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CORRELATION OF ROAD CRASHES WITH ROAD CHARACTERISTICS

Petcu Mihai Dragos, Ph.D. Student Eng., Technical University of Civil Engineering of Bucharest, Romania, e-mail: mihai-dragos.petcu@phd.utcb.ro
Răcănel Carmen, Ph.D. Eng. Professor, Technical University of Civil Engineering of Bucharest, Romania, e-mail: carmen.racanel@utcb.ro
Ioniță Ștefan, Ph.D. Eng. Executive Director C.N.A.I.R. S.A. – C.E.S.T.R.I.N, e-mail: stefan.ionita@cestrin.ro
Sandu Robert, Ph.D. Student Eng., Technical University of Civil Engineering of Bucharest, Romania and Technical Director C.N.A.I.R. S.A. – C.E.S.T.R.I.N, e-mail: robert-adrian.sandu@phd.utcb.ro

Abstract

Road safety remains a major global challenge, with more than 1.19 million fatalities recorded annually and persistent disparities between regions in terms of crash risk and infrastructure performance. Recent international reports indicate that progress in reducing road deaths has slowed, both globally and in the European Union, where 19,940 fatalities were registered in 2024—only a 2% decrease from the previous year. Romania continues to exhibit one of the highest fatality rates in the EU, with 4,527 serious crashes and 1,545 deaths reported in 2023. The PIARC methodologies (2003; updated 2025) provide a robust analytical framework based on reactive and proactive approaches, combining crash-based diagnostics with infrastructure-focused evaluations, including geometric consistency, friction management and the Potential for Improvement (PI) indicator. Recent studies further reinforce the established relationship between pavement condition, skid resistance, and crash occurrence, while technological advances—such as AI-based road anomaly detection—offer new avenues for proactive risk management. Integrating PIARC principles with national crash data and current research on infrastructure performance offers a coherent basis for modernizing Romania's road safety strategies and prioritizing interventions with the greatest expected impact on reducing crash frequency and severity.

Keywords: road safety; crash analysis; proactive assessment; skid resistance; pavement condition; safety improvement

1. INTRODUCERE

Road safety is a global priority and is recognized by the United Nations as a critical component of the 2030 Sustainable Development Goals, following the adoption of the *Global Plan for the Decade of Action for Road Safety 2021–2030* [1]. Worldwide, the WHO Global Status Report on Road Safety shows that road crashes remain one of the leading causes of death among young people, generating more than 1.19 million fatalities annually [2]. Road safety is thus not only a public health concern but also a strategic challenge for road administrations and transport policy.

Globally, the International Transport Forum indicates in its *Road Safety Annual Report 2024* that the pace of fatality reduction remains insufficient, with many countries experiencing stagnation or even increases in the number of victims despite significant investments in infrastructure and safety technologies [3]. The European Commission confirms in its 2024 and 2025 reports a modest reduction of approximately 2% in road fatalities compared with previous years, with 19,940 deaths recorded in 2024 [4], [5]. Regional discrepancies remain substantial: Northern Europe reports the lowest mortality rates, while Eastern Europe—including Romania—continues to present elevated risk levels [6].

Romania consistently ranks among the EU countries with the highest road risk. According to the 2023 Road Safety Bulletin, Romania recorded 4,527 serious crashes resulting in 1,545 deaths and 3,537 serious injuries—the equivalent of 12 serious crashes and four deaths per day [7]. ERSO profiles confirm the vulnerability of pedestrians, the increased exposure of rural areas, and a considerable gap relative to the European average [8].

To support targeted interventions, PIARC – the World Road Association – plays a central role. The 2003 edition of the *Road Safety Manual*, together with the updated 2025 online version [9], offers road administrations a rigorous assessment framework. The role of infrastructure within the Safe System approach is reaffirmed in the PIARC *Strategic Plan 2024–2027*, which prioritizes the updating of technical manuals, the transition to proactive evaluations, and the use of performance indicators for road safety [10].
PIARC distinguishes two complementary approaches: (1) Reactive, based on crash analysis, identification of hazardous sites, risk indicators (frequency, rate, EPDO), and advanced statistical models such as Empirical Bayes; (2) Proactive, centered on road safety audits, periodic inspections, geometric assessment, visibility, skid resistance, and roadside safety.

PIARC also introduces the Potential for Improvement (PI) concept, which prioritizes interventions by comparing the observed number of crashes with the expected number, identifying segments with the greatest potential for reducing risk [9].

