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PhD THESIS ABSTRACT

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ANALYSIS OF THE INFLUENCE OF TRANSPORT INFRASTRUCTURE ON ROAD TRAFFIC ACCIDENT OCCURRENCE

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CONTENTS

1. INTRODUCTION. THE NEED FOR AND SCIENTIFIC BASIS OF ANALYZING THE INFLUENCE OF ROAD INFRASTRUCTURE ON ROAD SAFETY

Road safety represents one of the major challenges facing contemporary society, with significant implications for public health, economic development, and quality of life. Despite the considerable progress achieved in vehicle design, road infrastructure development, and the implementation of Intelligent Transport Systems (ITS), road traffic accidents continue to result in a high number of fatalities, injuries, and economic losses worldwide. Consequently, road safety has become a priority of public policies promoted at both the international and the European levels.

Modern approaches no longer consider road traffic accidents solely as the consequence of human error but rather as the result of the interaction among the road user, the vehicle, the road infrastructure, and the traffic environment. Within this framework, road infrastructure plays a fundamental role in preventing accidents and mitigating their consequences by influencing road users' behaviour and the operating conditions of the transport system.

This chapter provides the scientific foundation of the research by highlighting the importance of road infrastructure within the road safety system and by justifying the need to develop modern methods for evaluating road infrastructure performance based on objective indicators and proactive approaches.

1.1 Road Safety as a Global Public Health and Sustainable Development Issue

Road safety is internationally recognized as one of the key components of sustainable mobility policies and public health protection. The World Health Organization identifies road traffic accidents as one of the leading causes of death worldwide, particularly among young people, while their economic and social impacts directly affect sustainable societal development.

Within the European Union, reducing the number of road traffic accidents and mitigating their consequences constitute fundamental objectives of transport policy. These objectives are supported through strategies promoting improvements in road infrastructure, the development of road safety technologies, and the implementation of efficient traffic management systems. In this context, road infrastructure is regarded as one of the components over which road authorities can directly intervene to reduce road traffic risk.

Road safety assessment should not be limited to evaluating the number of accidents but should also focus on identifying the factors contributing to their occurrence and on developing preventive measures capable of reducing both the probability of accident occurrence and the severity of their consequences.

1.2 The Role of Road Infrastructure within the Safe System Approach

Over the past decades, research has led to the development of the Safe System approach, which promotes an integrated framework for road safety management. According to this philosophy, human errors are inevitable; however, road infrastructure should be designed, operated, and maintained so that such errors do not result in serious or fatal crashes.

Within this approach, road infrastructure is no longer regarded solely as the physical support for traffic but as an active component of the transport system that influences operating speed, sight distance, road perception, and the driver's decision-making process. Consequently, the design and operation of road infrastructure should aim to minimize road traffic risk by adapting road characteristics to the biomechanical limits of the human body.

Road infrastructure therefore becomes a determining component of the transport system, and its performance should be assessed using indicators that reflect actual operating conditions and the effective level of road safety.

1.3 Relationship between Speed, Kinetic Energy, and the Severity of Road Traffic Accidents

Vehicle speed is one of the primary factors influencing both the occurrence and the severity of road traffic accidents. From a physical perspective, the kinetic energy generated at the moment of impact is proportional to the square of the vehicle speed, which explains the rapid increase in crash severity as travel speed increases.

At the same time, speed directly affects stopping distance, the time available for driver reaction, and the driver's ability to anticipate the evolution of traffic situations. For this reason, speed should be analysed together with the geometric characteristics of road infrastructure and the evaluation of sight distance and pavement friction conditions.

The correlation of these elements provides a more comprehensive understanding of the mechanisms leading to road traffic accidents and constitutes the basis for developing modern methods for evaluating the performance of road infrastructure.

1.4 The Role of Road Infrastructure in the Generation and Control of Road Traffic Risk

The geometric characteristics of a road alignment directly influence road user behaviour and the level of road safety. Elements such as the horizontal alignment, longitudinal profile, cross-section, curve radius, gradient, and sight distance determine operating speed and influence drivers' ability to perceive and anticipate the roadway ahead.

At the same time, road infrastructure affects operating conditions through pavement surface characteristics, the available level of pavement friction, and maintenance quality, all of which contribute to vehicle stability and braking performance.

Consequently, road infrastructure should be regarded as an active component in the control of road traffic risk, and its evaluation should go beyond conventional geometric analysis by incorporating the functional parameters that influence road user behaviour.

1.5 Sight Distance as a Determining Factor of Road Safety

Sight distance represents one of the principal indicators of the functional performance of road infrastructure. The available sight distance determines the driver's perception–reaction time and directly influences the ability to avoid an obstacle or a potential conflict situation.

Reduced sight distance may result from the geometric configuration of the roadway, the combination of horizontal curves with vertical curves, the presence of roadside obstacles, or the prevailing operating conditions. Under such circumstances, even when the geometric design complies with current standards, actual operating conditions may limit the driver's field of view and increase road traffic risk.

This justifies the need for three-dimensional sight distance evaluation and the application of modern analytical methods capable of accurately representing the conditions encountered during the operation of road infrastructure.

1.6 The Need for Proactive Approaches and Infrastructure Indicators in Road Safety Assessment

Traditional road safety assessment, based exclusively on the analysis of recorded road traffic accidents, presents significant limitations because it identifies hazardous road sections only after accidents have occurred. In recent years, international research has increasingly promoted the use of Safety Performance Indicators (SPI) and other functional road infrastructure indicators that enable the proactive assessment of road traffic risk.

This approach facilitates the identification of vulnerable road sections before accidents occur and supports the development of effective road safety management strategies. Within this framework, the Potential for Improvement (PI) indicator represents one of the tools used to comparatively evaluate the performance of road infrastructure and to prioritize safety interventions.

