complex interplay between safety regulations, economic considerations, and vehicle inspection systems. Second, we perform a general literature review considering the effects of PTI on road safety in various countries. The general literature findings show a positive correlation between PTI and road safety. A specific literature review was undertaken for two studies concerning Türkiye. The study by Schulz and Scheler (2016) was the first approach to measure statistically the impact of introducing PTI in Türkiye. The limitation of this study is that the time series is short. Suleiman et al. (2020) give an overview of the road safety situation in Türkiye based on empirical data. With our study, we want to overcome the limitations of the Schulz and Scheler study by using time series data from 1990 to 2022. Further, we want to prove that the introduction of PTI in Türkiye was a structural change.

This report provides a comprehensive review and analysis of the impact of Periodic Technical Inspections (PTI) on road safety in Türkiye. Leveraging robust datasets spanning from 1990 to 2022, the study employs various econometric models to explore the effectiveness of PTIs in enhancing road safety and reducing economic losses due to traffic accidents.

Key Findings are:

- Reduction in Traffic Fatalities and Accidents: The introduction of PTIs in 2008 has been associated with a notable decrease in road fatalities and accidents, suggesting that PTIs are an effective measure for improving road safety in Türkiye.
- Economic Impact: PTIs have led to considerable economic benefits by reducing the costs associated with traffic accidents. The economic analysis indicates that the benefits of PTIs significantly outweigh the costs, rendering them a viable policy option for enhancing national welfare.
- Regression Analysis: The models demonstrate strong relationships between the implementation of PTI and improvements in traffic safety, highlighting the empirical relevance of PTI in the context of Türkiye.

2 Introduction

In the comprehensive study entitled "Roadworthiness Inspection Regime in Türkiye – Impact Assessment," we embark on a detailed exploration of vehicle inspections, elucidating their implications for road safety and economic measures within Türkiye. The study unfolds several chapters, each contributing unique insights into various aspects of periodic technical inspections (PTIs).

The Executive Summary concisely encapsulates the study's key findings, underscoring the beneficial impacts of PTIs on enhancing road safety and fostering economic advantages in Türkiye. This summary sets the stage for deeper dives into specific topics throughout the subsequent chapters.

Chapter 3, Periodic Technical Inspections: Balancing Safety, Economics, and Regulation, is bifurcated into two critical discussions. The first is assessing the impact, efficiency, and necessity of PTIs, which debates their effectiveness within road safety and economic dynamics, integrating scholarly debates and empirical evidence. The second discussion navigates the economics of vehicle inspections, analyzing the interaction between PTIs and market efficiency, mainly focusing on credence goods.

The Literature Review in Chapter 4 synthesizes existing research on the causal relationships between roadworthiness tests and road safety, focusing on Türkiye. It assesses both global perspectives and localized impacts, offering a nuanced view of the specific effects of PTIs within the Turkish context.

Chapter 5 details the Road Safety Situation in Türkiye, presenting comprehensive statistical analyses of trends in vehicle registrations, accidents, and the impacts of regulatory measures over the years, illustrating the current state of road safety in Türkiye.

Chapter 6 introduces a novel analytical model designed to assess the impact of PTIs on road safety in Türkiye. This chapter details the methodological approaches employed, including trend analysis, economic determinants identification, and regression analyses across different periods relative to the implementation of PTIs.

In Chapter 7, the findings from the newly developed model are synthesized, providing a robust evaluation of PTI's effectiveness in enhancing road safety within the national context.

Chapter 8 explores the broader Macroeconomic Impacts of Roadworthiness Inspection, analyzing how enhancements in road safety translate into broader economic benefits for Türkiye, reinforcing the value of PTIs beyond mere compliance to substantial economic gains.

Chapter 9, Recommendations & Conclusions, draws together the insights gained throughout the study, offering strategic recommendations for policymakers. This chapter suggests ways to amplify the effectiveness of PTIs and proposes areas for further research, aiming to improve the PTI framework continuously.

The study concludes with a comprehensive Literature section and an Annex, which include all academic references and supplementary materials supporting the detailed analyses presented in the report.

Each chapter builds upon the previous, weaving a comprehensive narrative that not only details the functional impacts of PTIs but also contextualizes these within broader economic and safety-related frameworks, ensuring a thorough understanding of the multifaceted role of periodic technical inspections in enhancing road safety and economic efficiency in Türkiye.

3 Periodic Technical Inspections: Balancing Safety, Economics, and Regulation

This chapter delves into the complex discourse surrounding Periodic Technical Inspections (PTIs) for vehicles—a subject that draws both ardent advocacy and staunch opposition. PTIs are critical for road safety measures, economic considerations, and regulatory frameworks. Proponents see regular inspections as crucial for identifying and addressing technical faults, reducing accident risks, and enhancing road safety. Critics question their efficacy and highlight the financial burden on vehicle owners. The examination extends to the relationship between PTI regimes and traffic accident statistics, engaging with a spectrum of studies that shed light on this interaction. Additionally, the broader economic implications are considered, including the effects of PTIs on vehicle maintenance, consumer behavior, and national GDP. Through a detailed analysis of empirical evidence and economic theory, the chapter aims to dissect the arguments, explore market dynamics, and clarify the role of PTIs in promoting a safer and more responsible driving landscape.

3.1 The Debate on Periodic Technical Inspections: Assessing Impact, Efficiency, and Necessity in Road Safety and Economic Dynamics

The periodic technical inspection of cars and trucks is seen positively and negatively. The opponents of a periodic technical inspection (PTI) of vehicles always lead two main arguments against this inspection regime.

The first argument is that a rigid system overlooks technical defects in the vehicle. These defects will not be discovered until the next inspection. This argument implicitly assumes that if there were an onboard diagnostic system, the vehicle owner would immediately go to the garage to have the fault repaired. However, a car owner cannot always detect all the technical faults in his car:[1]

- The complexity of modern vehicle technology: The sources point out that modern cars have very complex technology, where not all defects are obvious to the driver. Problems can occur in areas such as electronics, powertrains, or steering without the driver being able to detect them immediately.

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[1] See: https://www.ra-kotz.de/halterhaftung-betriebsgefahr-technischer-fahrzeugdefekt.htm; https://eclgh.com/vehicle-inspection-and-why-it-is-important-for-car-owners/; https://www.tribtalk.org/2016/03/11/vehicle-safety-inspections-are-more-than-just-a-chore-theyre-a-tax/; https://ameauto.com.au/blog/vehicle-inspections/4-ways-in-which-vehicle-inspection-can-benefit-you/; https://www.theamericanconsumer.org/2019/06/do-mandatory-vehicle-inspections-really-make-us-safer/.

- Gradual deterioration of components: Some defects develop over a longer period, such as wear on drive or braking system parts. Such gradual problems are often difficult for the driver to detect.

The second main argument against PTI is that the car owner only has additional costs: the fee of the PTI-agency and the transaction costs like time costs and other opportunity costs. On the other hand, the car owner must always keep his vehicle in roadworthy condition and, as explained above, cannot detect certain deteriorations. Therefore, a statistically optimal period would have to be determined to detect possible technical defects. In this respect, it seems fair if a government regulation prescribes a fixed period for the PTI. This would give the driver legal certainty that he has not violated his duty of care. This discussion is associated with low legal costs for the European legal area. For the US legal system, however, such a regulation is generally better because it could reduce the risks associated with litigation costs by replacing personal responsibility with a legally prescribed framework. However, these legal consequences are not yet considered in the USA. These are the unrecognized advantages of a government-mandated vehicle inspection system.

The third argument is that there is no causal connection between the existence of a PTI regime and the reduction of traffic accidents. At this point, reference should be made to Hockey (2003), who does not consider a correlation between PTI and fewer accidents empirically reliable. On the other hand, reference should be made to Martín-delosReyes et al. (2021). The paper analyzes several studies based on the accidents investigated, which found that vehicles with regular inspections have fewer crashes than vehicles without inspections and, in the event of crashes, the severity of accidents is lower. In contrast to these studies, the present study examines from a macroeconomic perspective whether the introduction of the PTI has a statistically significant influence on the number of accidents.

The literature review provides a compromised overview of the current state of knowledge in the literature on the relationship between PTI and road safety.

The question is whether there are arguments that lead to the conclusion that the government must regulate the technical inspection of road vehicles. The following arguments justify the government's regulation of road vehicle inspections:

1. Safety and Environmental Concerns:[2]
    a. Mandatory vehicle inspection programs are mainly motivated by air pollution and road traffic safety concerns.
    b. Some studies find evidence that periodic vehicle inspections can reduce the risk of car crashes and improve the technical condition of inspected cars.
2. Effectiveness and Consistency:[3]
    a. There is debate about the effectiveness of vehicle inspections on safety grounds, with some studies unable to establish a causal

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[2] https://link.springer.com/article/10.1007/s11151-022-09864-z

[3] https://www.theamericanconsumer.org/2019/06/do-mandatory-vehicle-inspections-really-make-us-safer/

relationship between inspections and reduced motor vehicle injuries or fatalities.
   b. Inspections can be inconsistent in identifying mechanical concerns, with one study showing that most defects were not discovered during inspections.
3. Economic Considerations: [4]
   a. Inspection mandates create artificial demand for auto mechanics and can lead to unscrupulous practices, such as fabricating defects or accepting bribes to pass unsafe vehicles.
   b. Inspections cost motorists significantly, with one study in Texas finding that they have taken close to $2.4 billion out of drivers' pockets over ten years.
4. Regulatory Incentives and Leniency:
   a. Increased competition among inspection firms can lead to more lenient inspections, as firms may prioritize customer retention over strict adherence to safety standards.
   b. In Sweden, where car inspection firms are prohibited from engaging in other businesses, the system is designed to mitigate incentives to violate government regulations.
5. Public Trust and Legal Framework:
   a. Vehicle inspections can serve as a "trust signal" to authorities and the public that a vehicle meets safety and emissions standards.
   b. A fixed inspection period provides legal certainty for drivers and reduces liability risks, potentially replacing personal responsibility with a legally prescribed framework.
6. Variability and State Autonomy:[5]
   a. In the United States, car technical testing regulations vary from state to state, with some requiring regular safety inspections and others only emissions inspections or none.
   b. This variability allows states to tailor their inspection programs to their needs and priorities.[6]
7. Market Dynamics and Consumer Behavior:
   a. Drivers have strong incentives to maintain their vehicles in good condition, whether or not the government mandates inspections, as many safety-sensitive systems are typically repaired within a few weeks of detection.
   b. The average age of vehicles is increasing, which could imply a greater need for inspections to ensure older vehicles remain safe on the road.

In conclusion, the sources present a mixed view on the necessity of state regulation of car technical inspections. While safety and environmental motivations exist for such regulations, mandatory inspections' effectiveness and economic impact are debated.

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4 https://www.theamericanconsumer.org/2019/06/do-mandatory-vehicle-inspections-really-make-us-safer/
5 https://www.autodna.com/blog/car-inspection/
6 https://www.carchex.com/research-center/vehicle-inspections/do-state-vehicle-inspections-make-sense/

The arguments suggest that while there may be benefits to state-regulated inspections, significant costs and challenges must be

Beneath that, it has to be considered that the introduction of PTI has direct and indirect effects on traffic safety, which cannot be neglected.

The first direct effect is mechanistic. PTI detects and eliminates technical defects in a vehicle. Accidents resulting from this defect can thus be avoided. This is a fundamental statistical relationship. If technical defects are reduced through inspection, the likelihood of these defects causing accidents decreases. Determining the number of accidents caused by technical defects and empirically establishing the defect detection rate makes it easy to calculate the effect on road safety.

The second direct effect is that even if an accident is not avoided, the car has a lower accident severity or less material damage after eliminating the technical defect.

Indirect effects are that car owners try to repair technical defects in advance due to a mandatory PTI. This also results in more careful vehicle handling, leading to a more cautious driving style and reduced road accidents. An indirect economic effect is that the better condition of cars increases their residual value and, thus, the GDP value.

3.2 The Economics of Vehicle Inspections: Navigating Credence Goods and Market Efficiency

The car owner faces a conundrum, compelled to ensure their vehicle complies with legal performance standards while grappling with the reality that the car is a good credence (Darby, Karni, 1973). This term denotes a situation of information asymmetry where the consumer or buyer lacks full knowledge to assess the quality of the good.

Information asymmetry arises from several factors:

1. Sellers have comprehensive information but may withhold it, sharing only what promotes the sale while hiding the product's deficiencies.
2. This partial disclosure can characterize a 'lemon market,' where sellers predominantly offer data that benefits the sale.
3. Sellers may lack complete details from manufacturers who, in turn, operate as per points one and two.
4. Buyers typically lack the expertise to discern all attributes on their own. If they possessed such knowledge, the good would transform from a credence to an inspection good in economic parlance.

Consequently, without technical expertise, the average vehicle owner cannot accurately judge their car's condition. Hence, motor vehicles are classified as credence goods. Absent mandated inspections, owners would have to acquire expert knowledge to ensure their vehicles meet legal standards.

The critical question then becomes: can the government rely on owners to proactively seek qualified vehicle evaluations, or does the market sufficiently incentivize them to prevent technical issues? Empirical and theoretical evidence suggests that voluntary inspections fall short of the efficacy of mandatory ones:

- Regarding road safety, there is a significant divergence between subjective and objective risk assessment related to accidents. Drivers tend to undervalue their subjective risk of accidents, including those from technical failures, thereby increasing potential hazards for others (Schulz 2019).
- If mandatory inspections can reduce accident risk, all road users will benefit from enhanced safety and smoother traffic without compensating the owner who rectifies the fault. Given the systematic underestimation of risk and absence of compensation, there is little incentive to voluntarily address technical defects (Schulz, 2001).