Recent literature reinforces the importance of infrastructure in crash occurrence. Nicolosi et al. (2024) propose an innovative friction management approach, demonstrating significant increases in crash risk under reduced skid resistance conditions [11]. Al-Zubaidi (2023) shows that pavement surface distress influences both crash frequency and severity [12]. International studies highlight nonlinear relationships between pavement quality and driver behavior, particularly in urban environments [13], [14].

In Romania, recent research on national roads validates PIARC methodologies. Dumitrașcu et al. (2024) demonstrate that elements such as platform width, shoulder condition and roadside features influence crash severity on DN1/E68 [15]. International studies on rural–urban crash distribution confirm the vulnerability of rural areas, even in highly developed countries such as the United Kingdom [16]. ETSC's PIN Report 2025 reinforces persistent discrepancies between EU states and the need to accelerate infrastructure interventions [17].

Technological advances have added new dimensions to infrastructure assessment. Recent studies demonstrate the use of artificial intelligence for detecting road anomalies, degraded signage, and real-time evaluation of road conditions [18], expanding PIARC's proactive perspective through continuous monitoring and rapid intervention.

Integrating PIARC 2003 and 2025 methodologies with European and national crash data, as well as current research on infrastructure and smart technologies, provides Romania with a coherent framework for developing a modern road safety management system.

2. STUDII EFECTUATE PE DRUMURI NATIONALE. PRELUCRARI SI INTERPRETARI

The studies conducted on national roads DN1–DN7 aimed to analyze how different road characteristics influence the occurrence of road crashes, through detailed processing of available data for 2021–2024. For each road, percentage distributions of crashes were determined based on geometric configuration, skid resistance, meteorological conditions, and primary cause, allowing the identification of dominant patterns and road-specific features.

In parallel, to assess the influence of road condition on safety, both pavement structural condition and surface distress were analyzed for 2021–2023, with measurements available for 2023. Pavement structural condition was determined based on the design traffic calculated from the 2022 CESTRIN Census, required for applying the CD 155 classification and for assigning each road segment to its appropriate structural demand class.

This analytical structure enables consistent comparison across national roads and highlights both the infrastructure elements that favor crash occurrence and the situations where road condition directly or indirectly affects road safety.

2.1. National Road DN 1

Figure 1 shows the distribution of crashes by road geometry, Figure 2 highlights the influence of skid resistance on crash occurrence, and Figure 3 presents the distribution of crashes by weather conditions on DN1.

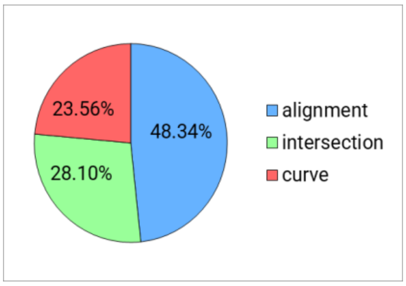


Figure 1. Percentage of the total number of crashes (2021-2024) by road geometry on DN1

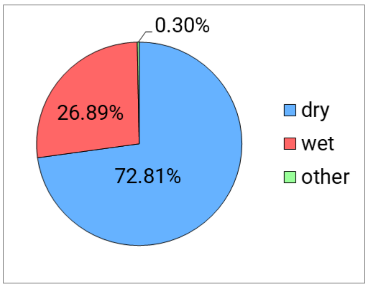


Figure 2. Percentage of the total number of crashes (2021-2024) by pavement skid resistance on DN1

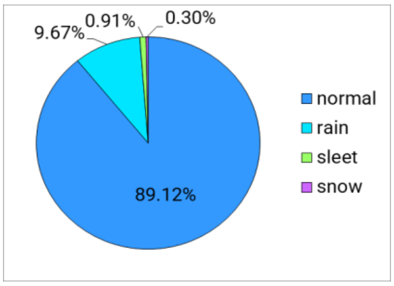


Figure 3. Percentage of the total number of crashes (2021-2024) by weather conditions on DN1

Most crashes occur on straight sections (48.34%) due to higher speeds and the perception of increased safety.

Dry pavement conditions account for 72.81% of crashes, reflecting reduced caution and higher speeds.

Normal weather is associated with 89.12% of crashes, as drivers tend to travel faster and with reduced vigilance.

Figure 4 presents the primary causes of accidents on DN1.

Crash distribution is dominated by failure to yield (26.06%) and excessive or inappropriate speed (17.82%), as these errors occur frequently under normal traffic conditions where risk is underestimated. Other causes remain below 5%, reflecting their low recurrence.

Figure 5 shows the relationship between the pavement structural condition of the road and crash occurrence, and Figure 6 presents the distribution of crashes according to pavement distress levels on DN1.