1.7 Research Motivation and Positioning

Building upon the aspects discussed in the previous sections, this research aims to investigate the influence of road infrastructure on road safety by correlating the technical characteristics of road infrastructure with the spatial distribution of road traffic accidents and by applying modern methods for evaluating road infrastructure performance. The study is based on the analysis of road traffic accidents that occurred between 2021 and 2024 on the Romanian national roads DN1–DN7, using accident data provided by the Romanian Police – Traffic Directorate, correlated with information on the technical condition and pavement condition of the roads from the database managed by CESTRIN.

The thesis seeks to contribute to a better understanding of the relationship between road infrastructure and road traffic risk by integrating the statistical analysis of road traffic accidents, the evaluation of the functional parameters of road infrastructure, sight distance studies, and the application of the Potential for Improvement (PI) indicator to identify priority sections for intervention. In this way, the research provides technical support for the development of measures aimed at improving road safety and prioritizing interventions across the national road network.

1.8 Structure of the Thesis

The thesis is organized into seven chapters followed by the bibliography. Its structure progressively develops the theoretical background of the research, the statistical analysis of road traffic accidents, the evaluation of the functional parameters of road infrastructure, the development of applied sight distance studies, and the application of the Potential for Improvement (PI) indicator for prioritizing interventions on road infrastructure.

The first two chapters present the conceptual framework and a critical review of the existing literature, while the central chapters develop the original contributions concerning accident analysis, sight distance evaluation, and the application of the Potential for Improvement (PI) indicator. The final chapter summarizes the general conclusions, original scientific contributions, future research directions, and the dissemination of the research results within the scientific community.

2. RESEARCH ON ROAD SAFETY AND ROAD INFRASTRUCTURE ASSESSMENT

In order to establish the scientific basis of the research, the main developments in the fields of road safety and road infrastructure assessment were analysed. The evolution of road safety management concepts, the role of road infrastructure within modern approaches, the indicators used to evaluate road infrastructure performance, and the main international methodologies applied in this field were examined.

The critical analysis of the scientific literature made it possible to identify the concepts and tools that formed the basis of the research presented in this thesis and highlighted the need to correlate the characteristics of road infrastructure with the distribution of road traffic accidents and the assessment of safety performance at the national road network level.

2.1 Evolution of Road Safety Approaches: From Reactive Interventions to Proactive Management

Road safety has evolved significantly over recent decades as research has demonstrated the limitations of approaches based exclusively on the retrospective analysis of road traffic accidents. Initially, road safety measures were almost entirely based on identifying road sections with a high frequency of accidents and implementing interventions only after accidents had occurred. Although this approach made it possible to reduce accidents in certain situations, it did not allow the identification of vulnerable road sections before road traffic accidents occurred.

The need to prevent road traffic accidents has led to the development of proactive approaches focused on the assessment of road infrastructure and the identification of factors that may contribute to accident occurrence. In this context, the emphasis has shifted from the exclusive analysis of road traffic accidents to the assessment of road infrastructure performance and the use of indicators capable of characterising the safety level of roads before accidents occur.

This paradigm shift forms the basis of modern road safety management systems and justifies the use of integrated assessment methods, in which road infrastructure is evaluated both through its technical characteristics and through its influence on road users' behaviour.

2.2 The Role of Road Infrastructure within the Safe System Approach

The Safe System concept represents one of the most important developments in the field of road safety. It is based on the principle that human errors are inevitable; however, their consequences can be limited through the appropriate design and operation of road infrastructure.

Within this approach, road infrastructure is regarded as an active component of the transport system that influences operating speed, sight distance, road perception, and the driver's decision-making process. Thus, road design aims not only to satisfy geometric and functional requirements but also to reduce the likelihood of serious road traffic accidents and mitigate their severity.

The scientific literature highlights that the implementation of the Safe System principles requires the integration of safety considerations throughout all stages of the road infrastructure life cycle, from design and construction to operation and maintenance. In this way, road infrastructure contributes not only to traffic operation but also to the management of road traffic risk and the protection of road users.

2.3 Indicators Used in Road Safety Assessment

The development of proactive approaches has led to the introduction of indicators capable of characterising the performance of road infrastructure independently of accident history. The scientific literature distinguishes between reactive indicators, based on the analysis of road traffic accidents, and proactive indicators, used to assess safety conditions before accidents occur.

An important role is played by the Safety Performance Indicators (SPI), which enable the assessment of road infrastructure through the analysis of the geometric, functional, and operational characteristics of the road. The use of these indicators facilitates the comparison of the performance of different road sections and the identification of the road infrastructure elements that influence the level of road safety.

Modern methodologies also employ the Potential for Improvement (PI) indicator, which expresses the difference between the accident frequency recorded on a road section and the reference level of the analysed road network. This indicator makes it possible to identify the road sections where interventions can achieve the greatest benefits in terms of reducing road traffic risk and represents one of the tools used in the research presented in this thesis.

2.4 International Methodologies for Assessing Road Infrastructure Safety

The assessment of road infrastructure performance is supported internationally by a number of methodologies developed by organizations such as PIARC, FHWA, and iRAP. These methodologies promote the use of standardized procedures for assessing road infrastructure safety and for prioritizing interventions according to the identified level of risk.

The methodologies analysed place emphasis on the assessment of the geometric characteristics of the road alignment, sight distance, pavement friction conditions, and road equipment elements, as well as on the use of synthetic indicators that allow the comparison of the performance of different road sections. They also highlight the importance of integrating road safety into the planning, design, operation, and maintenance of road infrastructure.

The analysis of these approaches demonstrates that road infrastructure assessment should be carried out in an integrated manner by correlating the technical parameters of the road with accident data and actual operating conditions, so that the adopted measures lead to an effective reduction in road traffic risk.