These factors—information asymmetry at purchase, the car's nature as a credence good, underestimated accident risks from technical flaws, and the impact of personal behavior on others' safety—signify market failures (Akerlof, 1970). Dulleck, Kerschbamer, and Sutter (2011) have identified additional inefficiencies like overtreatment, undertreatment, and overcharging for credence goods, using car repairs as an illustrative example.

It follows that self-regulation for vehicle technical inspections is ineffective. From an economic perspective, mandatory inspections serve as a market-enabling regulatory measure, not as a source of repair costs but as a foundational element of quality assurance in the automotive market.

4 Literature review

The literature analysis is divided into two parts. First, literature deals fundamentally with the connection between the leading technical inspection and the occurrence of accidents. Due to the study's budgetary limitations, the analysis is limited to the most essential sources. The second part of the literature analysis focuses on studies that deal with the effects on road safety in Türkiye.

As the first step within a literature review, the state of the art on the relationship between road accidents and roadworthiness testing is checked. The literature analysis was undertaken with Google Scholar, and the research words used in different combinations are “road accidents,” “roadworthiness testing,” “periodical inspection,” “vehicle inspection,” and “technical roadworthiness test.”

In the second step, the words Turkey and the newer official spelling Türkiye are added to the previous search words.

The revised text below corrects the usage of "nation" to more appropriately reflect the context of economic regions or study areas, replacing it with "economies" or similar terms where suitable:

The literature research clearly shows that the introduction of roadworthiness tests has a positive effect on reducing road accidents. These consistent study results are particularly significant because different road conditions apply in all economies, which introduced roadworthiness tests. The following is a list of some critical aspects that influence road safety and vary from economy to economy. Consider, for example, how speed limits are applied in different countries, influencing the likelihood of accidents. At the same time, the different road conditions in different economies also influence the probability of accidents and general road safety, especially if the extent of unrepaired road damage is very high. Different weather conditions also play a role in the likelihood of road accidents. For instance, numerous economies experience the risk of black ice due to regularly recurring winter temperature conditions, which significantly increases the risk of accidents for the motorists concerned. Conversely, some regions are affected by sandstorms, posing a great danger to motorists. Furthermore, weather conditions cause damage to the asphalt, which occurs to varying degrees across different regions and must be repaired at different intervals to maintain road safety.

Additionally, the general traffic load on roads, in terms of the number of cars regularly traveling on them, also influences the likelihood of road accidents. Considering these conditions collectively, it becomes clear that the road safety of different economies depends on several factors influencing each other, with regular and mandatory roadworthiness testing being an essential component. The fact that all studies on roadworthiness tests in various economies have demonstrated their positive effects on road safety emphasizes and proves their empirical relevance and significance for establishing and maintaining road safety and vehicle fitness. Therefore, the results of this literature analysis underscore the relevance of roadworthiness tests.

4.1 Concerning roadworthiness tests' causal relation to road accidents

The following articles are relevant to whether periodic technical inspection of road vehicles increases road safety.

- Paper 1: Lulić, Z., Pejić, G., Zovak, G., Škreblin, T., & Ormuž, K. (2018). Roadworthiness of Commercial Vehicles with Mass over 7 500 kg–Results of Roadside Inspections. In EVU 2018 Congress (pp. 63-79).
- Paper 2: Ionită, T. D., Ispas, N., Chiru, A., & Motoc, D. L. (2022). The connection between the quality of the periodic technical certification of lorries and the road traffic safety and other ecological and commercial aspects. In IOP Conference Series: Materials Science and Engineering (Vol. 1220, No. 1, p. 012048). IOP Publishing
- Paper 3: Hudec, J., & Šarkan, B. (2022). EFFECT OF PERIODIC TECHNICAL INSPECTIONS OF VEHICLES ON TRAFFIC ACCIDENTS IN THE SLOVAK REPUBLIC. Komunikácie, 24(3).
- Paper 4: Rao, D. S., Rao, M. S., & Kesavarao, V. V. S. (2024). Vehicle Road Worthiness Performance Indicator. *Migration Letters*, *21*(4), 442-454.
- Paper 5: Schulz, W. H., & Franck, O. (2021). An empirical study to estimate the economic effects of the introduction of a periodical technical inspection (PTI) for motor vehicles in Punjab (Pakistan). The Open Transportation Journal, 15(1).
- Paper 6: Schulz, W. H., & Scheler, S. (2019). Reducing the death toll of road accidents in Costa Rica through the introduction of roadworthiness inspections by the government. *Available at SSRN 3420341*.
- Paper 7: Wieteska, S. (2016). Rola Inspekcji Transportu Drogowego w ograniczeniu wypadków w ruchu drogowym w Polsce (The role of the Road Transport Inspection in reducing road traffic accidents in Poland). Acta Universitatis Lodziensis. Folia Oeconomica, 5(325), 65-76.
- Paper 8: Habte, O.A., Holm, H.J. Competition Makes Inspectors More Lenient: Evidence from the Motor Vehicle Inspection Market. Rev Ind Organ 61, 45–72 (2022). https://doi.org/10.1007/s11151-022-09864-z.
- Paper 9: Blows S, Ivers RQ, Connor J, Ameratunga S, Norton R. Does periodic vehicle inspection reduce car crash injury? Evidence from the Auckland Car Crash Injury Study. Aust N Z J Public Health. 2003;27(3):323-7. doi: 10.1111/j.1467-842x.2003.tb00401.x. PMID: 14712793.
- Paper 10: Richard Hockey, Periodic motor vehicle inspections are not the answer, Australian and New Zealand Journal of Public Health, Volume 27, Issue 6, 2003, Page 656, ISSN 1326-0200, https://doi.org/10.1111/j.1467-842X.2003.tb00618.x.
- Paper 11: Martín-delosReyes LM, Lardelli-Claret P, García-Cuerva L, Rivera-Izquierdo M, Jiménez-Mejías E, Martínez-Ruiz V. Effect of Periodic Vehicle Inspection on Road Crashes and Injuries: A Systematic Review. Int J Environ Res Public Health. 2021 Jun 15;18(12):6476. doi: 10.3390/ijerph18126476. PMID: 34203872; PMCID: PMC8296297.

The main results concerning the study's objective, methods, restrictions, and conclusion are more or less summarized for each study. All studies differ in their approach. Therefore, the summary structure is individual; following it covers all relevant information. It is important to note that the table headings reflect the key findings from the studies. As such, they are concise and not comprehensive.

Table 1: Roadworthiness of Commercial Vehicles

Paper 1	Lulić, Z., Pejić, G., Zovak, G., Škreblin, T., & Ormuž, K. (2018). Roadworthiness of Commercial Vehicles with Mass over 7 500 kg–Results of Roadside Inspections. In *EVU 2018 Congress* (pp. 63-79).

Objective: The study aims to ensure that hefty vehicles like buses, lorries, and trailers with a maximum authorized mass exceeding 7,500 kg are safe and environmentally sound throughout their use. This involves assessing the effectiveness of regular and periodic roadworthiness tests and roadside inspections.

Testing Frequency:

Regular Tests: These are mandatory annually for the specified vehicle category.

Periodic Tests: These depend on vehicle age; every six months is for vehicles aged 2-7 years, and every three months is for vehicles older than seven years.

Test Outcomes (2014):

Regular Tests: Conducted on 34,290 lorries and buses and 17,461 trailers; deficiency rates were 23.4% for buses, 24.2% for lorries, and 14.8% for trailers.

Periodic Tests: 61,906 tests were performed; faults were found in 27.9% of buses, 23.1% of lorries, and 22.3% of trailers.

Roadside Inspections: Over 70% of the vehicles inspected showed deficiencies, indicating a significantly higher incidence of issues than controlled test environments.

Conclusion: Vehicles in regular operation showed a deficiency rate about twice that of vehicles consistently undergoing regular and periodic tests. This discrepancy suggests that vehicles may degrade faster than the testing frequency currently accounts for or that conditions on the road lead to more rapid deterioration.

The results underline the need to review and possibly adjust the frequency and rigor of roadworthiness tests to capture better and mitigate deficiencies, thereby improving road safety and vehicle reliability.

Source: own summary.

Table 2: Quality of periodic technical certification and road safety

Paper 2	Ionită, T. D., Ispas, N., Chiru, A., & Motoc, D. L. (2022). The connection between the quality of the periodic technical certification of lorries and road traffic safety and other ecological and commercial aspects. In IOP Conference Series: Materials Science and Engineering (Vol. 1220, No. 1, p. 012048). IOP Publishing
Objective: The study examines the impact of lorries' periodic technical certification quality on road safety, ecological effects, and commercial aspects in Romania. **Regulatory Background**: It references EU directives that emphasize the importance of vehicle checks for safety, with new standards replacing outdated ones from 1977. Methodology **Data Collection**: The study involved detailed periodic technical inspections of light commercial vehicles, focusing on various components such as braking, steering, visibility, and emissions. **Simulation Tools**: Utilized the ADVISOR software to model and simulate the effects of modifications and overloads on vehicle performance and emissions. Key Findings **Technical Condition and Road Safety**: The technical condition of vehicles, especially those that are frequently used at maximum or overloaded capacity, critically influence road safety and environmental impact. **Unauthorized Modifications**: Many vehicles showed unauthorized and unsafe modifications, like altered suspensions for carrying overloads, which were not detected in periodic inspections but significantly affected vehicle safety and road performance. **Simulation Results**: Simulations showed that overloading vehicles can lead to significantly higher emissions and fuel consumption, exceeding Euro 4 emission limits. Conclusions **Risk from Overloading**: Overloaded and modified lorries present a considerable safety risk, potentially leading to more frequent and severe road accidents. **Regulatory Implications**: Current inspection practices may need adjustments to detect better and prevent unsafe modifications, particularly in vehicles used beyond their intended capacity. **Environmental Impact**: The study suggests inadequate technical checks and maintenance can lead to higher pollutant emissions, undermining environmental protection efforts. This research underscores the need for stricter enforcement of roadworthiness tests and the adaptation of current practices to better account for vehicle modifications and real-world usage conditions, aiming to enhance safety and environmental outcomes.	

Source: own summary.

Table 3: Country Study: PTI and Traffic Accidents

Paper 3	Hudec, J., & Šarkan, B. (2022). EFFECT OF PERIODIC TECHNICAL INSPECTIONS OF VEHICLES ON TRAFFIC ACCIDENTS IN THE SLOVAK REPUBLIC. Komunikácie, 24(3).
Purpose: The study investigates the impact of Periodic Technical Inspections (TIs) on road safety, mainly focusing on how the timing and rigor of these inspections influence traffic accidents due to technical defects in vehicles in Slovakia. **Data Utilized**: Utilizes statistical data on traffic accidents and TI data to assess the effectiveness of inspections. Key Findings **Increased Accident Probability Near TI Expiry**: There is a noticeable increase in the probability of accidents as a vehicle's TI expiration approaches, indicating that regular TIs have a preventative effect on accidents. **Decrease in Accidents with Rigorous TIs**: The study identifies a correlation between stringent TIs and decreased traffic accidents caused by technical defects. This suggests that more thorough inspections can significantly enhance road safety. **Predictive Analysis**: Regression analysis within the study suggests that increasing the strictness of TIs could potentially reduce the incidence of traffic accidents related to vehicle defects to zero. **Recommendations and Conclusions** **Policy Enhancement**: The study recommends focusing efforts on improving the quality of TIs through stricter enforcement and better oversight rather than questioning the necessity of the inspections. **Broader Implications**: While the findings are consistent with global research that underscores the importance of technical vehicle inspections for safety, the specific context of Slovakia might limit the generalizability of the results to other regions with different standards and driving conditions. Limitations and Critique **Methodological Constraints**: The reliance on statistical data analysis might not fully account for all factors influencing traffic accidents, such as driver behavior or environmental conditions. **Optimistic Predictions**: The model's suggestion that stricter TIs could eliminate traffic accidents due to technical defects might be overly optimistic, given the complex nature of road safety, including numerous variables beyond vehicle conditions. This analysis provides a detailed insight into how periodic technical vehicle inspections can potentially reduce traffic accidents in Slovakia, emphasizing the need for rigorous inspections and continuous monitoring of vehicle roadworthiness to enhance overall traffic safety.	

Source: own summary.

Table 4: Indicator for Vehicle Road Worthiness Performance

Paper 4	Rao, D. S., Rao, M. S., & Kesavarao, V. V. S. (2024). Vehicle Road Worthiness Performance Indicator. *Migration Letters*, *21*(4), 442-454.
Research Question The study focuses on quantifying the reliability of vehicles to reduce accidents caused by component failures. Given that a significant 3.6% of road accidents are due to such failures, there is a clear need for a systematic scientific approach to mitigate these issues effectively. **Methodology** The authors employ a mixed-method approach incorporating both Principal Component Analysis (PCA) and the Analytical Hierarchy Process (AHP). This methodology is used to develop a vehicle roadworthiness performance indicator, assessing various critical vehicle parameters that impact safety, including the braking system, fuel supply, and electrical systems. **Key Findings** The braking system is identified as the most critical component influencing vehicle safety. Other significant factors include fuel supply and electrical systems, highlighting the multifaceted nature of vehicle components that contribute to road accidents. Regular safety inspections and proper maintenance are emphasized as essential practices to ensure vehicles remain roadworthy. **Limitations** The complex interrelations between various vehicle parameters and their impact on safety are acknowledged, with a note that external factors such as road conditions and driver behavior also play significant roles. The study's methodological focus on PCA and AHP might not fully capture the dynamic interactions between different vehicle components and human factors in real-world scenarios. **Further Research** There is a call for more comprehensive models that include real-time data on vehicle usage and integrate behavioral studies on driver interactions with vehicle safety systems. Evaluating the effectiveness of the proposed measures in diverse geographical and regulatory environments is suggested to understand their global applicability. Overall, this article provides crucial insights into the technical aspects of vehicle safety, proposing a structured approach to improving roadworthiness through systematic inspections and targeted enhancements of critical vehicle components to reduce the number of accidents caused by vehicle failures drastically.	