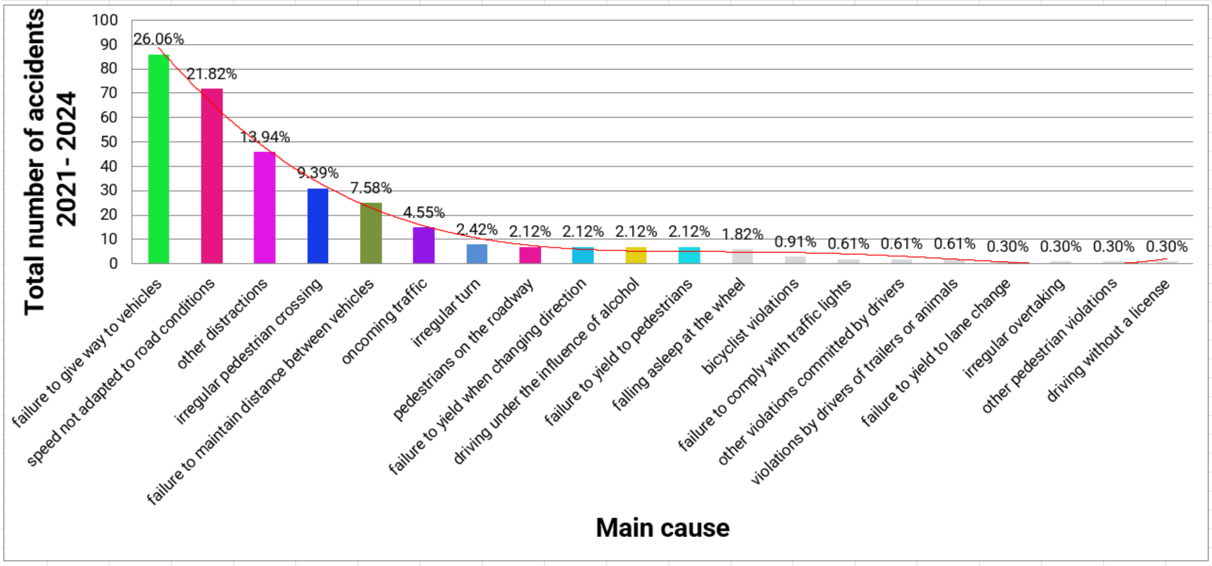


Figure 4. Percentage of the total number of crashes (2021–2024) by primary cause on DN1

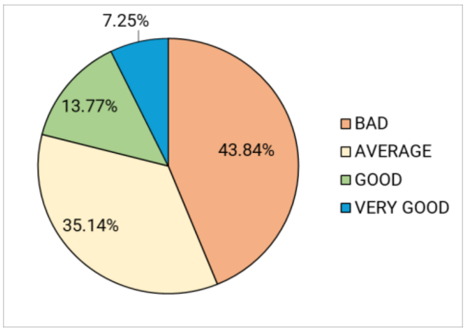


Figure 5. Percentage of the total number of crashes (2021–2023) by pavement structural condition on DN1

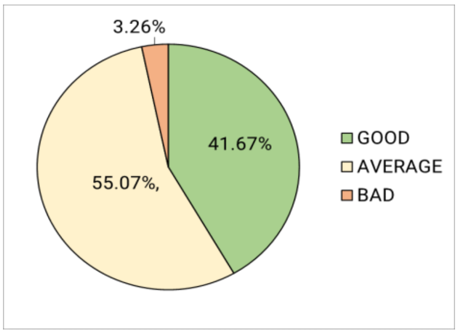


Figure 6. Percentage of the total number of crashes (2021–2023) by pavement distress level on DN1

Segments in poor pavement structural condition account for 43.84% of crashes, as structural defects affect vehicle stability.

Moderate pavement distress leads to 55.07% of crashes, as such defects are often underestimated by drivers.

Segments in poor condition account for 43.84% of crashes, as structural defects affect vehicle stability.

Moderate distress levels lead to 55.07% of crashes, since such defects are often underestimated by drivers.

2.2. National Road DN 2

Figure 7 shows the distribution of crashes by road geometry, Figure 8 presents how skid resistance influences crash occurrence, and Figure 9 shows the distribution of crashes by weather conditions on DN2.