2.5 Critical Review and Positioning of the Research within the Context of Existing Methodologies

The analysis of the scientific literature shows that modern methods for assessing road infrastructure safety are increasingly focused on the proactive identification of vulnerable road sections and on the use of performance indicators within the road safety management process. However, the application of these methods depends on the availability of comprehensive databases containing information on road traffic accidents and road infrastructure characteristics, as well as on the possibility of correlating these data for each road section.

The concepts and methodologies analysed in this chapter provide the foundation for the applied research presented in the following chapters, which focus on the correlation between road traffic accidents and road infrastructure characteristics, the evaluation of the influence of functional parameters on road safety, and the application of the Potential for Improvement (PI) indicator in the process of prioritizing interventions on road infrastructure.

3. CORRELATIVE ANALYSIS OF ROAD INFRASTRUCTURE CHARACTERISTICS AND ROAD TRAFFIC ACCIDENTS ON THE NATIONAL ROADS DN1–DN7

This chapter presents the correlational analysis carried out between road traffic accidents occurring on the national roads DN1–DN7 and the characteristics of road infrastructure. The research aims to highlight the relationships between the geometric configuration of the road, operating conditions, the condition of the road infrastructure, and the distribution of road traffic accidents, in order to identify the factors influencing the level of road safety.

The analysis is structured according to the distribution of road traffic accidents in relation to the main characteristics of road infrastructure and is complemented by their correlation with the pavement condition and the technical condition of the roads, as well as by a comparative analysis at the level of the entire investigated network.

3.1 Database and Analysis Period (2021–2024)

The correlational analysis was carried out using road traffic accident data recorded during the period 2021–2024 on the national roads DN1–DN7, provided by the Romanian Police – Traffic Directorate, and correlated with the available information regarding the technical condition and pavement condition of the roads from the database managed by CESTRIN.

For each kilometre position, information regarding the horizontal alignment, gradient, pavement surface condition, weather conditions, the primary cause of the accidents, the technical condition, and the pavement condition of the road infrastructure was analysed. The use of the kilometre position as a common reference element made it possible to correlate the two categories of information and to perform a consistent analysis across the entire investigated road network.

3.2 Methodology for Processing Accident Data

The road traffic accident data and the road infrastructure characteristics were organised into a unified database, using the kilometre position as the main correlation criterion. For each analysed road section, the percentage distributions of accidents were determined according to the geometric configuration of the road, gradient, pavement surface condition, weather conditions, and the primary causes of the accidents.

In the subsequent stage, these results were correlated with information regarding the technical condition and pavement condition of the roads in order to highlight the influence of road infrastructure on road safety. The results were graphically presented and compared both for each national road and for the entire analysed road network.

3.3 Distribution of Road Traffic Accidents According to Road Infrastructure Characteristics

3.3.1 Horizontal Alignment (Tangent, Curves and Intersections)

The analysis of accident distribution according to road alignment shows that approximately 52% to 86% of all road traffic accidents occur on tangent sections, while curves account for approximately 6% to 33% of the total. This distribution reflects the predominance of tangent sections within the analysed road network while also highlighting the influence of the geometric configuration of the road on accident occurrence.

For the DN2 and DN5 national roads, the proportion of accidents occurring on tangent sections exceeds 78–85%, suggesting the influence of operating speed and the functional characteristics of the road alignment. In contrast, the distribution on DN7 is more balanced, with approximately 55% of accidents occurring on tangent sections and 32% on curves, reflecting the specific configuration of the mountainous route and the sequence of geometric elements.

The results indicate that road traffic risk is not determined exclusively by the presence of curves, but rather by the interaction between the geometric configuration of the road, operating speed, and actual operating conditions.

3.3.2 Road Gradient

The distribution of accidents according to the longitudinal gradient shows that more than 85–95% of road traffic accidents occur on road sections characterized by low gradients (less than 1%). This distribution confirms that the longitudinal gradient, when considered individually, is not the primary factor determining accident occurrence.

However, in combination with other geometric elements, such as horizontal curves and sight distance limitations, the gradient influences stopping distance, vehicle stability, and the driver's ability to adapt speed to actual traffic conditions.

3.3.3 Pavement Surface Friction Condition (Dry/Wet)

The analysis of pavement surface conditions shows that approximately 70–92% of road traffic accidents occur under dry pavement conditions, whereas accidents occurring on wet pavement account for approximately 8–27% of the total.

The results indicate that most accidents occur under normal operating conditions, highlighting the influence of operating speed and driver behaviour on the level of road traffic risk. Furthermore, these findings justify the detailed analysis of the influence of the pavement friction coefficient on braking distance and road safety.

3.3.4 Weather Conditions

The distribution of accidents according to weather conditions indicates that more than 80–98% of road traffic accidents occur under normal weather conditions, while accidents occurring during precipitation generally account for less than 16% of the total.

This distribution indicates that road infrastructure and road user behaviour have a greater influence on the level of road safety than weather conditions considered individually.

3.3.5 Primary Causes of Road Traffic Accidents

The analysis of the primary causes of road traffic accidents highlights the predominance of speed inappropriate for road conditions, reaching values of up to approximately 30% of all accidents on certain analysed road sections. Other important causes include failure to give priority and failure to maintain a safe following distance, reaching values of up to approximately 22%.

The results confirm that road infrastructure indirectly influences accident occurrence through its effect on operating speed and the driver's decision-making process.

3.4 Correlation Between Road Traffic Accidents and Pavement Condition

The correlation between road traffic accidents and pavement condition shows that road sections classified as being in fair condition frequently account for approximately 25–80% of the analysed accidents. The results confirm the influence of pavement deterioration on ride comfort, pavement friction, and vehicle dynamic stability, and support the need for continuous monitoring of road infrastructure condition.

3.5 Correlation between Road Traffic Accidents and the Technical Condition of the Road

The analysis of the technical condition indicates that road sections classified as being in poor condition frequently account for between 33% and 100% of the analysed accidents. This distribution highlights the influence of the structural and functional characteristics of the road on the level of road safety and confirms the need to include the technical condition in the assessment of road infrastructure performance.