Source: own summary.

Table 5: Country Study (Punjab Pakistan): Economic Effects introducing PTI

Paper 5	Schulz, W. H., & Franck, O. (2021). An empirical study to estimate the economic effects of the introduction of a periodical technical inspection (PTI) for motor vehicles in Punjab (Pakistan). *The Open Transportation Journal*, *15*(1).
Background The analysis uses a cost-benefit analysis (CBA) approach to measure the economic implications of the PTI system. This approach is crucial in a region like Punjab, which has a high population and vehicle count, contributing to a significant number of fatal traffic accidents. The lack of a systematic regulatory body to ensure vehicle quality is identified as a primary factor in these accidents, highlighting the need for an effective PTI system. **Objective** The study's objective is to assess the feasibility and economic effectiveness of the PTI system in Punjab. By calculating a benefit-cost ratio (BCR), the study aims to determine whether the PTI system would provide a positive economic impact, serving as a basis for policy-making decisions. **Methods** The CBA method employed allows for a detailed comparison of the benefits and costs associated with the PTI system. A BCR greater than one would indicate that the benefits of the system outweigh the costs, suggesting that the PTI system is economically beneficial and socially desirable. **Results** According to the study, implementing the PTI system would result in a BCR of 12.45, indicating that every dollar spent on the system could yield an economic benefit of approximately $12.45. The analysis also estimates significant reductions in fatalities and injuries, with potential savings from avoiding 198 fatalities estimated at $11,616,462 and an additional $1,568,874 saved from 382 fewer injuries. Emission reductions would further save about $2,647,966.87, leading to total estimated benefits of $15,833,302.9 against inspection costs of $1,271,460 for 179,977 vehicles. **Conclusion** The PTI system in Punjab would not only reduce the number of road accidents but also significantly enhance the economic welfare of the region. Despite some limitations in data availability, particularly regarding noise reduction, the high BCR strongly supports the implementation of the PTI system as economically and socially beneficial. This empirical evidence provides a compelling case for policymakers to consider the broader implementation of such inspection systems.	

Source: own summary.

Table 6: Country Study (Costa Rica): Safety Effects of introducing PTI

Paper 6	Schulz, W. H., & Scheler, S. (2019). Reducing the death toll of road accidents in Costa Rica through the introduction of roadworthiness inspections by the government. *Available at SSRN 3420341*.

Background and Objectives

Introduction of RITEVE: The system was introduced to address the high incidence of traffic-related fatalities and injuries, which notably affected the nation's GDP. This was part of a broader national road safety plan initiated to curb mortality rates.

Research Goals: The primary goals were to assess if the PTI system directly contributed to a reduction in accidents and to analyze the cost-benefit of the RITEVE system.

Methodology

Analytical Approach: The study utilized regression analysis to differentiate the effects of the RITEVE system from other interventions like the seatbelt law. A cost-benefit analysis (CBA) was performed to determine the economic effectiveness of PTI in reducing traffic accidents.

Cost-Benefit Analysis Steps: These included defining cases with and without PTI, identifying relevant parameters, quantifying physical effects, converting these effects into monetary values, and calculating the benefit-cost ratio.

Results

Accident Reduction: Following the introduction of RITEVE, traffic accidents were reduced significantly by around 40% initially, indicating a positive impact of the system.

Economic Impact: The cost-benefit analysis showed high ratios, suggesting substantial economic benefits relative to the costs of implementing the PTI system.

Conclusions

Effectiveness of PTI: The findings support the effectiveness of periodic technical inspections in reducing traffic accidents and their associated costs, making a compelling case for other countries to consider similar measures.

Policy Implications: The high benefit-cost ratios provide strong empirical support for the continuation and expansion of PTI systems like RITEVE in enhancing road safety and reducing economic losses from traffic accidents.

Overall, the study underscores the significant role that systematic vehicle inspections can play in improving traffic safety and reducing the economic impact of road accidents, advocating for broader implementation of such systems.

Source: own summary.

Table 7: Country Study (Poland): Effects of PTI on road traffic accidents

Paper 7	Wieteska, S. (2016). Rola Inspekcji Transportu Drogowego w ograniczeniu wypadków w ruchu drogowym w Polsce (The role of the Road Transport Inspection in reducing road traffic accidents in Poland). Acta Universitatis Lodziensis. Folia Oeconomica, 5(325), 65-76.
Research Question and Object of Study: The study aims to understand how the technical certification quality of lorries influences their safety on roads, their environmental impact due to emissions, and various commercial aspects such as changes in vehicle ownership. **Methodology:** Using data from periodic technical inspections, the authors construct scenarios demonstrating lorries' impact on road safety and the environment. They employ ADVISOR, a simulation software, to analyze the consequences of vehicle modifications—such as adjustments in suspension for overloading—on vehicle performance and emission levels. **Findings:** The findings indicate that lorries, often operated at maximum or overloaded capacities, present significant risks due to technical shortcomings that may not be detected during inspections. These deficiencies can lead to increased road accidents, elevated fuel consumption, and higher emission levels that exceed the EU's Euro 4 emission standards. Simulation results show that unauthorized modifications intended to increase load capacity significantly worsen lorries' environmental and safety performance. **Limitations:** The research's scope is somewhat limited to Romanian road conditions, potentially affecting its applicability in different geographic and regulatory contexts. Moreover, reliance on simulation for generating data might not capture all variables affecting lorry performance and safety in real-world scenarios. **Future Research Needs:** The study suggests a need for broader research to examine the applicability of its findings in varied geographic and regulatory environments. Further comprehensive studies incorporating newer vehicle technologies and the changing dynamics of road use and vehicle performance standards are recommended to understand better and address the identified risks. This research highlights the critical importance of stringent and current technical inspections and regulations in ensuring road safety and environmental protection in the context of commercial vehicle operations.	

Source: own summary.

Table 8: Quality of PTI

Paper 8	Habte, O.A., Holm, H.J. Competition Makes Inspectors More Lenient: Evidence from the Motor Vehicle Inspection Market. Rev Ind Organ 61, 45–72 (2022). https://doi.org/10.1007/s11151-022-09864-z
Research Question and Object of Study: The research focuses on whether higher competition among vehicle inspection stations leads to increased leniency in passing vehicles that might not meet standard requirements. The study explores this in the context of Sweden, a country known for strong adherence to regulations and a high rule of law index. **Methodology:** The authors employ a robust dataset covering 22.5 million car inspections from 2010 to 2015. They control for potential endogeneity of competition among stations using fixed effects and instrumental variable estimations. This methodology allows them to isolate the effect of competition on inspection outcomes from other confounding factors. **Findings:** The study finds that inspection stations in more competitive markets tend to show higher leniency by passing cars at a higher rate compared to those in less competitive markets. This tendency remains significant even after accounting for various control variables and using different econometric techniques to ensure robustness. **Limitations**: The study is geographically limited to Sweden, and its findings might not directly translate to countries with different regulatory environments or lower adherence to the rule of law. Additionally, the observational nature of the data may not fully capture all nuances of individual station behavior or customer-station interactions. **Future Research Needs:** The paper suggests that further research could explore the mechanisms of competition and leniency in other regulatory environments or markets with different regulatory scrutiny levels. It also raises the question of whether similar patterns are observable in other industries where safety and regulatory compliance are critical. Overall, this article provides insightful evidence on how market competition can influence regulatory compliance in a highly regulated environment, suggesting a potential trade-off between the benefits of competition and the integrity of regulatory outcomes.	

Source: own summary.

Table 9: Case study: PTI effects on car crash injury

Paper 9	Blows S, Ivers RQ, Connor J, Ameratunga S, Norton R. Does periodic vehicle inspection reduce car crash injury? Evidence from the Auckland Car Crash Injury Study. Aust N Z J Public Health. 2003;27(3):323-7. doi: 10.1111/j.1467-842x.2003.tb00401.x. PMID: 14712793
Objectives: This paper examines the association between periodic motor vehicle inspections, frequent tire pressure checks, and the risk of car crash injury. **Methods:** Data were analyzed from the Auckland Car Crash Injury Study, a population-based case-control study in Auckland, NZ, where vehicles are required to undergo six-monthly safety inspections. Cases were all cars involved in crashes in which at least one occupant was hospitalized or killed, which represented 571 drivers. Controls were randomly selected cars on Auckland roads (588 drivers). Participants completed a structured interview. **Results:** Vehicles that did not have a current certificate of inspection had significantly greater odds of being involved in a crash where someone was injured or killed compared with cars that had a current certificate, after adjustment for age, sex, marijuana use, ethnicity, and license type (OR 3.08, 95% CI 1.87-5.05). Vehicles that had not had their tire pressure checked within the past three months also had significantly greater odds of being involved in a crash compared with those that had a tire pressure check after adjustment for age, sex, ethnicity, seatbelt use, license type, self-reported speed and hours per week of driving exposure (OR 1.89, 95% CI 1.16-3.08). **Conclusions:** This study provides new evidence, using rigorous epidemiological methods and controlling for multiple confounding variables, of an association between periodic vehicle inspections and three-monthly tire pressure checks and reduced risk of car crash injury. **Discussion:** This research suggests that vehicle inspection programs should be continued where they already exist and contributes evidence in support of introducing such programs to other areas.	

Source: own summary.

Table 10: Country Studies (Australia & New Zealand) PTI are not the answer

	Richard Hockey, Periodic motor vehicle inspections are not the answer, Australian and New Zealand Journal of Public Health, Volume 27, Issue 6, 2003, Page 656, ISSN 1326-0200, https://doi.org/10.1111/j.1467-842X.2003.tb00618.x.
Research Question The study investigated whether introducing periodic vehicle inspections could reduce injuries resulting from motor vehicle crashes. **Methodology** The authors of the paper analyzed data from crashes involving vehicles with and without current inspection certificates. They examined the association between the status of vehicle inspections and the likelihood of these vehicles being involved in injury crashes. **Findings** The study found that vehicles lacking a current certificate of inspection were more likely to be involved in injury crashes. However, the paper also noted that a direct causal link between the absence of periodic inspections and higher crash rates could not be conclusively established. The paper compared these findings with other studies that considered driver licensing and vehicle registration status, suggesting that behaviors associated with non-compliance in these areas might reflect a broader pattern of disregard for regulations rather than being directly causative of crashes. **Limitations** One of the primary limitations highlighted is the assumption of causality between inspection status and crash involvement. The article critiques this by pointing out that all injury crashes were included in the study, regardless of whether they were directly attributable to a vehicle defect. Previous reviews have indicated that only a small percentage of injury crashes involve vehicle defects, questioning the effectiveness of inspections in significantly reducing crash rates. **Future Research Needs** The paper suggests the need for more comprehensive studies to determine the effectiveness of periodic vehicle inspections conclusively. Such studies would need to better differentiate between crashes due to vehicle defects and those due to other factors and possibly examine the broader context of compliance with traffic laws and regulations.	

Source: own summary.

Table 11: Review of other Studies: Relation between PTI and road safety

<table>
<tr><td>Paper 11</td><td>Martín-delosReyes LM, Lardelli-Claret P, García-Cueva L, Rivera-Izquierdo M, Jiménez-Mejías E, Martínez-Ruiz V. Effect of Periodic Vehicle Inspection on Road Crashes and Injuries: A Systematic Review. Int J Environ Res Public Health. 2021 Jun 15;18(12):6476. doi: 10.3390/ijerph18126476. PMID: 34203872; PMCID: PMC8296297.</td></tr>
<tr><td colspan="2">Research Question/Investigated Topic: The systematic review investigated the effect of periodic motor vehicle inspections on road crashes and injuries. It aimed to determine if vehicles undergoing periodic inspections have fewer road crashes and injuries than those with fewer or no inspections.
Methodology: The review used a comprehensive search strategy across multiple databases (Medline, Web of Science, and Scopus) to identify relevant studies. It excluded ecological studies due to their weak causal evidence. Six studies met the inclusion criteria, encompassing a range of designs: one experimental, two cohort studies with a comparison group, two cohort studies without a comparison group, and one case-control study. A quantitative synthesis of results was not performed due to the heterogeneity of study designs and the varying nature of the interventions and comparison groups used.
Findings: The findings were mixed:
One case-control study found a significant association between the lack of a valid vehicle inspection certificate and higher road crash involvement.
Other studies showed slight reductions in crash rates or no significant association.
Some studies even found a higher crash rate in vehicles with more frequent inspections. The heterogeneity in findings suggests that while there might be a slight reduction in road crashes due to inspections, the evidence is not strong enough to establish causality conclusively.
Limitations: The primary limitation identified in the review was the significant risk of residual confounding bias across the observational studies, which could explain the varied results. Additionally, the heterogeneous nature of the study designs and the intervention groups used posed challenges in synthesizing the data.
Further Research Needs: Further research is needed to:
Overcome the limitations of heterogeneity and confounding factors in observational studies.
Investigate the causality between vehicle inspections and crash rates more robustly.
Explore the economic implications of periodic inspections in relation to their effectiveness in reducing road crashes and injuries.</td></tr>
</table>

Source: own summary.