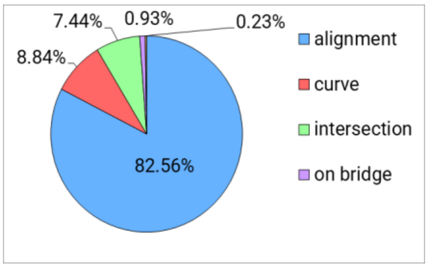


Figure 7. Percentage of the total number of crashes (2021-2024) by road geometry on DN1

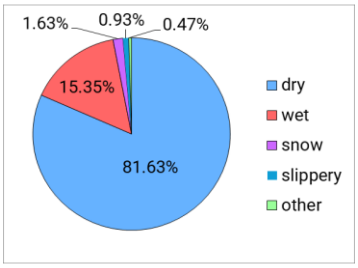


Figure 8. Percentage of the total number of crashes (2021-2024) by pavement skid resistance on DN1

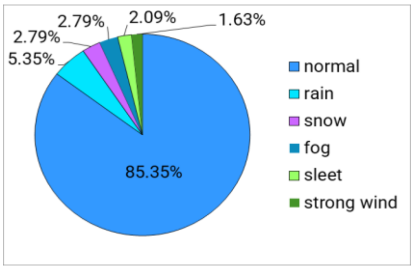


Figure 9. Percentage of the total number of crashes (2021-2024) by weather conditions on DN1

Straight sections account for 82.56% of crashes, due to high travel speeds and reduced driver attention on linear segments. Dry pavement represents 81.63% of cases, as drivers tend to be less cautious under conditions perceived as safe. Normal weather accounts for 85.35% of crashes, reflecting higher speeds and reduced attention compared with rainy conditions.

Figure 10 presents the dominant causes of crashes on DN2.

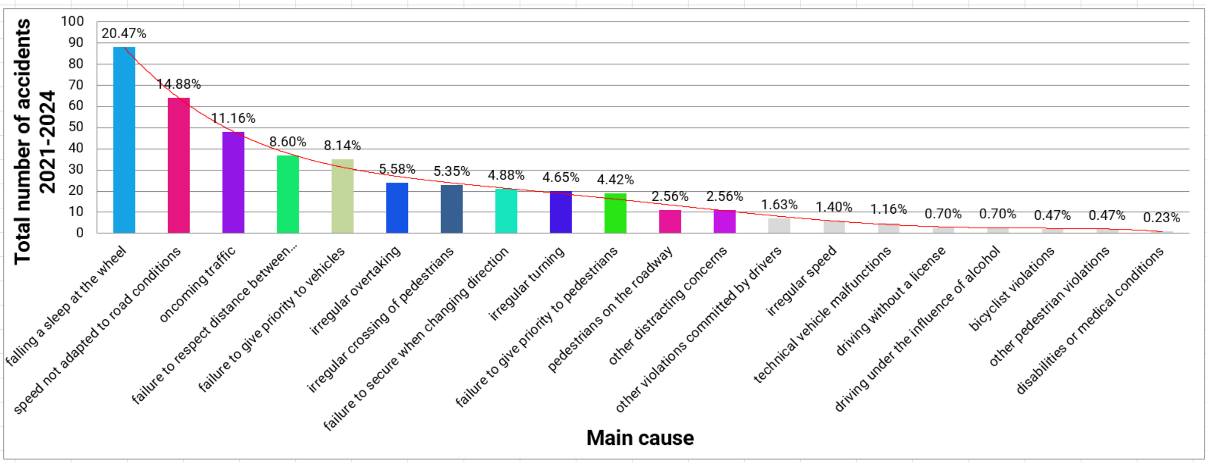


Figure 10. Percentage of the total number of crashes (2021–2024) by primary cause on DN2

The high proportions associated with failure to ensure safety before changing direction (20.47%) and excessive or inappropriate speed (14.88%) indicate that crashes mainly stem from frequent observation and decision-making errors, while the lower-percentage causes (below 5%) correspond to rarer situations that do not significantly influence the overall risk.

Figure 11 analyzes the influence of pavement structural condition on crash occurrence, and Figure 12 shows the distribution of crashes according to visible pavement distress on DN2.