3.6 Comparative Analysis at the National Level

The comparative analysis of the national roads DN1–DN7 highlights the existence of specific characteristics for each route, determined by the geometric configuration, operating conditions, and traffic characteristics. Lowland roads are characterized by a high proportion of accidents occurring on tangent sections and under high-speed conditions, whereas mountainous routes present a more balanced distribution between tangent sections and curves, reflecting the combined influence of sight distance, gradient, and speed adaptation.

Overall, the results confirm that road traffic risk is determined by the interaction between the characteristics of road infrastructure and road user behaviour, while the analysis of accident distribution provides the basis for identifying vulnerable road sections.

3.7 Intermediate Conclusions on the Relationship Between Road Traffic Accidents and Road Infrastructure

The results presented in this chapter highlight the existence of direct relationships between the distribution of road traffic accidents and the characteristics of road infrastructure. The analysis demonstrates that the geometric configuration of the road, pavement friction conditions, pavement condition, and the technical condition of the road influence the level of road safety, with their effects depending on the actual operating conditions and the behaviour of road users.

The conclusions drawn provide the basis for the analyses developed in the following chapters, in which the influence of the pavement friction coefficient, sight distance, and geometric parameters on road safety is investigated, together with the evaluation of the applicability of the Potential for Improvement (PI) indicator for identifying priority road sections requiring intervention.

4. INFLUENCE OF PAVEMENT FRICTION, SIGHT DISTANCE, AND GEOMETRIC PARAMETERS ON ROAD SAFETY CONDITIONS

This chapter analyses the influence of the pavement friction coefficient, operating speed, gradient, and geometric configuration on braking distance and the sight distance required for safe stopping. The research aims to evaluate how variations in these parameters affect the functional performance of road infrastructure and influence road safety conditions.

The analysis is based on the theoretical relationships describing the tyre–pavement interaction and is complemented by numerical simulations performed in Scilab for different operating speeds, pavement friction coefficient values, and road gradients. The obtained results are compared with the analytical relationships presented in the scientific literature and with the values specified in STAS 863-85, PD 162-2002, and Order No. 1296/2017, in order to evaluate the influence of the functional parameters on braking and sight distances.

4.1 Pavement Friction Coefficient and Adhesion Coefficient – Definitions and Relationships

The first part of the chapter presents the theoretical foundations of the pavement friction coefficient and the adhesion coefficient, highlighting the influence of operating speed, pavement microtexture and macrotexture, and pavement surface condition on braking performance. The relationships used to characterise pavement friction and their implications for road safety are analysed.

4.2 Relationship Between Speed, Pavement Friction, and Braking Distance

This section analyses the combined influence of operating speed, the pavement friction coefficient, and road gradient on braking distance using numerical simulations performed in Scilab for different operating scenarios. The analyses were carried out for tangent sections and curves, corresponding to level, upgrade, and downgrade conditions, as well as for different pavement surface conditions and pavement types.

The results highlight the nonlinear increase in braking distance with increasing operating speed, whose influence becomes predominant at high speeds. A reduction in the pavement friction coefficient leads to increases in braking distance exceeding 30–50%, depending on operating speed and road gradient, with the effects being amplified on downgrade sections and under wet pavement or reduced-friction conditions. The simulations demonstrate that operating speed and the pavement friction coefficient act cumulatively on braking performance, while the road gradient may either increase or reduce these effects depending on the direction of travel.

4.3 Evaluation of Sight Distance Under Standard Traffic Conditions

Based on the braking distance results, the sight distances required for safe stopping are analysed under different traffic conditions, considering operating speed, the pavement friction coefficient, road gradient, and the geometric configuration of the road. Scenarios corresponding to tangent sections and curves were evaluated for operating speeds ranging from 20 to 140 km/h and for different pavement friction coefficient values representative of dry and wet pavement conditions.

The results show that the required sight distance increases progressively with increasing operating speed and decreasing pavement friction coefficient, the effects becoming particularly pronounced at high speeds. The sensitivity analyses indicate that relatively small variations in the pavement friction coefficient lead to significant changes in the required sight distance, especially when combined with negative gradients and curved sections. Comparison of the simulation results with the analytical relationships and the values specified in the design standards reveals differences of approximately 15–60% under dry pavement conditions and 2–40% under wet pavement conditions, with these differences becoming more pronounced at higher operating speeds.

4.4 Synthesis of the Sight Distance Results

The final part of this chapter synthesizes the results of the numerical simulations and compares them with the analytical relationships presented in the scientific literature and with the values specified in STAS 863-85, PD 162-2002, and Order No. 1296/2017, in order to evaluate the influence of the functional and geometric parameters on sight distance.

The comparison of the results shows that the sight distances obtained through the simulations are generally shorter than those determined using the analytical relationships, with differences of approximately 15–60% under dry pavement conditions and 2–40% under wet pavement conditions, these differences becoming more pronounced as operating speed increases.

Compared with the values specified in STAS 863-85, the simulations indicate shorter sight distances in most cases, by approximately 15–40% under dry pavement conditions and 1–35% under wet pavement conditions. Compared with PD 162-2002, the differences are approximately 30–50% under dry pavement conditions, while under wet pavement conditions, at high operating speeds, they are generally below 15%.

The obtained results confirm the need to use assessment models that simultaneously integrate the influence of operating speed, the pavement friction coefficient, road gradient, and the geometric configuration of the road in order to provide a more realistic evaluation of sight distance conditions and the functional performance of road infrastructure.

4.5 Chapter Conclusions

The obtained results demonstrate that operating speed is the main factor influencing braking and sight distances, while a reduction in the pavement friction coefficient and changes in road gradient significantly increase the requirements for safe stopping. The comparative analysis with the analytical relationships and the provisions of STAS 863-85 and PD 162-2002 shows that sight distance limitations are predominantly generated by the combined effect of the horizontal and vertical alignment, pavement friction conditions, and operating speed. Overall, the results confirm the need to use integrated assessment models capable of reflecting actual operating conditions and supporting the design and verification of the functional performance of road infrastructure.