The reviewed papers collectively underscore the importance and effectiveness of periodic technical inspections (PTIs) in improving road safety, although views on their economic and commercial impacts vary. While most studies (e.g., Papers 1, 2, 3, 5, 6, 7, 9, 11) affirm the positive role of PTIs in enhancing vehicle safety and reducing accidents, others (Papers 8 and 10) highlight potential drawbacks, such as leniency due to market competition or argue against their overall effectiveness. This synthesis helps in understanding the multifaceted impacts of PTIs and suggests areas for further research, especially concerning the balance between market forces and regulatory effectiveness in maintaining rigorous inspection standards. The following table gives a summarized overview of the research on the impact of PTI on road safety and related Aspects.

Table 12: Overview of Research on the Impact of Periodic Vehicle Inspections on Road Safety and Related Aspects

Paper Number	Focus	Key Findings
1	Examines roadworthiness of heavy commercial vehicles through data from roadside inspections.	Highlights the challenges and common failures in heavy vehicles, underlining the need for stringent inspections.
2	Explores the relationship between the quality of lorry inspections and safety, ecological, and commercial outcomes.	Demonstrates a positive correlation between thorough technical inspections and improved road safety and environmental impacts.
3	Assesses the impact of vehicle inspections on reducing traffic accidents in Slovakia.	Provides evidence supporting the effectiveness of periodic inspections in reducing accidents.
4	Introduces a new indicator for assessing vehicle roadworthiness.	Proposes a comprehensive metric that could enhance current inspection protocols.
5	Analyzes the economic impact of introducing periodic vehicle inspections in Punjab, Pakistan	Highlights significant economic benefits alongside improvements in road safety.
6	Evaluate the effectiveness of roadworthiness inspections in reducing fatalities in Costa Rica.	Confirms the positive impact of government-implemented vehicle inspections on road safety.
7	Discusses the role of road transport inspections in reducing road traffic accidents in Poland.	Emphasizes the critical role of transport inspections in enhancing road safety.
8	Investigates how competition in the vehicle inspection market affects inspector stringency.	Suggests that increased competition may lead to more lenient inspections, potentially undermining road safety.
9	Examines the impact of vehicle inspections on car crash injuries in Auckland.	Provides evidence that periodic inspections do reduce the severity and frequency of car crash injuries.
10	Critiques the effectiveness of periodic vehicle inspections in improving road safety.	Argues against the efficacy of inspections, suggesting that they do not significantly reduce accidents.
11	Systematic review of the impact of vehicle inspections on road safety.	Confirms a generally positive effect of inspections on reducing road crashes and injuries.

Source: own compilation.

4.2 Literature review concerning roadworthiness tests in Türkiye

The Turkish-specific literature analysis focuses on the following articles and studies:

1. Suleiman, G., Dahamsheh, A. M., & Ergun, M. (2020). Assessment of fatal road traffic crashes in Turkey. *International Journal of Safety and Security Engineering*, *10*(6), 733-737.
2. Schulz, W. H., & Scheler, S. (2020). Getting ready for Europe: an empirical assessment for the introduction of periodical technical inspections of road vehicles in Turkey. *Available at SSRN 3523602*.
3. Schulz, W.H., Scheler, S., (2016). Impact study to estimate the economic effects of the introduction of PTI in Turkey, Meerbusch.

The study **"Assessment of Fatal Road Traffic Crashes in Turkey,"** which was published in the International Journal of Safety and Security Engineering in December 2020, provides insights into the magnitude and causes of road traffic accidents in Turkey and models to predict traffic injuries. This information could be quite relevant to investigations related to technical inspections and their potential impact on reducing road accidents.

The research used accident data from 2009 to 2019, developing models to understand the characteristics of fatal traffic accidents, the involvement rates of pedestrians, drivers, and vehicles, and the behavior of drivers leading to accidents. It found that driver and pedestrian errors were the predominant causes of accidents, contributing to 88% and 8% of total accidents, respectively.

In terms of economic impact, traffic accidents have significant costs. It was estimated that the costs associated with traffic accidents in Turkey reach approximately 20 billion Turkish Lira annually, a substantial figure compared to the national GDP.

Precisely, the costs for fatal and injury-causing accidents were quantified as follows: **1,206,982 TL per fatality, 127,732 TL per seriously injured person, and 9,302 TL** per slightly injured person. Traffic accidents with only material damage were estimated at 1,797 TL per vehicle.

The study also emphasized the drop in the number of casualties in recent years due to a decrease in heavy vehicle mobility and a slowdown in the growth rate of registered vehicles. This aspect could indirectly suggest the influence of interventions, such as technical inspections, although the study does not establish a direct correlation.

The information from the study could be instrumental in advocating for more stringent traffic laws and regulations, enhancing the level of driving certification, and improving road safety culture among drivers and pedestrians alike. The findings underline the need for decision-makers and related authorities to intensify efforts to address the road traffic accident problem, potentially including the impact of technical inspections on reducing accidents.

For further information on the study's findings and methodology, referring to the original publication would be recommended.

The paper **"Getting ready for Europe: An Empirical Assessment for the Introduction of Periodical Technical Inspections of Road Vehicles in Turkey"** by Prof. Dr. Wolfgang H. Schulz and Sebastian Scheler assesses the impact of introducing Periodical Technical Inspections (PTI) on traffic safety and economic benefits in Turkey, contextualized within Turkey's convergence with European Union standards.

The study utilizes a unique panel dataset and triangulation methodology to investigate the effects of PTI, introduced in Turkey in 2008. The research finds measurable improvements in traffic safety post-PTI implementation and estimates monetary benefits for the Turkish economy. It also provides insights into potential benefits for other countries considering similar measures to enhance road safety.

Critically, while the paper establishes a link between PTI and improved traffic safety, it also acknowledges the limitation of PTI's scope, as technical inspections cannot prevent accidents caused by human error, which accounts for most accidents. The paper suggests that PTI, while beneficial, should be part of a broader set of safety measures.

For the new analysis, this paper offers valuable insights into the value of PTI. However, considering broader factors like driver education, infrastructure quality, and emergency response times could provide a more comprehensive understanding of traffic safety improvements. Additionally, the study's findings are based on data from Turkey, which may have unique contextual factors affecting the implementation and outcomes of PTI. Therefore, while the paper's methodology and results are robust for Turkey, applying these findings to different contexts would require careful consideration of local conditions.

In the context of the investigation, this research underlines the crucial role of technical inspections in preventing accidents due to vehicle defects. It supports the argument for maintaining, if not enhancing, periodic technical inspections as part of a holistic approach to road safety. For future research, it would be beneficial to incorporate more diverse datasets and consider additional factors affecting road safety to build a more comprehensive understanding of how to reduce traffic accidents effectively.

The study by Schulz and Scheler (2016) focused on the effects of introducing PTI in Türkiye. 2008 Türkiye adopted a comprehensive Periodical Technical Inspection (PTI) system to enhance road safety and vehicle reliability. This transition offered a unique opportunity to evaluate the effects of PTIs on reducing traffic accidents and their associated economic impacts, employing an extensive dataset spanning from 1990 to 2015.

The study leveraged data sourced from Turkstat and TÜVTürk, which included information on vehicle populations, specifics of road accidents, and various economic indicators. This data was meticulously preprocessed using Microsoft Excel, with subsequent analyses conducted using the IBM SPSS Statistics 20.0 statistical software. The methodology employed a multi-model approach to assess the impact of PTIs. This approach encompassed **Pure Time-Series Models (PTSM)**, which predicted future values based on past data trends; **Pure Traffic-Parameter Models (PTPM)**, focusing solely on traffic-related variables; **Pure Socio-Economic Models (PSEM),** which considered socio-economic factors such as GDP and population; and

Mixed Models, which integrated elements from the models mentioned above to provide a comprehensive view of the impacts of PTI.

The results indicated a significant correlation between the introduction of PTIs and a reduction in road fatalities and accidents, suggesting improvements in road safety following the implementation of PTIs. Economically, the implementation of PTIs was associated with considerable reductions in costs related to traffic accidents. The regression analyses demonstrated high model fits, emphasizing strong relationships between the implementation of PTI and improvements in traffic conditions.

The discussion highlights that PTIs have positively impacted road safety and economic factors in Türkiye. The decrease in road fatalities and injuries post-implementation indicates the system’s effectiveness. From an economic perspective, reducing the costs associated with traffic accidents post-PTI implementation has rendered substantial benefits, justifying continued investments in road safety measures.

In conclusion, the introduction of PTI has significantly improved road safety and reduced the economic burdens of traffic accidents in Türkiye. This study supports the potential broader application of PTI systems in regions with high rates of traffic incidents, suggesting substantial global improvements in road safety could be achieved. Continued research is essential to adapting and optimizing PTI systems to align with current and future traffic and automotive technologies.

This chapter delves into the specific impacts and contexts of Periodical Technical Inspections (PTI) within the Turkish road safety landscape. This review synthesizes findings from several vital studies that analyze both the causes and effects of road traffic accidents in Türkiye and the economic impacts of these accidents.

The first study, which Suleiman, Dahamsheh, and Ergun (2020) reviewed, assessed fatal road traffic crashes in Türkiye. Utilizing data from 2009 to 2019, this study developed models to understand the dynamics and characteristics leading to traffic accidents. The study finds that driver and pedestrian errors constitute the majority of accident causes, suggesting a critical area for improvement in road safety measures.

The second study by Schulz and Scheler (2020) explores the readiness of Türkiye for European Union road safety standards through the lens of PTI. This study highlights the tangible improvements in traffic safety post-PTI implementation and estimates significant economic benefits from reduced accident costs.

Lastly, the 2016 study by Schulz and Scheler offers a comprehensive analysis of the economic effects of PTI implementation in Türkiye. Using extensive data from 1990 to 2015, the study employs various statistical models to prove a strong correlation between PTI and reduced traffic accidents and fatalities.

Collectively, these studies contribute to a nuanced understanding of the multifaceted impact of PTI in enhancing road safety and reducing economic losses due to traffic accidents in Türkiye. The literature review underscores the effectiveness of PTIs and frames them as an integral component of national road safety strategies, aligning with global safety standards and contributing positively to public welfare.

5 Road Safety Situation in Türkiye

Table 13 reflects overall growth in vehicle numbers and population, alongside fluctuations in accidents, fatalities, and injuries over the years.

Table 13: Key figures for the road safety analysis of Türkiye (period from 2007 to 2022)

Year	Population	Road Vehicles	Road Accidents	Fatalities	Injuries
2007	70 586 256	13 022 945	825 561	5 007	189 057
2008	71 517 100	13 765 395	950 120	4 236	184 468
2009	72 561 312	14 316 700	1 053 346	4 324	201 380
2010	73 722 988	15 095 603	1 106 201	4 045	211 496
2011	74 724 269	16 089 528	1 228 928	3 835	238 074
2012	75 627 384	17 033 413	1 296 634	3 750	268 079
2013	76 667 864	17 939 447	1 207 354	3 685	274 829
2014	77 695 904	18 828 721	1 199 010	3 524	285 059
2015	78 741 053	19 994 472	1 313 359	7 530	304 421
2016	79 814 871	21 090 424	1 182 491	7 300	303 812
2017	80 810 525	22 218 945	1 202 716	7 427	300 383
2018	82 003 882	22 865 921	1 229 364	6 675	307 071
2019	83 154 997	23 156 975	1 168 144	5 473	283 234
2020	83 614 362	24 144 857	983 808	4 866	226 266
2021	84 680 273	25 249 119	1 186 353	5 362	274 615
2022	85 279 553	26 482 847	1 232 957	5 229	288 696

Source: Turkish Statistical Institute, Indicators of 100 Years, Ankara 2023.

This analysis delves into the road traffic statistics in Türkiye from 2007 to 2022, scrutinizing the evolution of population, vehicle registration, road accidents, fatalities, and injuries. This period marks significant socio-economic changes and developments in road safety measures in Türkiye.

Firstly, the population of Türkiye exhibited a steady growth from approximately 70.6 million in 2007 to about 85.3 million in 2022, reflecting an overall increase of 20.8%. The annual average growth rate hovered around 1.3%, indicating a consistent demographic expansion. Concurrently, the number of road vehicles almost doubled, escalating from around 13 million to over 26 million, representing an impressive 103.4% increase. This surge at an average annual rate of 6.5% underscores rapid motorization in the country, which correlates with urban expansion and economic growth.

The pattern of road accidents provides further insights. The number of reported incidents steadily climbed to a peak in 2015, with approximately 1.31 million accidents recorded. This was followed by a reduction, most notably in 2020, which reported about 984,000 accidents, a decline likely influenced by the mobility restrictions imposed during the COVID-19 pandemic. From the 2007 baseline to the peak in 2015, accidents rose by 59%, yet from 2015 to 2022, there was a marginal cumulative decrease of 6%.

The analysis of fatalities and injuries over these years reveals critical fluctuations. In 2015, the fatalities surged to 7,530, marking a 50.3% increase from the previous year, which starkly contrasts with the preceding trend of gradual reductions. This anomaly could be attributed to traffic law enforcement lapses or regulatory changes that year. Post-2015, fatalities and injuries showed a general downward trend, suggesting possible improvements in road safety protocols or vehicular safety technology.