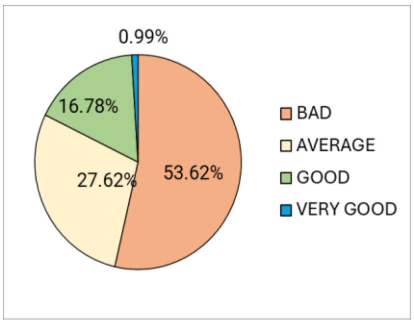


Figure 11. Percentage of the total number of crashes (2021–2023) by pavement structural condition on DN2

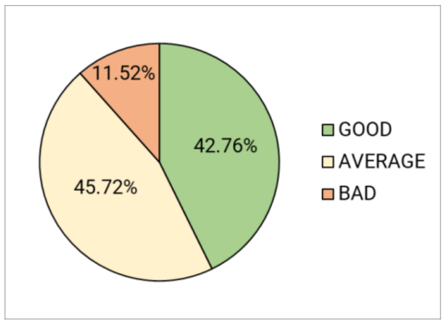


Figure 12. Percentage of the total number of crashes (2021–2023) by pavement distress level on DN2

Segments in poor pavement structural condition account for 53.62% of crashes, due to reduced structural performance, while those with moderate pavement distress represent 45.72%, as such defects are less noticeable and tend to be underestimated by drivers.

Interestingly, it is the moderately distressed sections—rather than the severely deteriorated ones—that concentrate most crashes. This trend may indicate that obvious deterioration prompts drivers to adopt more cautious behavior, whereas moderate, less visible defects can lead to unexpected vehicle responses and delayed driver reactions.

2.3. National Road DN 3

Figure 13 shows the distribution of crashes on DN3 by road section type, Figure 14 presents the relationship between pavement skid resistance and crash distribution on DN3, and Figure 15 analyzes how weather conditions influence crash occurrence on DN3.

Crashes occur almost exclusively on straight sections (95.83%), with intersections accounting for only a minimal share. This concentration is explained by higher speeds and reduced driver attention on straight segments perceived as low-risk.Most crashes occur on dry pavement (75.00%), while low-friction situations are rare. This is due to drivers tending to travel faster and with less caution when they perceive the pavement as safe.

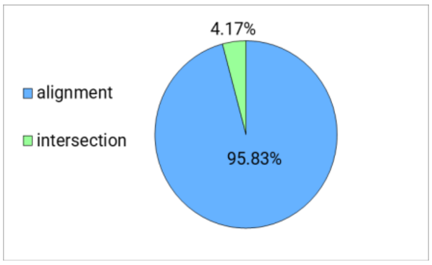


Figure 13. Percentage of the total number of crashes (2021-2024) by road geometry on DN3

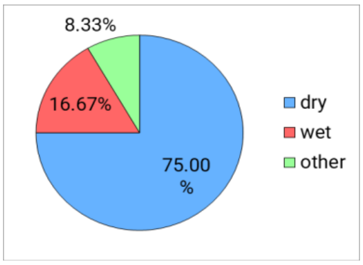


Figure 14. Percentage of the total number of crashes (2021-2024) by pavement skid resistance on DN3

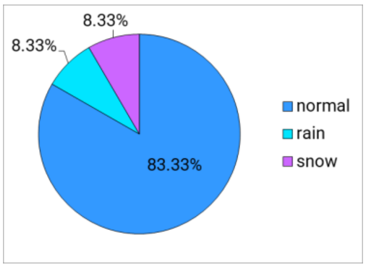


Figure 15. Percentage of the total number of crashes (2021-2024) by weather conditions on DN3

Crashes occur almost entirely under normal weather conditions (83.33%), with rain having only a minor impact. This pattern is explained by higher speeds and reduced vigilance when conditions appear risk-free, in contrast to adverse weather, when drivers tend to be more cautious.

Figure 16 highlights the dominant causes of crashes on DN3.