5. APPLICATION OF SIGHT DISTANCE ANALYSIS AND GEOMETRIC CONFIGURATION UNDER REAL-WORLD CONDITIONS

This chapter presents the practical application of the sight distance assessment methodology to representative sections of road infrastructure. The analysis aims to highlight the influence of the geometric configuration of the road on the level of road safety by using three-dimensional modelling of the road infrastructure and simulation of the driver's field of view.

The evaluations were performed using Civil Site Design software, which allows the determination of sight distance under conditions close to actual operating conditions and the analysis of the influence of geometric elements and roadside obstacles on the driver's field of view.

5.1 The Role of Sight Distance in the Assessment of Road Infrastructure Safety

Sight distance is one of the main functional indicators used in the assessment of road infrastructure safety, directly influencing the driver's ability to perceive obstacles and to perform the manoeuvres required to avoid road traffic accidents.

In this research, sight distance is analysed not only from the perspective of compliance with the criteria specified in the design standards but also from the perspective of the actual operating conditions of the road infrastructure. This approach makes it possible to identify road sections where the geometric configuration limits the available field of view and leads to an increase in road traffic risk.

The results confirm that sight distance assessment should be carried out in an integrated manner by simultaneously considering the road geometry, operating speed, and the location of roadside obstacles.

5.2 Distribution of Road Traffic Accidents According to Road Geometry Combinations

The analysis of accident distribution according to combinations of horizontal and vertical alignment elements shows that road traffic risk is influenced by the interaction between these elements rather than by each parameter considered individually. Configurations consisting of horizontal curves combined with low gradients (≤1%) account for a high proportion of road traffic accidents, reaching up to approximately 80% of the total in certain cases.

Similarly, combinations of horizontal curves with upgrades or downgrades are characterised by a lower proportion of accidents but are associated with more demanding operating conditions that may increase the severity of road traffic accidents. These results confirm that the isolated analysis of geometric elements is not sufficient and that their combined assessment under actual traffic conditions is required.

5.3 Sight Distance Assessment Methodology Using Civil Site Design Software

For the realistic assessment of sight distance, Civil Site Design (ARD) software was used, enabling three-dimensional modelling of the road alignment and simulation of the driver's field of view under conditions close to actual operating conditions.

The applied methodology involved modelling the horizontal and vertical alignment, incorporating roadside infrastructure elements, defining the positions of the driver's eye and the obstacle, and simulating the line of sight as a function of operating speed. This approach makes it possible to identify specific road sections with sight distance deficiencies and to highlight the limitations generated by the geometric configuration of the road.

Compared with theoretical methods, three-dimensional modelling provides a much more realistic representation of the behaviour of road infrastructure under operating conditions, highlighting situations in which the criteria specified in the design standards do not accurately reflect actual sight distance conditions.

5.4 Case Studies

5.4.1 Motorway – Two Sections

The analysis of the motorway section shows that, although the geometric parameters generally comply with the requirements of the design standards, sight distance may be limited by the interaction between horizontal curves, vertical curves, and roadside infrastructure elements, particularly the median barrier.

The obtained results show that, at an operating speed of 100 km/h, sight distance deficiencies of approximately 25–35% are observed, while at 120 km/h these deficiencies range between 10% and 20%, and at 140 km/h they may reach 15–40%. In areas with crest vertical curves, the limitations are much more pronounced, with deficiencies reaching 60–75% at 120 km/h and exceeding 70–80% at 140 km/h.

The analysis also highlights the influence of the median barrier on the driver's field of view. Repositioning the barrier generally leads to an increase in sight distance; however, under certain geometric configurations, the opposite effect may occur, confirming the complex interaction between the different road infrastructure elements.

5.4.2 Road

For the analysed road section, the results show that, at an operating speed of 80 km/h, the available sight distance in the area of crest vertical curves frequently represents only 20–40% of the minimum value specified by the design standards, corresponding to deficiencies of 60–80%.

The analysis of the influence of operating parameters shows that increasing the driver's eye height results in only a limited improvement in sight distance, of approximately 10–25%, without consistently satisfying the minimum requirement specified in the design standards. In contrast, obstacle height plays a decisive role, with lower obstacles being associated with the greatest sight distance deficiencies.

The results confirm that the vertical alignment is the primary factor limiting sight distance, even where the horizontal alignment is favourable.

5.4.3 Intersection

The analysis of the intersection reveals the existence of significant sight distance deficiencies, particularly with respect to the functional criteria specified in the design standards. At an operating speed of 60 km/h, the available sight distance frequently represents only 5–15% of the required value, corresponding to deficiencies of 85–95%. At 50 km/h, the level of sight distance provision increases slightly, ranging between 10% and 25%, although the deficiencies remain significant, between 75% and 90%.

Reducing the operating speed to 40 km/h improves sight distance conditions, while at 30 km/h the available values become, in many cases, comparable to the required values. The analysis of the manoeuvring criterion highlights even more restrictive sight distance conditions, with values frequently below 10% for operating speeds of 50–60 km/h.

These results confirm that, under the existing configuration, road safety is strongly influenced by operating speed and the local geometry of the intersection.

5.5 Discussion and Correlation Between Theoretical Results and Case Studies

The comparison of the results obtained from the three-dimensional simulations with the theoretical relationships and the provisions of the design standards shows a general agreement regarding the trends in sight distance variation, while also highlighting significant differences caused by actual operating conditions.

The analysis demonstrates that the influence of operating speed, geometric configuration, and roadside obstacles may lead to limitations of the driver's field of view even when the geometric criteria specified in the design standards are satisfied.

The results highlight the need to use three-dimensional assessments for evaluating the functional performance of road infrastructure and for identifying road sections with a high level of vulnerability.