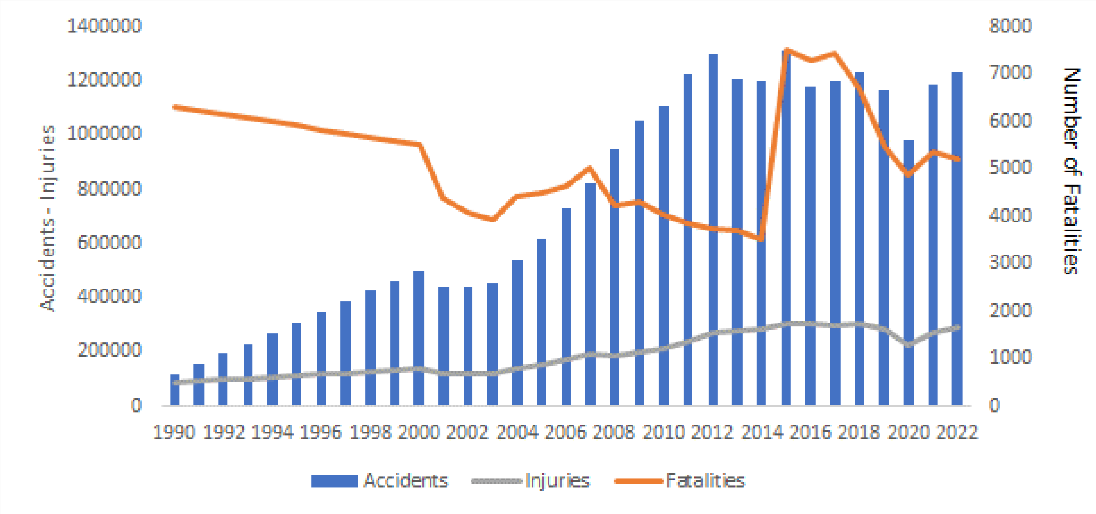
However, injuries again escalated in the subsequent years, with a brief dip in 2020 attributed to the pandemic's impact on traffic volume.

In sum, the time series development from 2007 to 2022 indicates that while Türkiye has experienced significant motorization accompanying population growth, it has also faced challenges in road safety management. The year 2015 stands out as an anomalous peak in adverse outcomes, highlighting the need for detailed analysis to understand the underlying causes. Suleiman and Ergun (2020) point out that the recording of fatalities was changed. Until 2015, only those who died at the scene of the accident were counted as fatalities. If the injured person died later in hospital, they were not counted. In order to meet the usual standards of international statistics, since 2015, injured persons who die in hospital 30 days after the accident are also counted as road fatalities. Therefore, if the effects of introducing the periodic inspection are examined in more detail, the time series of road fatalities is unsuitable. The study will, therefore, focus on the time series of road traffic accidents.

Overall, reducing accidents, fatalities, and injuries post-2015 suggests progressive enhancement in road safety measures. The fluctuations necessitate ongoing evaluation to sustain and improve road safety outcomes amidst increasing road vehicle numbers and urbanization pressures.

Overall, the time series of data from 2007 to 2022 shows a high level of dynamism. As part of the study, a before and after analysis is to be carried out to determine the development of road accidents after introducing the TüVTürk. Figure 1 shows the long-term development of road traffic accidents, fatalities, and injuries.

Figure 1: **Trends in Road Traffic Accidents, Fatalities, and Injuries in Türkiye: 1990–2022**



Source: Turkish Statistical Institute, Indicators of 100 Years, Ankara 2023; own graphic.

The dataset spanning from 1990 to 2022 provides a comprehensive overview of road traffic accidents, fatalities, and injuries within Türkiye. An inspection of the temporal progression of these variables suggests a possible structural shift in the year 2008. Such an assertion necessitates a methodical approach, typically involving statistical tests identifying breakpoints in time series data, such as the Chow test for single breakpoints or the Bai-Perron test for multiple breaks. Though the actual execution of these tests is beyond the scope of this discussion, a qualitative analysis can still yield substantial insights.

A significant escalation in road accidents is observed, surging from 825,561 incidents in 2007 to 950,120 in 2008, marking an increase of approximately 15%. This abrupt amplification disrupts the previously observed trend of gradual increments. In stark contrast, fatalities related to road incidents depict a converse movement, with figures descending from 5,007 to 4,236, resulting in a notable reduction of approximately 15.4% during the same period. Additionally, injuries decreased slightly from 189,057 to 184,468 in 2008, a modest decline of about 2.4%.

The divergent trajectories of these variables are intriguing. The substantial rise in accidents juxtaposed against the simultaneous decrease in fatalities and injuries in 2008 could denote a structural break. Several plausible catalysts for such a divergence include:

- Policy Implementation: The enactment of new traffic legislation, more rigorous enforcement of existing laws, or an enhancement in the public's road safety awareness could potentially explain the improved fatality and injury rates despite the growing number of accidents.
- Economic Oscillations: Fluctuations in the economic landscape could influence driving patterns, vehicle maintenance, and overall road usage, thereby affecting accident outcomes.
- Alterations in Data Recording: Modifications in the methodologies used to record and report traffic incidents could have resulted in discrepancies between the actual and reported figures, manifesting as structural shifts in the observational data.

Notably, identifying a structural break merely by visual inspection and rudimentary analysis remains speculative. An econometric analysis is essential to establish the presence of a structural break conclusively. This would involve estimating regression models separately for periods before and after the suspected breakpoint and conducting formal statistical tests to assess the stability of the model parameters across the structural boundary delineated by the year 2008.

6 Developing a New Model to Assess the Impact of PTI on Road Safety in Türkiye

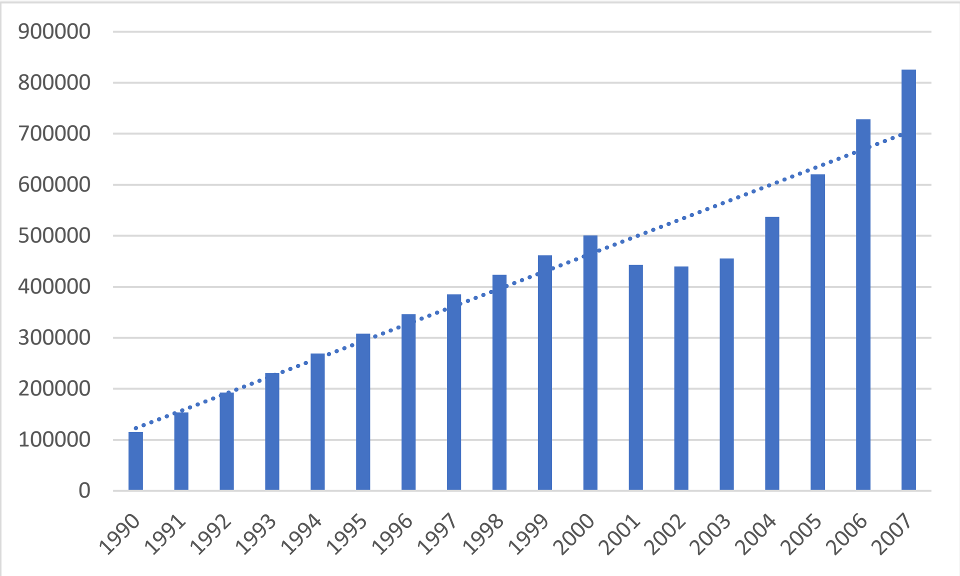
To effectively demonstrate the impact of technical vehicle inspections, it is essential to statistically verify whether their implementation in Turkey has resulted in a structural break. This investigation employs three distinct methods. Firstly, a visual analysis of trend developments assesses changes over time. Secondly, the progression of autoregressive processes is examined to identify any patterns or shifts. Lastly, the Chow test is utilized for structural breaks in the data.

6.1 Identifying Structural Breaks in Traffic Accident Data

6.1.1 Trend Analysis

The trend analysis starts with a graphical illustration of the time series data to gain an initial understanding of trends and seasonality. Analyzing the road accident data in Türkiye from 1990 to 2022 means dividing the time-series data into two data sets: the period prior to the implementation of periodic technical inspections (PTI) from 1990 to 2007 and the subsequent period from 2008 to 2022 following the introduction of PTI. Estimating separate trends for the periods before and after the PTI implementation makes it possible to compare these trends to reveal any shifts in the accident rate trends before and after the policy was introduced.

Figure 2: Trends in Road Accidents in Türkiye from 1990 to 2007



Source: General Directorate of Public Security and General Command of Gendarmerie, 2024; own figure.

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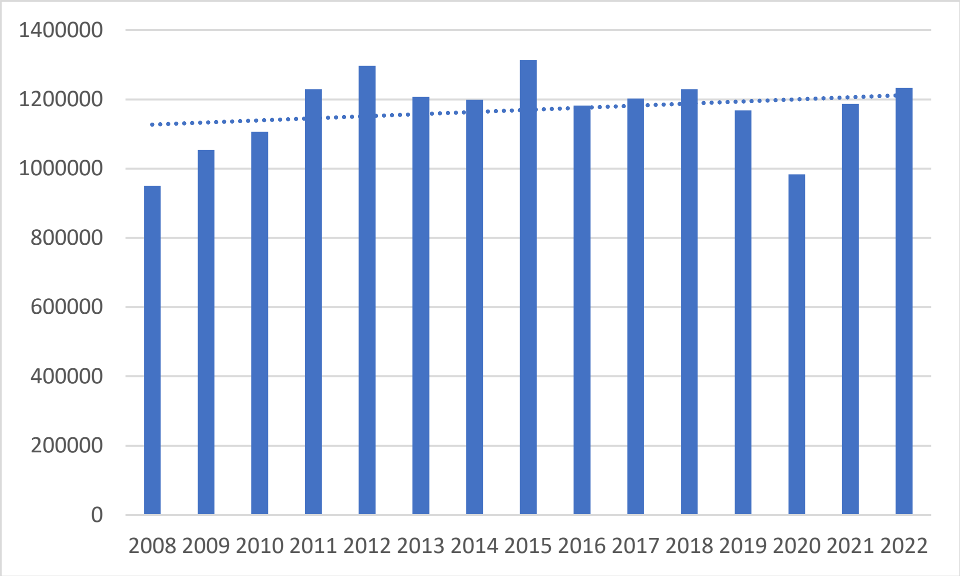
Figure 3: Development of Road Accidents in Türkiye from the year 2008 and 2022



Source: General Directorate of Public Security and General Command of Gendarmerie 2024; own figure.

The slope and intercept for the period preceding the structural break (1990 to 2007) are as follows (see Figure 1):

- Slope: 34,163
- Intercept: 88,701
- Coefficient of determination (R^2): 0.917

For the period following the structural break (2008 to 2022), the values are (Figure 2):

- Slope: 6,054
- Intercept: 1,000,000
- Coefficient of determination (R^2): 0.068

The markedly higher slope prior to the structural break suggests that the number of road accidents was increasing at a more rapid pace during this interval. Post-break, the slope is substantially lower, indicating a deceleration in the growth of accident figures. The coefficient of determination for the period before the structural break is very high, signifying a strong fit of the model to the data. Conversely, the coefficient of determination post-break is relatively low, which could imply that the model does not adequately explain the data or that post-2008, there may be additional factors at play not captured by a simple linear model.

Comparing these slopes scientifically, the following aspects should be considered:

- Absolute difference: Subtract the smaller slope coefficient from the larger one to find the absolute difference between the two. The absolute difference is 28.110.
- Relative difference: The slope of the accident trend for the period from 2008 to 2022 has decreased by -82.3% compared to the trend slope for the period before the introduction of the PTI. If this change is converted to an annual

percentage rate of change, the average annual rate of change is approximately -1.29%. This means that the number of accidents has decreased by an average of 1.29% each year compared to the previous year.

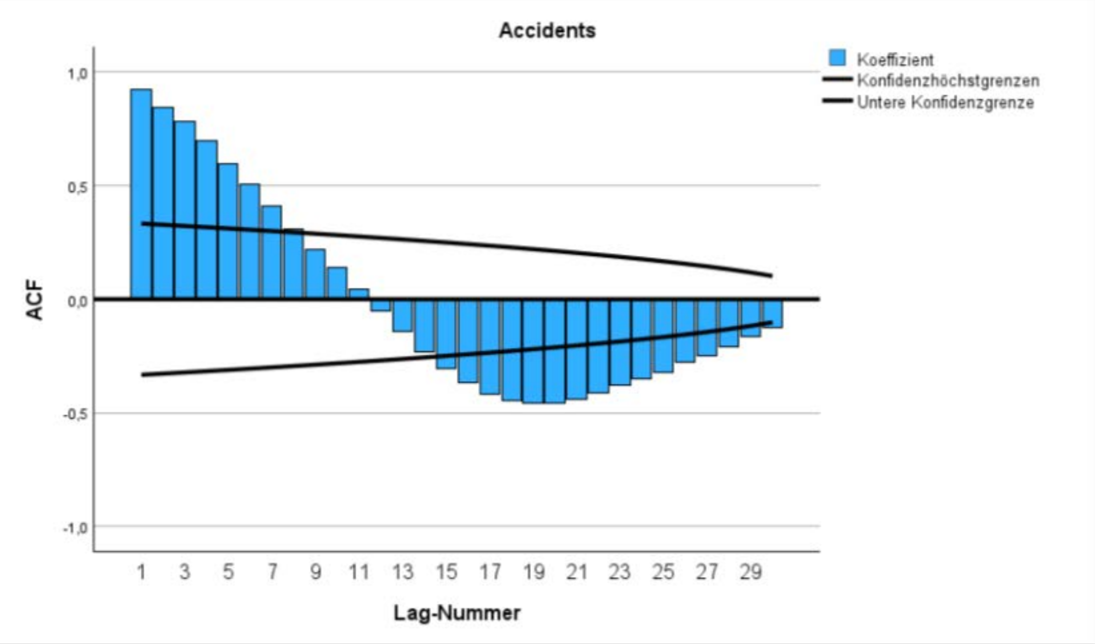
6.1.2 Stationarity and autocorrelation

Another way to identify a possible structural break in a time series is to check whether the time series is stationary, whether there is an autocorrelation within the time series, and how this develops over time.