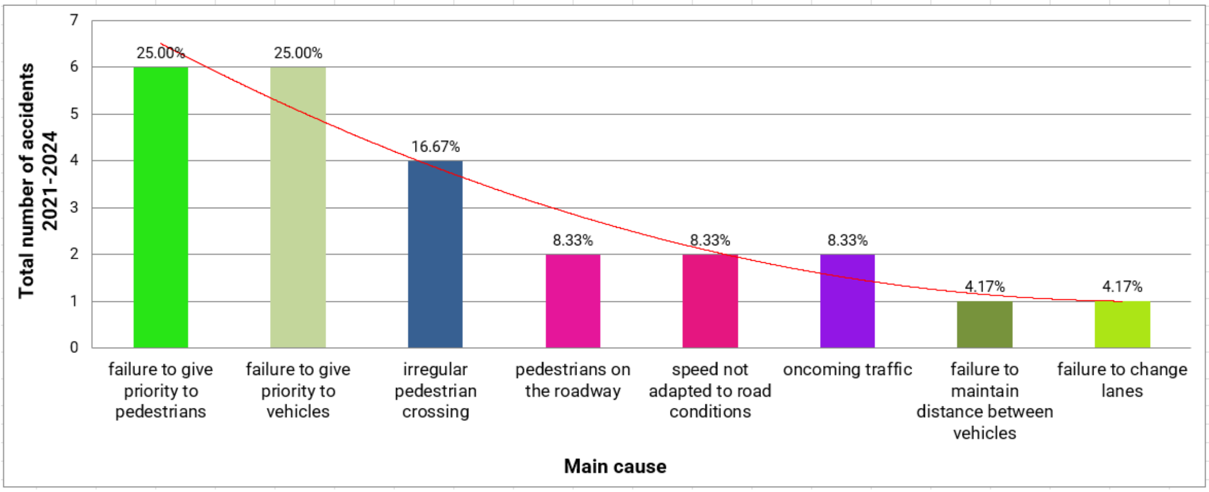


Figure 16. Percentage of the total number of crashes (2021–2024) by primary cause on DN3

The fact that failure to yield to pedestrians and vehicles together accounts for 50% of crashes, followed by jaywalking (16.67%), indicates that most incidents stem from direct priority-related conflicts, while the remaining causes (below 10%) occur less frequently and have a limited influence on overall risk.

Figure 17 presents the distribution of crashes according to the pavement structural condition of DN3, and Figure 18 analyzes the relationship between visible pavement distress levels and crash occurrence on DN3.

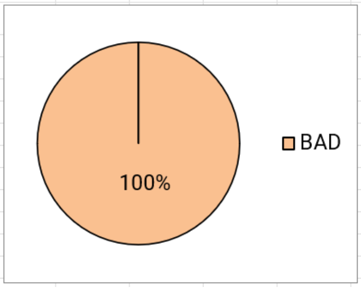


Figure 17. Percentage of the total number of crashes (2021–2023) by pavement structural condition on DN3

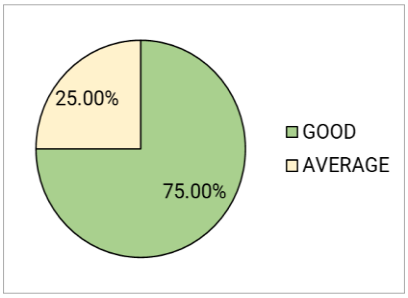


Figure 18. Percentage of the total number of crashes (2021–2023) by pavement distress level on DN3

All crashes are associated with sections in poor pavement structural condition, representing 100% of cases. This situation indicates a pronounced structural vulnerability that favors instability during driving and the occurrence of unexpected events. Crashes are concentrated in sections with minor distress (75%), while moderately distressed areas account for 25%. This pattern is explained by drivers' tendency to underestimate risk in locations where defects are not clearly visible.

2.4. National Road DN 4

Figure 19 presents the distribution of crashes on DN4 by road section type, Figure 20 shows how pavement skid resistance influences crash distribution on DN4, and Figure 21 highlights the relationship between weather conditions and crash occurrence on DN4.

Most crashes occur on straight sections (75%), while curves and intersections each account for 12.50%. The high share of crashes on straight sections is explained by increased speeds and reduced attention in areas perceived as "easy." Dry pavement is associated with most crashes (77.78%), whereas wet pavement accounts for 22.22%. This pattern reflects higher speeds on dry surfaces and a heightened perception of safety, which reduces driver caution.

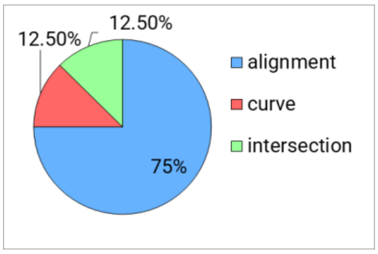


Figure 19. Percentage of the total number of crashes (2021-2024) by road geometry on DN4

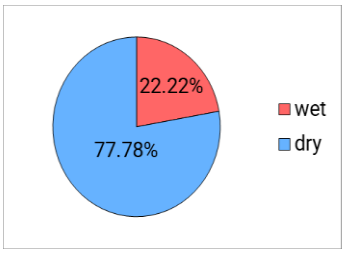


Figure 20. Percentage of the total number of crashes (2021-2024) by pavement skid resistance on DN4

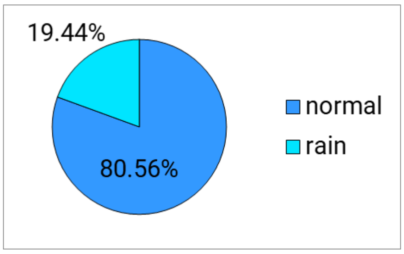


Figure 21. Percentage of the total number of crashes (2021-2024) by weather conditions on DN4

Most crashes occur under normal weather conditions (80.56%), while rain has a smaller impact (19.44%). This pattern is explained by higher speeds and reduced vigilance when no obvious hazards are present, in contrast to adverse weather, when drivers tend to be more cautious.