5.6 Chapter Conclusions

The research results confirm that three-dimensional modelling of road infrastructure makes it possible to realistically assess sight distance and to identify road sections where the geometric configuration limits the driver's field of view.

The analyses carried out highlight the decisive influence of the horizontal alignment, vertical alignment, and roadside obstacles on the level of road safety, demonstrating that an assessment based exclusively on the geometric criteria specified in the design standards is not sufficient to characterize the behaviour of road infrastructure under operating conditions.

Overall, the obtained results demonstrate the usefulness of three-dimensional modelling as a tool for the functional assessment of road infrastructure and for supporting the decision-making process aimed at improving road safety.

6. ASSESSMENT OF THE POTENTIAL FOR IMPROVEMENT IN ROAD SAFETY AND PRIORITISATION OF INTERVENTIONS USING THE PI INDICATOR

This chapter presents the application of the Potential for Improvement (PI) indicator to assess the safety performance of road infrastructure and to identify priority sections for intervention on the national roads DN1–DN7. The methodology compares the observed safety level at each kilometre position with a reference level established for the entire analysed road network, making it possible to identify the sections where accident frequency exceeds the average network performance.

The application of the PI indicator complements the statistical analysis of road traffic accidents by introducing a synthetic tool intended for the proactive management of road infrastructure safety and the prioritization of interventions according to the level of risk.

6.1 Definition of the National Reference Level

The determination of the Potential for Improvement (PI) indicator requires the establishment of a reference level that characterizes the average safety performance of the analysed road network.

In this research, the reference level was determined using the distribution of road traffic accidents recorded on the national roads DN1–DN7 during the analysed period, related to the investigated kilometre positions. The use of a single reference level makes it possible to compare all analysed road sections and to identify those where the accident frequency exceeds the average level of the road network.

The establishment of the reference level forms the basis for calculating the PI indicator and enables a consistent assessment of the safety performance of road infrastructure.

6.2 Calculation of the Potential for Improvement (PI) Indicator for DN1–DN7

The Potential for Improvement (PI) indicator was calculated for each kilometre position along the national roads DN1–DN7, using the reference level established for the analysed road network.

Negative values of the indicator characterize road sections with a safety performance comparable to or better than the reference level, whereas positive values indicate sections where the accident frequency exceeds the network average, highlighting the existence of a Potential for Improvement.

The calculation of the PI indicator enables a consistent assessment of all analysed road sections and provides an overall view of the distribution of safety performance across the investigated national road network.

6.3 PI Analysis According to Road Infrastructure Characteristics

6.3.1 Pavement Surface Friction Condition (Dry/Wet)

The analysis of the distribution of the PI indicator according to pavement surface conditions shows that, under both dry and wet pavement conditions, most kilometre positions exhibit negative PI values, typically ranging from approximately −3 to 0. These values indicate road sections where the accident frequency is lower than the average level of the analysed road network and suggest a relatively favourable road infrastructure safety performance.

Under dry pavement conditions, the distribution of the PI indicator shows a higher frequency of positive exceedances of the reference level, with most values ranging from approximately +3 to +8, and locally reaching +10 to +20. Under wet pavement conditions, the PI values are generally more concentrated around the reference level, typically ranging between −2 and +5, suggesting a more uniform distribution of safety performance.

Overall, the results confirm that most of the analysed road sections exhibit safety performance comparable to or better than the network average, while the sections with a Potential for Improvement are limited in number and localized.

6.3.2 Geometric Configuration (Curve + Upgrade / Downgrade / Gradient ≤ 1%)

The analysis of the distribution of the PI indicator according to the geometric configuration shows that most kilometre positions exhibit negative PI values, typically ranging from approximately −3 to 0, indicating a safety performance comparable to the reference level.

PI values close to zero indicate road sections with a safety level close to the network average, not requiring priority interventions but requiring continuous monitoring of operating conditions.

Positive PI values are concentrated mainly on road sections characterized by combinations of horizontal curves with upgrades, horizontal curves with downgrades, and horizontal curves with gradients ≤ 1%, where the combined influence of the geometric configuration and operating conditions leads to an increase in the frequency of road traffic accidents.

Overall, the distribution of the PI indicator shows that more than 60–70% of the analysed kilometre positions exhibit safety performance comparable to or better than the network average, whereas road sections with a genuine Potential for Improvement account for less than 20–25% and are concentrated in well-defined local areas.

6.4 Identification of Kilometre Positions with a High Potential for Improvement

The application of the Potential for Improvement (PI) indicator made it possible to identify road sections with poor safety performance and to establish priority kilometre positions for intervention.

Among the analysed road sections, the following stand out:

- DN1 – km 468+438, with a PI value of approximately +14.6, associated with a horizontal curve and a high number of road traffic accidents;
- DN2 – km 192+450, with a PI value of approximately +20.6, characterized by high traffic volumes and high operational demand;
- DN3 – km 167+000, with a PI value of approximately +7.6, indicating a moderate Potential for Improvement;
- DN4 – km 18+200, with a PI value of approximately +5.6, located near an intersection;
- DN5 – km 27+400, with a PI value of approximately +5.6, associated with roadside accesses and variations in traffic volume;
- DN6 – km 34+900, with a PI value of approximately +8.6, influenced by the geometric configuration and pavement friction conditions;
- DN7 – km 175+800, with a PI value of approximately +11.6, corresponding to a transition zone between a tangent section and a curve.

The results show that road sections with high PI values frequently coincide with areas characterized by sight distance limitations, complex geometric configurations, local variations in pavement friction, or unfavourable functional conditions of the road infrastructure.

6.5 Ranking and Prioritization of Interventions

Based on the PI values, the analysed road sections were ranked according to their safety performance.

The results highlight the predominantly localized nature of the road sections with poor safety performance, allowing interventions to be directed towards the locations where engineering measures can achieve the greatest benefits in reducing road traffic risk.