Stationary means: The statistical properties of a time series are constant over time. These include the expected values, variances, and covariances between observation intervals. When a time series is stationary, these properties do not depend on the time at which the series is observed. The time series does not follow a systematic pattern, such as accidents occurring every six months. These seasonal changes within a year do not affect the time series under consideration because only annual values are used. Therefore, a time series with monthly values for traffic accidents is more likely to be non-stationary because the number of accidents will systematically increase or decrease with the seasons. If the time series consists of annual values, then in principle, it should be stationary. However, a structural break is probable if the analysis shows that a time series based on yearly values is non-stationary.

Since both economic and induced time series are subject to a fundamental growth process, the result of the previous year determines the level of the following year. This relationship can be determined using autocorrelation. If the autocorrelation of an annual time series decreases, this indicates a change in the strength of growth, which can be caused, for example, by a structural break.

Figure 4: Identification of the autocorrelation structure of the time series data road accidents in Türkiye from 1990 to 2022



Source: own calculation with SPSS version 29.

The provided autocorrelation function (ACF) plot (see Figure 4) is a tool used in time series analysis to identify patterns in data, such as seasonality, cycles, or, in this case, potential structural breaks. In the context of analyzing road traffic accidents, the ACF plot shows the correlation of the series with itself at different lags.

A structural break indicates a significant change in a time series's pattern or generation process. This could be due to a significant policy change, economic event, technological innovation, or, in this case, the introduction of a new regulation like the technical Inspection in Türkiye in 2008.

The plot shows that the autocorrelations are significant (outside the confidence bounds) at various lags, particularly at a lag marked as 1991. This indicates that the number of accidents in a given year significantly correlates with the previous years.

The structural break, likely related to the introduction of the vehicle inspection in 2008, would manifest in a couple of ways:

- Change in Level: A sudden and sustained change in the average number of accidents before and after 2008 could indicate that the policy had an immediate and lasting effect.
- Change in Variability: There might be a decrease in the variability of accidents, which could suggest that the number of accidents became more stable after the implementation of the vehicle inspection.
- Change in Autocorrelation Structure: If the autocorrelations after 2008 show a different pattern than before 2008, this would also suggest a structural break.

Given that lag one is set in 1991, this might be interpreted as the beginning of the timeframe under consideration. The structural break in the focus is presumably around 2008 when the policy change occurred. If the ACF for lags corresponding to years after 2008 significantly differs from those before, it would suggest that the introduction of PTI impacted the autocorrelation structure of the series, thus indicating a structural break.

To determine the exact time frame of the structural break, a further analysis with additional data would be necessary, possibly using a structural break test, such as the Chow test, which could more formally identify the point of change. It would also be essential to control other factors that could affect the number of accidents to isolate the effect of the PTI. This methodological step can be considered when it comes to the building of the impact assessment model.

6.2 Identification of Key Economic Determinants

From a macroeconomic perspective, the development of the population and the growth of the Gross Domestic Product (GDP) or Social Product are critical variables for explaining the development of road traffic accidents. Here is why population growth and GDP growth are the main macroeconomic variables relevant for the main impact on the development of road accidents:

1. Population Growth:
   - Increased Number of Road Users: As the population grows, the number of potential road users naturally increases. This includes drivers, passengers, pedestrians, and cyclists. The more people there are, the higher the probability of traffic accidents.

- Urbanization: Population growth often leads to urbanization, which usually means more densely populated areas with higher volumes of traffic and, consequently, a greater likelihood of accidents.
- Demographics: The age structure of a population can also influence accident rates. For example, younger populations might have higher rates of accidents due to less driving experience.
- Demand for Transportation: More people result in a higher demand for transportation, both public and private, leading to congested roads, which can increase the risk of accidents.

2. GDP Growth:

- Vehicle Ownership: Economic growth often leads to increased individual wealth and higher rates of vehicle ownership, which results in more vehicles on the roads and a higher risk of collisions.
- Infrastructure Development: While economic growth can lead to better road infrastructure, which might reduce accidents, the construction phase and the adjustment period to new traffic patterns can temporarily increase the risk of accidents.
- Mobility and Economic Activity: As economies grow, the mobility of goods and people increases. More commercial and work-related travel can lead to higher traffic volumes and a greater chance of accidents.
- Technological Advancement: Higher GDP might correlate with more advanced vehicle safety features and better emergency response services, potentially reducing the severity and frequency of accidents, although the initial adoption might be uneven.

In econometric modeling, the inclusion of both population growth and Gross Domestic Product (GDP) as predictors can lead to multicollinearity, particularly when these variables are used to forecast factors such as road accident rates. This concern stems from the economic theory, which recognizes that a growing population typically leads to higher GDP levels as more individuals produce and consume goods and services, thus increasing the overall economic output.

However, this direct relationship does not imply a proportional increase in GDP per capita, which is a crucial distinction. GDP per capita, the ratio of GDP to population size, reflects economic performance adjusted for population count. It captures the economic output per individual, which is influenced by factors beyond mere population increases, such as productivity enhancements, technological advancements, and improvements in human capital.

The use of both population size and total GDP in the same regression model may introduce multicollinearity, which complicates the estimation of regression coefficients. Multicollinearity makes it challenging to distinguish the individual contributions of correlated predictors to the dependent variable. For instance, in a model predicting road accident rates, the collinear relationship between population growth and GDP could obscure which variable significantly impacts the accident rates.

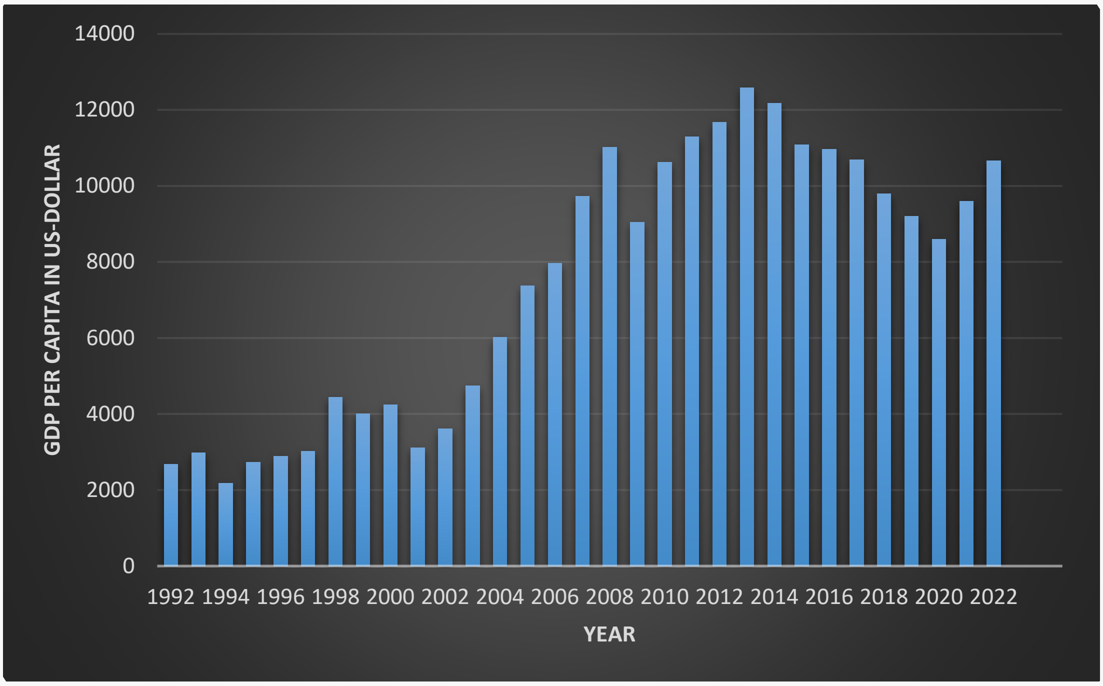
To circumvent these issues, GDP per capita is a more appropriate predictor than total GDP in models where population growth is also included. By employing GDP per capita, the influence of population size on economic growth is accounted for, isolating the economic growth attributable to factors other than population increase. This adjustment allows for more precise insights into how economic conditions influence the dependent variable, in this case, road accident rates.

In conclusion, employing GDP per capita instead of total GDP in econometric models that also include population growth is advisable. This approach mitigates the risk of multicollinearity and enhances the clarity and reliability of the model outcomes, providing a more precise and valid interpretation of how economic factors affect road safety. This methodological adjustment is crucial for accurately understanding the dynamics at play in economic and social phenomena.

Figure 5 systematically presents the annual Gross Domestic Product (GDP) per capita values in Türkiye, expressed in current US dollars, from 1990 to 2022. This longitudinal dataset allows for an in-depth analysis of the economic progression per individual over a period of more than three decades, offering insights into the economic well-being and standard of living of the populace.

In each column, the table lists the respective year alongside the GDP per capita for that year, facilitating a clear year-over-year comparison of economic output attributed to each citizen. This arrangement aids in identifying trends, such as periods of significant growth, economic downturns, or stability, reflecting the impact of both domestic economic policies and global economic conditions on Türkiye's economy.

Figure 5: Annual GDP Per Capita Trends in Türkiye from 1990 to 2022 (USD))



Source: Turkish Statistical Institute, Indicators of 100 Years, Kişi başına gayrisafi yurt içi hasıla (devam), Ankara 2023.

6.3 Growth Rate Models

Growth rate models are highly beneficial in analyzing traffic accident data because they can detrend and stabilize this type of data. Such models focus on changes over time rather than absolute values, which is essential for uncovering underlying trends driven by factors such as population growth, vehicle ownership increases, or road infrastructure enhancements. By concentrating on the rate of change rather than raw numbers, growth rate models provide a more precise depiction of the dynamics affecting traffic accidents, independent of the scale of the underlying data.

Moreover, growth rate models enhance comparability across different times and jurisdictions by standardizing the data. This normalization is particularly advantageous in traffic safety analysis, where variations in data collection methods, population sizes, and vehicle densities can distort absolute figures. Using growth rates, the data across various regions or periods can be compared more meaningfully, facilitating a more accurate assessment of traffic safety interventions across different settings.

In growth models, **a constant may not play a significant role** in regression analyses because the primary focus is on modeling the change or growth of individual parameters over time, rather than the absolute values of these parameters[7]. This is particularly relevant in latent growth models, which aim to capture the development of unobservable variables such as intelligence, reading ability, or the introduction of a new regulation like PTI.

In these models, the intercept (I) and slope (S) of an individual's growth curve are estimated, with the intercept representing the initial level of the variable and the slope indicating the rate of change over time[8]. The constant term, which is typically represented by the intercept, may not be of primary interest in growth models, as the focus is on understanding the patterns and rates of change rather than the absolute starting points.

Furthermore, growth models often involve the analysis of panel data, where the same individuals are observed at multiple time points[9]. In such cases, the constant term may be absorbed by the individual-specific effects, which are accounted for in the model. This means that the constant term may not provide additional information beyond what is already captured by the individual-specific effects.

In addition, growth models may employ techniques such as centering or standardization, which can reduce the impact of the constant term on the analysis[10]. Centering involves subtracting the mean of the variable from each observation, which can help to reduce the effect of the constant term. Standardization, on the other hand,

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7 https://www.kai-arzheimer.com/strukturgleichungsmodelle-fuer-politikwissenschaftler/0-strukturgleichungsmodelle-beispiele/beispiel-strukturgleichungsmodelle-latente-wachstumsmodelle/

8 https://www.kai-arzheimer.com/strukturgleichungsmodelle-fuer-politikwissenschaftler/0-strukturgleichungsmodelle-beispiele/beispiel-strukturgleichungsmodelle-latente-wachstumsmodelle/

9 https://www.researchgate.net/publication/260461007_Regressionsmodelle_zur_Analyse-von-Paneldaten

10 https://ethz.ch/content/dam/ethz/special-interest/math/statistics/sfs/Education/Advanced%20Studies%20in%20Applied%20Statistics/course-material-1921/Regression/reg-script-full.pdf; https://temme.wiwi.uni-wuppertal.de/fileadmin/kappelhoff/Downloads/Vorlesung/regression

involves scaling the variables to have a mean of zero and a standard deviation of one, which can also reduce the impact of the constant term.

Overall, while the constant term is an essential component of traditional regression models, its role may be diminished in growth models, where the focus is on modeling change and development over time rather than absolute values.

These models also emphasize incremental changes, which are crucial for policy analysis. Understanding whether traffic accident rates are increasing or decreasing offers more actionable insights than raw accident counts, allowing policymakers and researchers to assess the efficacy of safety measures directly by observing trends in accident rates.

Additionally, growth rate models mitigate the impact of significant base effects. Minor absolute changes might appear negligible in datasets with substantial base numbers, and significant base figures can mask actual progress or setbacks. By focusing on proportional changes, growth rate models provide a more sensitive measure that detects even slight shifts in trends, enhancing the interpretability of traffic accident data.

Another significant advantage is their ability to handle non-stationarity—a common feature of traffic accident data, where statistical properties such as mean and variance evolve. Growth rate models inherently aid in rendering the data series stationary, a condition necessary for applying many time series analytical methods. Ensuring stationarity is crucial for the validity of inferential statistics, making growth rate models suitable and essential for conducting rigorous statistical analysis in traffic accident research.

Lastly, understanding the growth rates of traffic accidents can yield predictive insights crucial for future planning and policy development. If the growth rate of accidents is increasing, it might indicate a need for more robust traffic laws, improved road infrastructure, or intensified public awareness campaigns.