Figure 22 presents the distribution of crashes on DN4 by identified primary cause.

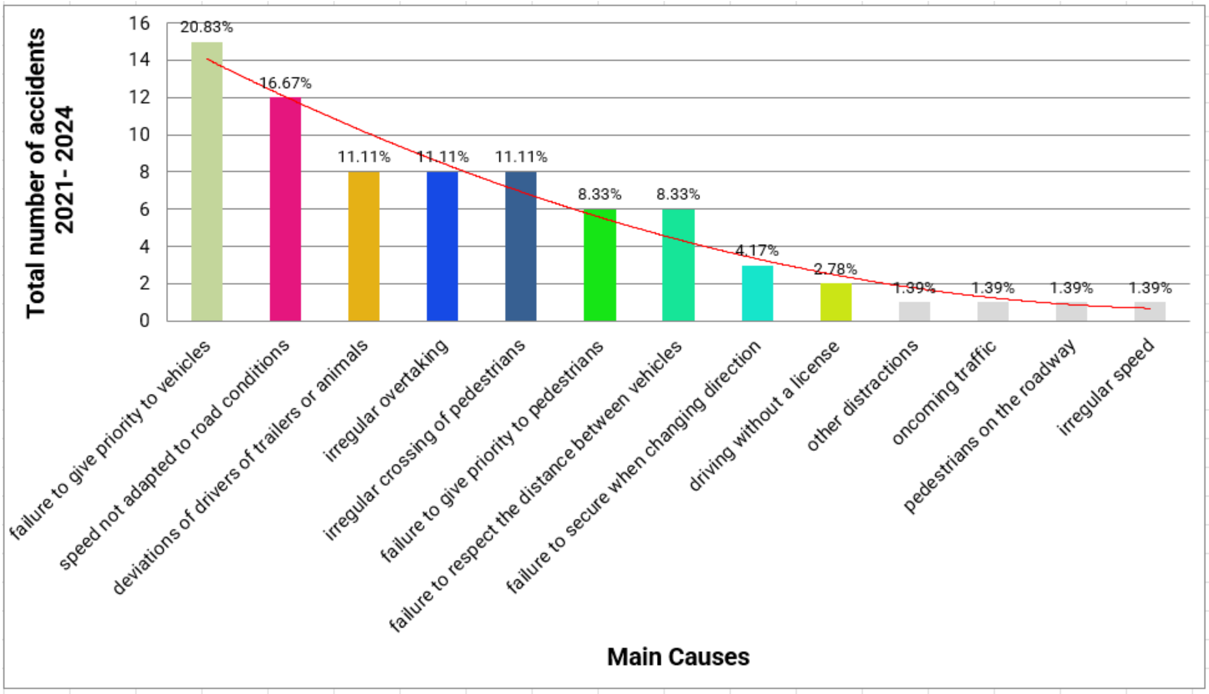
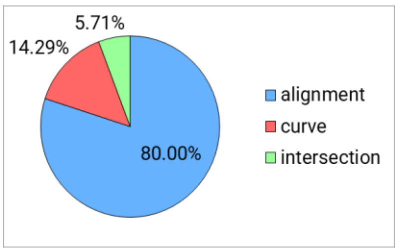


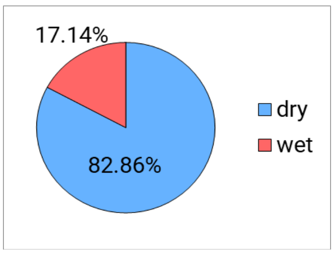
Figure 22. Percentage of the total number of crashes (2021–2024) by primary cause on DN4

2.5. National Road DN 5

Figure 23 presents the distribution of crashes on DN5 by road section type, Figure 24 shows the influence of skid resistance on crash occurrence on DN5, and Figure 25 illustrates the distribution of crashes on DN5 according to weather conditions.

Crashes are concentrated on straight sections (80.00%), with curves contributing 14.29% and intersections 5.71%. The predominance of straight sections is explained by higher speeds and the perception of lower risk in these areas. Most crashes occur on dry pavement (82.86%), while wet surfaces account for only 17.14%. This difference reflects reduced vigilance and higher speeds on dry surfaces. All crashes recorded on DN5 occurred under normal weather conditions (100%), indicating that the risk is driven primarily by driver behavior rather than by adverse meteorological conditions.