Depending on the characteristics of each road section, the main intervention measures include optimizing the geometric configuration of the road, improving sight distance conditions, increasing pavement surface friction, and implementing effective speed management and traffic management measures.

The application of the PI indicator therefore provides an objective basis for establishing investment priorities and directing resources towards the road sections with the greatest potential for reducing road traffic risk.

6.6 Chapter Conclusions

The application of the Potential for Improvement (PI) indicator confirms its usefulness in assessing the safety performance of road infrastructure and identifying priority road sections for intervention.

The results show that road infrastructure vulnerabilities are localized and are mainly associated with the geometric configuration of the road, sight distance conditions, pavement friction, and the functional characteristics of the road.

Overall, the analysis demonstrates that the use of the PI indicator, correlated with the evaluation of road infrastructure characteristics and the distribution of road traffic accidents, provides an objective basis for establishing intervention priorities and supports the decision-making process in road safety management at the national road network level.

7. GENERAL CONCLUSIONS, ORIGINAL CONTRIBUTIONS, FUTURE RESEARCH DIRECTIONS, AND DISSEMINATION OF RESULTS

7.1 Conclusions Derived from the Chapter Analyses

The objective of this thesis was to analyse the influence of road infrastructure on road safety across the Romanian national road network during the period 2021–2024, through an integrated approach combining the statistical analysis of road traffic accidents with the evaluation of the functional parameters of road infrastructure. The research structure enabled the scientific approach to be developed progressively, from the conceptual and methodological framework to the applied analyses and the use of performance indicators for prioritizing interventions.

The analysis presented in Chapter 1 shows that road safety should be understood as the result of the interaction between infrastructure, the road user, and the vehicle within a complex system in which road infrastructure plays an active role in generating and controlling road traffic risk. Operating speed is the determining factor influencing accident severity, while sight distance and the geometric configuration of the road directly affect drivers' ability to perceive and anticipate traffic situations.

The results presented in Chapter 2 highlight the transition from reactive to proactive approaches in road safety assessment and emphasize the importance of using performance indicators in road infrastructure analysis. The Potential for Improvement (PI) indicator is identified as a relevant tool for the comparative assessment of road section performance and for supporting intervention planning.

The correlational analysis presented in Chapter 3 shows that the distribution of road traffic accidents is influenced by the characteristics of road infrastructure and operating conditions. Approximately 52–86% of road traffic accidents occur on tangent sections, while curves account for approximately 6–33% of the total. On DN2 and DN5, the proportion of accidents occurring on tangent sections frequently exceeds 78–85%, whereas on DN7 the distribution is more balanced, with approximately 55% of accidents occurring on tangent sections and 32% on curves. The gradient analysis shows that more than 85–95% of road traffic accidents occur on sections with low gradients, indicating that the gradient itself is not the determining factor, while the risk is mainly influenced by operating speed and operating conditions. At the same time, approximately 70–92% of accidents occur under dry pavement conditions, and more than 80–98% occur under normal weather conditions, highlighting the decisive role of driver behaviour under normal traffic conditions. The correlation between road traffic accidents and pavement condition indicates that sections classified as being in fair condition frequently account for approximately 25–80% of the analysed accidents, while the correlation with the technical condition of the road indicates that sections classified as being in poor condition frequently account for 33–100% of the analysed accidents, highlighting the influence of ride comfort and structural capacity on vehicle dynamic stability.

The analysis presented in Chapter 4 highlights the influence of the pavement friction coefficient, operating speed, sight distance, and geometric parameters on road safety conditions. The comparative evaluation of sight distances obtained through numerical simulations, analytical relationships, and the provisions of the national design standards demonstrates the direct influence of the pavement friction coefficient on the stopping distance required for safe vehicle operation. Compared with the analytical relationships, the values obtained through simulation are approximately 15–60% lower under dry pavement conditions and 2–40% lower under wet pavement conditions, with the differences becoming more pronounced at higher operating speeds. Compared with STAS 863-85, the simulated sight distances are, in most cases, approximately 15–40% lower under dry pavement conditions and 1–35% lower under wet pavement conditions. Compared with PD 162-2002, the simulated values are approximately 30–50% lower under dry pavement conditions, whereas under wet pavement conditions, at high operating speeds, the differences are generally below 15%. The results demonstrate that sight distance limitations are predominantly generated by the combined effect of the horizontal and vertical alignment, pavement friction conditions, and operating speed, highlighting the need to use integrated models for evaluating the functional performance of road infrastructure.

The results obtained in Chapter 5, through the application of three-dimensional modelling using Civil Site Design (ARD), show that the available sight distance may be significantly shorter than the values specified in the design standards as a result of the combined effect of the horizontal and vertical alignment, operating speed, and roadside obstacles. Comparison with the provisions of PD 162-2002 shows sight distance deficiencies of approximately 25–35% at 100 km/h, 10–20% at 120 km/h, and 15–40% at 140 km/h on the analysed motorway section, while in areas with crest vertical curves these deficiencies may reach 60–75% at 120 km/h and exceed 70–80% at 140 km/h. For the analysed road section, the available sight distance frequently represents only 20–40% of the minimum value specified in the design standards, while at the analysed intersection, for operating speeds of 50–60 km/h, it frequently represents only 5–25% of the required value, corresponding to deficiencies of 75–95%. The results confirm that the vertical alignment, horizontal alignment, and roadside infrastructure elements have a decisive influence on the driver's field of view and highlight the need to use three-dimensional assessments during the design process and the verification of the functional performance of road infrastructure.