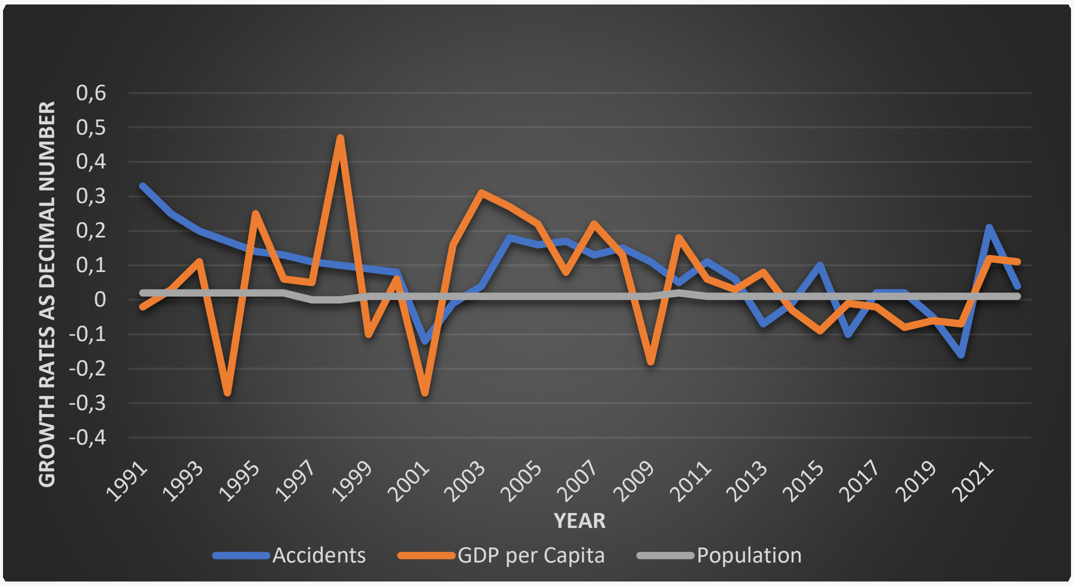
Growth rate models offer a robust analytical framework for interpreting traffic accident data. They provide an academically rigorous, more straightforward, and more scientifically sound approach to examining how various factors influence the rate of traffic accidents over time, which is vital for crafting effective traffic safety policies and interventions. This model's application can substantially enhance the precision and effectiveness of traffic safety measures and their evaluation in academic and policy contexts.

Figure 6 shows the growth rate as decimal numbers for road accidents, the GDP per capita, and the population in Türkiye for the period from 1991 to 2022. The development of the different growth time series data can be described as follows:

- An overarching decrease in accident rates is evident from the data, with a peak in 1991 (0.33) descending to a notably negative growth rate in 2020 (-0.16). This stark reduction coincides with the global lockdown, suggesting a potential correlation between reduced human mobility and accident occurrences. The subsequent rise to 0.21 in 2021 may reflect a return to pre-pandemic activity levels.

- The GDP per capita growth fluctuates markedly, capturing the populace's economic instability and resilience over the years. 1998 stands out with a substantial growth rate of 0.47, contrasting sharply with the deep contractions in 1994 and 2001. 2020 exhibits a negative growth rate (-0.07), aligning with the economic downturn induced by the lockdown before a modest recovery is observed in 2021 (0.12).
- Population growth rates exhibit a remarkable consistency throughout the period, hinting at a robust and steady demographic increase. The minimal variation around 0.01-0.02 is disrupted in 2020, which maintains the trend, possibly indicating that the effects of the lockdown on population growth were not immediately discernible or were mitigated by other factors.

Figure 6: Growth Rates of Accidents, GDP per Capita, and Population from 1991-2022 for Türkiye



Source: own calculations.

6.4 Methodological Approach

It can be deduced from the previous chapters that the time series of road traffic accidents is non-stationary and that there is a high probability of a structural break around 2008. It can be deduced from the previous chapters that the time series of road traffic accidents is non-stationary and that there is a high probability of a structural break around 2008. Therefore, these two factors must be taken into account when deriving the impact model. This requires the following methodological steps:

- In order to eliminate the problem of fundamental non-stationarity, growth rates are formed. The advantage of forming growth rates results from the fact that the formation of growth rates can establish stationarity in a non-stationary time series for several reasons: Growth rates effectively represent a form of differencing, where each value in the series is replaced by the difference (or ratio, in the case of growth rates) between it and the preceding value. This process can help stabilize the mean of the series by removing or reducing trends and cycles, leading to a mean that does not systematically change over time. Non-stationary time series often exhibit varying variances over time. Calculating growth rates can help stabilize the variance, mainly if the original series exhibits exponential growth or decline. By transforming the data into growth rates, the transformed series may exhibit homoscedasticity (constant variance), which is a characteristic of stationarity.

- A total of three regression analyses are carried out. The time series is broken down into two samples: The regression analysis is carried out for the period from 1990 to 2007, the period from 2008 to 2022, and the overall period from 1990 to 2022. Based on the results, it is possible to finally carry out the Chow test to check whether a structural break (Snow 1977) actually occurred in 2008.

6.4.1 Regression Analysis of Road Accidents from 1990 to 2007

Table 2 gives an overview of the results from the regression analysis with the growth rate of road accidents as the dependent variable, the growth rate of the GDP per Capita, and the population growth rate as independent variables.

Table 14: Regression Analysis Model I (Years from 1990-2007)

Model Summary			
Time Scope	1990-2007		
R Square	0.683		
Adjusted R Square	0.641		
F-Value (Anova)	16.150	Significance	<0.001
Residual Sum of Squares	0.138		
Variables Summary			
Independent Variables	Coefficient	T-Value	Significance
Growth rate GDP per Capita	0.162	1.428	0.174
Growth rate Population	8.196	4.926	<0.001

Source: own calculations.

In statistical analysis, especially in regression, the T-value measures how many standard deviations the estimated coefficient is away from the null hypothesis coefficient (usually 0, which means no effect). The significance level (Sig.) indicates the probability that the observed effect occurred by chance, assuming the null hypothesis is true.

The independent variable ´Growth rate GDP per Capita´ shows a T-value of 1.428 and a significance level (p-value) of 0.174 in the given output. This value is acceptable because the sample was split; this is an exploratory research step, and the model is estimated in its entirety at the end.

The independent variable, ´Growth rate Population, ' is significant.

6.4.2 Regression Analysis of Road Accidents from 2008 to 2022

This regression model, with its exploration of the impacts of GDP growth rate and population growth rate on a dependent variable, primarily serves as an intermediary step towards conducting a Chow Test for detecting a structural break event (Chow 1960). The Chow Test is a statistical test used to determine whether there are significant differences in the relationship between variables across different subsets of data, which, in this case, might be before and after a specific event within the 2008 to 2022 timeline. The regression analysis findings, indicating a low R Square value and non-significant coefficients for the independent variables, suggest that further investigation into potential structural breaks in the data series could be warranted. Identifying such breaks with the Chow Test could provide insights into periods where the relationship between these economic indicators and the dependent variable fundamentally changes, potentially due to policy shifts, economic crises, or other significant events.

Table 15: Regression Analysis Model II (Years from 2008 to 2022)

Model Summary			
Time Scope	2008-2022		
R Square	0.177		
Ajusted R Square	0.051		
F-Value (Anova)	1.400	Significance	0.281
Residual Sum of Squares	0.122		
Variables Summary			
Independent Variables	Coefficient	T-Value	Significance
Growth rate GDP per Capita	0.291	1.126	0.281
Growth rate Population	2.198	1.137	0.276

Source: own calculations.

6.4.3 Comprehensive Regression Analysis and Structural Break Detection via Chow Test

This regression model analyzes the relationship between the growth rate of GDP, the growth rate of the population, and a dependent variable over a more extended period from 1990 to 2022. The R Square value of 0.466 suggests that about 46.6% of the variance in the dependent variable is explained by the independent variables in the model. This indicates a moderate fit, showing that while the model captures some of the dynamics affecting the dependent variable, other factors not included in the model may also play significant roles.

The F-value of 13.077 is a measure of the overall significance of the regression model. A higher F-value indicates that the model is a good fit for the data, and in this context, an F-value of 13.077 suggests that the model significantly fits well, especially when compared to the model in the previous scenario. This indicates that the independent variables collectively have a statistically significant effect on the dependent variable.

The Residual Sum of Squares (RSS) is 0.312, which measures the discrepancy between the data and the estimation model. Although it is an absolute measure and needs context to be fully understood, in combination with the R Square and F-value, it suggests the model has a reasonable fit but with room for improvement.

The coefficient for the Growth rate of GDP is 0.215, with a t-value of 1.973 and a significance level of 0.058. This indicates a positive relationship between GDP growth and the dependent variable, albeit on the margin of statistical significance ($p<0.10$). Economic theory suggests that as GDP grows, indicative of economic expansion, various sectors, and aspects related to the dependent variable might also see growth due to increased investments, consumption, and overall economic activity.

The Growth rate of the Population has a coefficient of 5.609, with a t-value of 4.204 and a significance level of less than 0.01, indicating a highly statistically significant relationship. This suggests a strong positive impact of population growth on the dependent variable. From an economic standpoint, population growth can significantly affect demand dynamics, labor markets, and potentially the supply of goods and services, depending on what the dependent variable represents.

Overall, the model indicates that both the growth rate of GDP and population have essential, albeit differently weighted, impacts on the dependent variable over the period from 1990 to 2022. The population growth rate, in particular, seems to be a more significant predictor, which could imply that demographic factors play a crucial role in the economic phenomenon being studied. This can be especially relevant in contexts where population dynamics significantly influence market sizes, labor supply, and demand patterns.

However, given that the R Square value suggests other factors also affect the dependent variable, future models might benefit from including additional variables such as technological advancements, policy changes, international trade dynamics, or other socio-economic factors that could provide a more comprehensive understanding of the phenomenon.

Table 16: Regression Analysis Model for the whole sample 1990 to 2022

Model Summary			
Time Scope	1990-2022		
R Square	0.466		
Adjusted R Square	0.430		
F-Value (Anova)	13.077	Significance	<0.001
Residual Sum of Squares	0.312		
Variables Summary			
Independent Variables	Coefficient	T-Value	Significance
Growth rate GDP per Capita	0.215	1.973	0.058
Growth rate Population	5.609	4.204	<0.01

Source: own calculations.

The Chow test is a statistical and econometric test to check for the presence of a structural break in a time series. This means it helps to determine whether there are significant differences in the relationships between variables in different sub-samples of a dataset. The test is widely used in econometrics to test the stability of parameters across different groups or time periods (see Fisher 1979, Green 1993).

The basic idea behind the Chow test is to compare the fit of a single regression model applied to the entire data set with the fit of two separate models applied to two subdivisions of the data set. The test evaluates whether the coefficients of the independent variables are the same in the two sub-periods or sub-groups.

The formula for the Chow test in the context of a simple linear regression (assuming dividing the dataset into two groups) is (Green 1993):

$$F = (RSS_{pooled} - (RSS_1 + RSS_2))/k/((RSS_1 + RSS_2)/(N_1 + N_2 - 2k))$$

Where:

- RSS_{pooled} is the sum of squared residuals from the pooled dataset (using a single model for the entire dataset).

- RSS_1 and RSS_2 are the sums of squared residuals from the sub-samples.

- N_1 and N_2 are the number of observations in each sub-sample.

- k is the number of parameters (including the intercept) estimated in the regression.

- F is the calculated F-statistic from the Chow test.

The null hypothesis of the Chow test states that there is no structural break, meaning the parameters (regression coefficients) are the same across the sub-samples. If the F-statistic exceeds a critical value from the F-distribution (dependent on the chosen significance level and degrees of freedom), the null hypothesis is rejected, suggesting a structural break in the time series data.

This test can be beneficial in analyzing economic data, where external shocks or policy changes might alter the behavior of the variables under study, leading to structural breaks in the model. Der F-Wert für den Chow-Test is 23.21, which is higher than the critical value from the F-distribution, which is 3.328. Therefore, the structural brake in 2008 is proven.

6.5 Assessing the Impact of PTI on Road Safety Dynamics through Dummy Variable Integration

As it is now clear that in 2008, a structural change in road accidents happened, it is now time to integrate a dummy variable into the regression analysis (see Table 4).

Table 17: Regression Analysis Model with Dummy 1990 to 2022

Model Summary			
Time Scope	1990-2022		
R Square	0.547		
Adjusted R Square	0.500		
F-Value (Anova)	11.665	Significance	<0.001
Residual Sum of Squares	0.312		
Variables Summary			
Independent Variables	Coefficient	T-Value	Significance
Growth rate GDP per Capita	0.188	1.822	0.079
Growth rate Population	8.001	4.901	<0.01
Dummy	-0.073	-2.278	0.03

Source: own calculations.

The dummy variable has a value of zero from 1990 to 2007, and afterward, from 2008 until 2022, the value of the dummy variable is one.

As expected, the dummy variable, when taken into account, has a negative sign for the effect coefficient. The assumption is that introducing the PTI will reduce the number of road accidents. However, there is still a problem with the significance of per capita income. The variables of population growth and changes in per capita income were chosen as starting variables because, ultimately, these are the macroeconomic variables that have an impact on car ownership and mileage. As one of the variables is insignificant, both variables are replaced by the growth rate of the vehicle population. The results of the regressions can be found in the following table.

Table 18: Regression Analysis Model with Dummy 1990 to 2022 (dependent variable growth rate of road accidents (WACC)

Model Summary			
Time Scope	1990-2022		
R Square	0.659		
Adjusted R Square	0.636		
F-Value (Anova)	29.9335	Significance	<0.001
Residual Sum of Squares	0.199		
Variables Summary			
Independent Variables	Coefficient	T-Value	Significance
Growth rate of the number of road motor vehicles	1.718	7.458	<0.001
Dummy	-0.052	-2.178	0.037

Source: own calculations.