The analysis presented in Chapter 6 demonstrates the usefulness of the Potential for Improvement (PI) indicator in assessing the safety performance of road infrastructure and identifying priority road sections for intervention on the national roads DN1–DN7. The distribution of PI values shows that most analysed kilometre positions exhibit negative values, typically ranging between approximately −3 and 0, indicating safety performance comparable to or better than the network average. Positive exceedances are generally moderate, with most values ranging from approximately +3 to +8 and locally reaching +10 to +20, highlighting the existence of localized road sections with a high Potential for Improvement. The analysis according to operating conditions and geometric configuration shows a similar distribution of the PI indicator, with positive exceedances being frequently associated with restrictive geometric configurations, sight distance limitations, and unfavourable functional conditions of the road infrastructure. The results confirm the predominantly localized nature of road safety vulnerabilities and demonstrate that the use of the PI indicator constitutes an effective tool for prioritizing interventions and supporting road infrastructure safety management decisions, in accordance with the principles of the Safe System approach and the Network Safety Management concept.

7.2 Original Contributions of the Research

The research contributes to the advancement of knowledge in the field of road safety by integrating theoretical, statistical, and applied analyses into a coherent framework for road infrastructure assessment.

A first contribution consists of an extensive literature review, which enabled the integration of modern road safety concepts and provided the basis for a prevention-oriented approach. At the same time, the research clarifies the role of road infrastructure as an active factor in generating and controlling road traffic risk, highlighting the relationship between geometric parameters, sight distance, and driver behaviour.

An important contribution is the development of a unified approach to the analysis of road traffic accidents at the kilometre position level, making it possible to identify the relationships between accident frequency and road infrastructure characteristics. This approach showed that most accidents are concentrated on tangent sections, while curved sections present a higher specific risk.

The research also demonstrates that more than 85–95% of road traffic accidents occur on sections with low gradients, indicating that the level of risk is determined primarily by operating speed and actual operating conditions.

Another original contribution is the integration of pavement friction and sight distance analyses into the assessment of road safety, demonstrating that a reduction in the pavement friction coefficient may increase braking distance by more than 30–50% and that the available sight distance may be significantly shorter than the values specified in the design standards.

Through the use of three-dimensional modelling, the research highlights the differences between theoretical and actual operating conditions and demonstrates the need for the functional assessment of road infrastructure.

A central contribution is the application of the Potential for Improvement (PI) indicator, which enables the comparative assessment of the performance of road sections and the identification of high-risk areas. The results highlight the localized nature of road sections with poor safety performance and make it possible to identify critical areas along the DN1–DN7 national road network.

Overall, the contributions of this research establish an applied methodological framework for the assessment and management of road infrastructure safety, aimed at identifying priority road sections for intervention and supporting engineering decision-making.

7.3 Future Research Directions

The results obtained in this research provide a basis for extending and further developing the analyses related to road infrastructure safety.

Future research should primarily focus on applying the developed methodology to larger sections of the road network in order to optimize the intervention prioritization process.

In addition, the Potential for Improvement (PI) indicator should be integrated into existing road infrastructure management systems to support the decision-making process.

Another important research direction is the correlation of road safety assessment results with the planning of maintenance and rehabilitation works in order to improve investment efficiency. At the same time, the development of predictive models capable of anticipating changes in road safety resulting from variations in infrastructure parameters represents another relevant direction for future research.

7.4 Final Conclusion

Overall, this research demonstrates that the assessment of road infrastructure safety cannot rely exclusively on the analysis of recorded road traffic accidents but must also incorporate the functional characteristics of the road and actual operating conditions.

The results show that road safety risk is determined by the interaction between road infrastructure and driver behaviour and that safety-related vulnerabilities are concentrated at specific locations. The application of the Potential for Improvement (PI) indicator enables the identification of these locations and provides an objective basis for planning infrastructure interventions.

By integrating statistical, theoretical, and applied analyses, the research contributes to the development of a coherent framework for road safety management focused on accident prevention and the optimisation of road infrastructure performance.

7.5 Dissemination of Results

The results of this research have been disseminated within the scientific community through publications in specialised journals and presentations at relevant international conferences in the fields of transport infrastructure and road safety.

The published papers addressed topics including sight distance assessment, the influence of geometric parameters on road safety, and the relationship between road traffic accidents and road infrastructure characteristics. Participation in international scientific conferences enabled the validation of the research findings and their integration into the current international research context.

The results concerning the assessment of sight distance and the influence of geometric parameters on road safety were presented at the 8th International Conference on Road and Rail Infrastructure (CETRA 2024) through the paper:

Petcu Claudia, Răcănel Carmen, **Petcu Mihai Dragoș** – *Study on Road Visibility in the Context of Road Safety*, 8th International Conference on Road and Rail Infrastructure (CETRA 2024), Cavtat, Croatia, 2024.

The influence of driver eye height and obstacle height on sight distance was investigated and published in the paper:

Petcu Mihai Dragoș, Petcu Claudia, Răcănel Carmen – *Influence of Driver Eye Height and Obstacle Height on Sight Distance*, *Romanian Journal of Transport Infrastructure*, Vol. 13 (2024), No. 1, pp. 1–14.

Furthermore, the results concerning the influence of cut slope geometry on sight distance at T-intersections were presented in the paper:

Petcu Mihai Dragoș, Petcu Claudia, Răcănel Carmen – *Study about the Influence of the Road's Angle Cut Slope in a "T" Intersection*, *Journal of Applied Engineering Sciences*, Vol. 14 (27), Issue 2, 2024, pp. 308–315.

The analysis of the relationship between road geometric characteristics and the distribution of road traffic accidents was published in the paper:

Petcu Mihai Dragoș, Răcănel Carmen, Ioniță Ștefan, Sandu Robert – *Correlation of Road Crashes with Road Characteristics*, *Romanian Journal of Transport Infrastructure*, Vol. 14 (2025), No. 2, pp. 1–20.

Through these scientific contributions, the research carried out within this doctoral thesis has undergone international academic peer review and has contributed to the dissemination of research on the proactive assessment of road infrastructure safety, strengthening both the practical relevance and the scientific visibility of the doctoral research.