Both variables are now significant. The R square has even increased slightly.

In the mixed model, the dummy variable represents a structural break in the year 2008. The coefficient of the dummy variable is -0.052, which means that after the introduction of the dummy variable in 2008 (from 2008 to 2022), the growth rate of the number of road vehicles has decreased by 0.052 units compared to the period from 1990 to 2007, holding all other factors constant.

The interpretation of this coefficient should be seen in the context of the dependent variable WACC, which presumably measures the rate of accidents or a similar criterion. The negative value of the coefficient (-0.052) suggests that there has been a reduction in the growth of the magnitude measured by the WACC variable after 2007.

Assuming that the dummy variable reflects the effect of a specific measure or event in 2008 (such as the introduction of a technical inspection or a new traffic safety regulation), this would indicate that after the implementation of this measure, the growth of accidents decreased by 0.052 units for each percentage point increase in the growth rate of road vehicles.

It is also worth noting that the significance of the dummy coefficient (p-value = 0.037) is below 0.05, which suggests that the effect is statistically significant and does not seem to be due to chance.

If WACC directly represents the number of accidents, it could be said that accidents per percentage point increase in the growth rate of road vehicles have decreased by 0.052 accidents after 2007.

7 Evaluating the Effectiveness of the Periodic Technical Inspection Program on Road Safety in Türkiye

Using the results from the previous chapter, it is now possible to calculate how many accidents have been prevented by introducing PTI in Türkiye. Table 7 shows the impact of Periodic Technical Inspection (PTI) regimes on the growth rates of road accidents in Türkiye and estimates the number of road accidents that were potentially averted due to the implementation of PTI.

The first column reveals the observed accident growth rates in the presence of PTI, while the second column posits the expected growth rates in the absence of such a regimen, suggesting what might have occurred had no vehicle inspections been enforced.

Table 19: Impact of Periodic Technical Inspection on Road Accident Trends and Prevention in Türkiye

Year	Actual accident growth rate with PTI	Accident growth rate without PTI	The additional number of road accidents
2008	+15.1	+20.3	42929
2009	+10.9	+16.1	49406
2010	+5.0	+10.2	54774
2011	+11.1	+16.3	57522
2012	+5.5	+10.7	63904
2013	-6.9	-1.7	67425
2014	-0.7	+4.5	62782
2015	+9.5	+14.7	62349
2016	-10.0	-4.8	68295
2017	+1.7	+6.9	61490
2018	+2.2	+7.4	62541
2019	-5.0	+0.2	63927
2020	-15.8	-10.6	60743
2021	+20.6	+25.8	51158
2022	+3.9	+9.1	61690

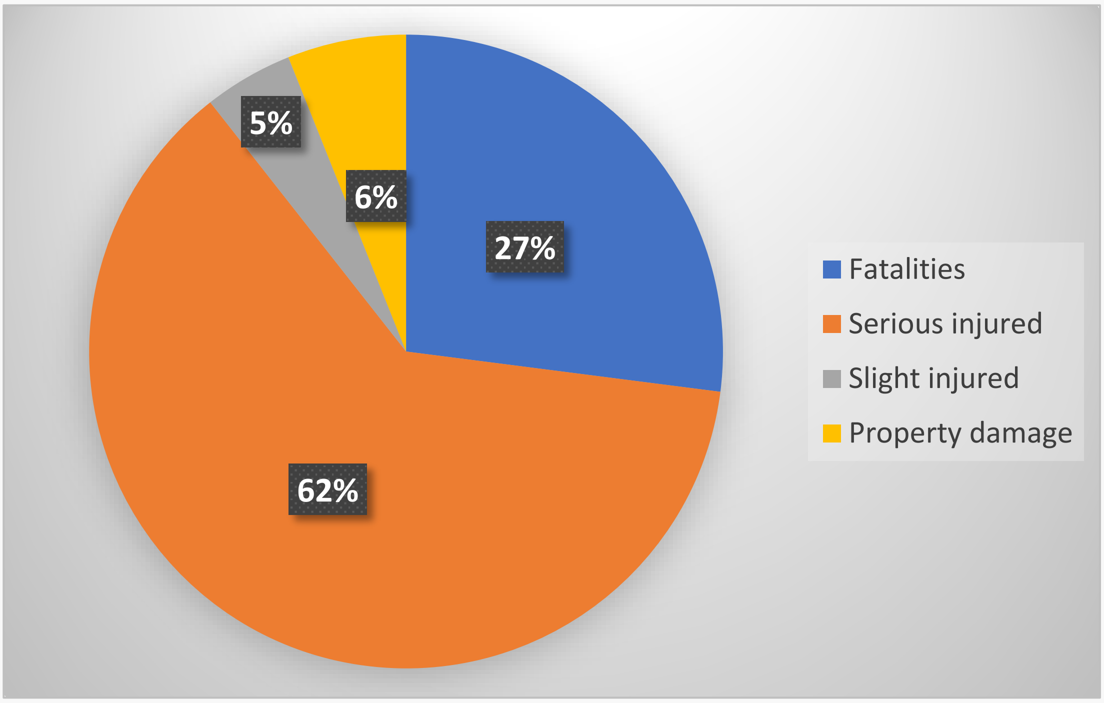
Source: own calculations.

Since the implementation of the PTI in Türkiye, 890,936 road accidents could be avoided. The monetary estimation must consider that the number of fatalities changed in 2015. Therefore, the average relations between road accidents and fatalities and between road accidents and injuries are calculated on average for the time period from 2015 to 2022. That means one road accident is, on average, related to 0.0524 fatalities and 0.24079 injuries. 15% of road accidents are fatal accidents. Over the time period from 2008 to 2022, the number of fatal accidents avoided was 133,604. On average, 0.03766 is the share of fatalities related to fatal accidents. With that, it was possible to avoid 5,033 fatalities. The share of injured persons per fatal accident is, on average, 1.6429, which means that 219.498 injured persons could be avoided. As the split between the serious and slightly injured is not yet known, it is assumed that 50% are severe and 50% are slightly injured.

The cost unit rates for fatalities are 1,206,982 (Turkish-Lira) TL, 127,732 TL per seriously injured and 9,302 TL per slightly injured person. The cost unit rate for property damage is 1,797 TL (Suleiman, Ergun 2020).

From 2008 to 2022, 22.48 billion TL was saved. That means that 1.5 billion TL could be saved every year because of the introduction of PTI.

Figure 7: Average Proportional Impact of Periodic Technical Inspections (PTI) on Road Safety Outcomes in Türkiye for the time period 2008 to 2022



Source: own calculations.

8 Macroeconomic Impacts of Roadworthiness Inspection on Growth and Welfare

When crashes are avoided, economic costs are saved. Economic costs are sometimes difficult for people to understand. When an accident is prevented, it means that someone is not killed or injured, and the car is not damaged. However, because the event did not occur, the consequences for the person who was not killed are incalculable. In economic terms, however, it is noticeable that more production factors are available, and that social welfare can be increased as a result. This saving of resources becomes noticeable because a monthly salary continues to be paid, the salary is used for consumption, the work performed leads to something being physically created, and thus, the social product is increased. These effects, which are triggered because resources continue to be available and are not destroyed in a traffic accident, trigger further growth effects. For Turkey, a study was conducted to determine the multiplier effect of additional resources. According toWhen accidents occur, the consequences can be catastrophic not only for individuals and families but for the economy as a whole. The actual cost of accidents is often difficult to quantify, but it is clear that the prevention of accidents can lead to significant economic savings. By preventing accidents, immediate physical harm can be avoided that is caused, and more resources can be created, leading to increased social welfare and economic growth.

The economic benefits of preventing accidents extend far beyond avoiding physical harm. When accidents are prevented, more resources are available for use, leading to increased social welfare. This is because salaries can continue to be paid, which drives consumption and the creation of physical products. This, in turn, leads to an increase in social output, further fueling economic growth.

The impact of preventing accidents is far-reaching and can lead to a multiplier effect. In Turkey, for example, a study by Meschi et al. (2011) found that the multiplier effect of investing additional resources was 1.5, demonstrating how preventing accidents can trigger further growth effects.

Preventing accidents ensures that resources are not destroyed, leading to a safer and more prosperous society for all. This is because preventing accidents avoids immediate harm and creates economic benefits that can fuel growth and development. A safer, healthier, and more prosperous world can be created by preventing accidents. In this study, the multiplier is 1.5. That means that the annual resource savings of 1.5 billion TL have a growth effect on the GDP by 2.25 billion TL. Altogether, the average annual benefit for the economy of Türkiye is estimated to be 3.75 billion TL.

9 Recommendations & Conclusions

The findings affirm that PTIs play a crucial role in enhancing road safety and offer substantial economic benefits by reducing the incidence and severity of traffic accidents. However, the effectiveness of PTIs is not absolute, and they should be viewed as part of a broader set of safety measures, including driver education, infrastructure quality improvements, and stringent enforcement of traffic laws.

Following recommendations for policy and further research can be made:

- Enhanced PTI Frequency and Coverage: To capture and mitigate vehicle deficiencies more effectively, it is recommended to increase the frequency and coverage of PTIs, especially for vehicles that are more prone to wear and tear.
- Integration with Other Safety Measures: PTIs should be part of an integrated road safety strategy that includes educational programs for drivers, improvements in road infrastructure, and stricter enforcement of traffic laws.
- Longitudinal Studies: Further research should focus on longitudinal studies to track the long-term effects of PTIs on road safety and economic factors. Additionally, investigating the indirect effects of PTIs, such as improvements in vehicle maintenance culture and reductions in insurance premiums, could provide deeper insights.
- Comparative Analysis: Comparative studies with other countries that have similar traffic conditions and PTI policies could help benchmark and refine Türkiye's PTI practices.
- Policy Adaptation: As vehicle technology evolves, PTI criteria and techniques should also be updated to address new safety challenges and technological advancements in automotive design and functionality.

By continuing to refine and adapt PTI policies based on empirical evidence and research, Türkiye can enhance its road safety outcomes and economic performance, setting a benchmark for global best practices in vehicle inspection and road safety management.

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Annex

Table 20: Autocorrelation lag structure for time series data road accidents in Türkiye (1990 to 2022)

Autokorrelationen

Zeitreihe: Accidents

Lag	Autokorrelation	Std.-Fehler[a]	Box-Ljung-Statistik Wert	df	Sig.[b]
1	,921	,166	30,618	1	<,001
2	,843	,164	57,086	2	<,001
3	,783	,161	80,663	3	<,001
4	,695	,158	99,899	4	<,001
5	,594	,156	114,462	5	<,001
6	,506	,153	125,395	6	<,001
7	,413	,150	132,974	7	<,001
8	,307	,147	137,324	8	<,001
9	,220	,144	139,658	9	<,001
10	,137	,141	140,602	10	<,001
11	,046	,138	140,713	11	<,001
12	-,050	,135	140,849	12	<,001
13	-,140	,132	141,985	13	<,001
14	-,231	,128	145,228	14	<,001
15	-,307	,125	151,281	15	<,001
16	-,370	,121	160,583	16	<,001
17	-,416	,118	173,064	17	<,001
18	-,446	,114	188,406	18	<,001
19	-,459	,110	205,788	19	<,001
20	-,455	,106	224,192	20	<,001
21	-,441	,102	242,875	21	<,001
22	-,411	,098	260,617	22	<,001
23	-,378	,093	277,135	23	<,001
24	-,353	,088	293,089	24	<,001
25	-,325	,083	308,327	25	<,001
26	-,280	,078	321,241	26	<,001
27	-,247	,072	332,989	27	<,001
28	-,209	,066	343,059	28	<,001
29	-,164	,059	350,830	29	<,001
30	-,124	,051	356,713	30	<,001

a. Der angenommene zugrundeliegende Prozeß ist Unabhängigkeit (weißes Rauschen)

b. Beruht auf der asympototischen Chi-Quadrat-Approximation.

Source: own calculations.

This autocorrelation table presents the autocorrelations for a time series of accidents at different lags, which measure the correlation of the series with its own past values.

A lag of 1 indicates the correlation with the previous time point, and a lag of 2 with two time points past.

The autocorrelation coefficients are quite high at the initial lags, starting with .921 at lag one and gradually decreasing as the lag increases. This suggests a strong persistence in the data, indicating that the number of accidents is highly correlated with the number of accidents in previous periods. Such a pattern often implies that past values are helpful for predicting future values in the time series.

However, the standard errors associated with these autocorrelations increase as the lag increases, which is typical because estimates based on longer lags use less data and, therefore, tend to be less precise.

The Box-Ljung test statistic, which tests the null hypothesis that the data are independently distributed (i.e., there is no autocorrelation up to a certain number of lags), is also reported. Given the very small p-values (< .001) at all lags, the null hypothesis of independence in the series at all considered lags is rejected, indicating that there is significant autocorrelation at these lags.

This test can be beneficial for identifying whether the observed series is random or if there are underlying patterns in the data that could be modeled. In this case, the strong autocorrelation and the significant Box-Ljung test results suggest that the time series of accidents has a structure that could potentially be explained by factors not included in a simple random process, and further analysis could be conducted to understand the determinants of these patterns.

Given that the table indicates strong autocorrelation at early lags that tends to decay over time, this could imply that short-term factors are more influential in predicting accidents. Moreover, if there were any structural changes in the policy or environment (such as the introduction of a technical inspection in 2008 in Türkiye), one might expect to see changes in the level or stability of the autocorrelations after the intervention. The table does not directly show this, but a separate analysis comparing autocorrelation functions before and after 2008 could reveal such effects.