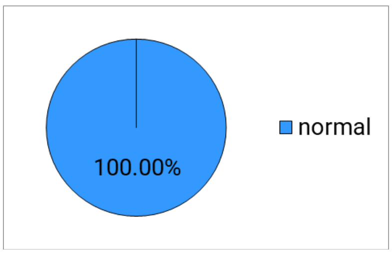


Figure 23. Percentage of the total number of crashes (2021-2024) by road geometry on DN5

Figure 24. Percentage of the total number of crashes (2021-2024) by pavement skid resistance on DN5

Figure 25. Percentage of the total number of crashes (2021-2024) by weather conditions on DN5

Figure 26 presents the main causes that generated crashes on DN5.

The high proportions associated with excessive or inappropriate speed (22.86%), failure to yield (22.86%), and failure to maintain adequate distance between vehicles (20.00%) indicate that most crashes result from misjudgment of speed and spacing in traffic, while the remaining causes (below 10%) reflect isolated situations with limited impact on the overall distribution.

Figure 27 shows how the pavement structural condition of DN5 is associated with crash occurrence, and Figure 28 highlights the distribution of crashes according to the level of pavement distress.

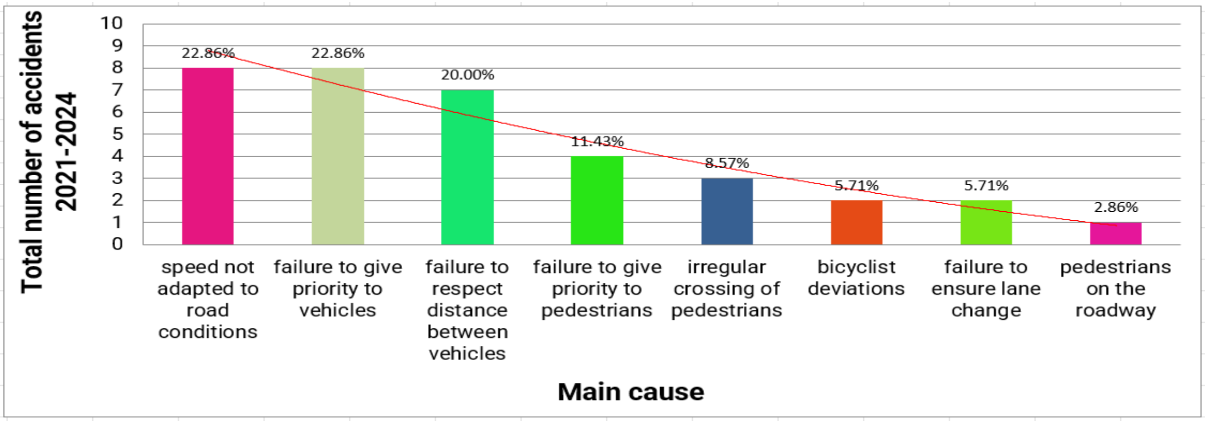


Figure 26. Percentage of the total number of crashes (2021–2024) by primary cause on DN5

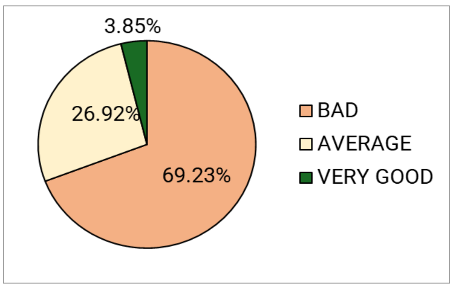


Figure 27. Percentage of the total number of crashes (2021–2023) by pavement structural condition on DN1

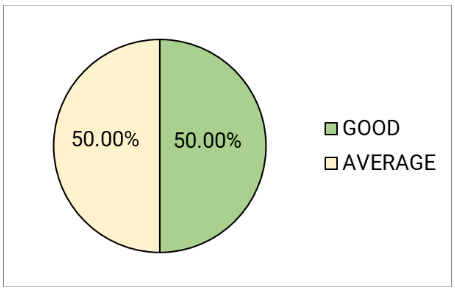


Figure 28. Percentage of the total number of crashes (2021–2023) by pavement distress level on DN1

Sections in poor pavement structural condition generate 69.23% of crashes, explained by structural defects that reduce vehicle stability. Areas in good condition have only a minor impact on the overall distribution. Crashes are evenly split between slight and moderate pavement distress, indicating that on DN5, visible defects are not the sole determining factor, with driver behavior playing a decisive role.

2.6. National Road DN 6

Figure 29 shows the distribution of crashes on DN6 according to road geometric configuration, Figure 30 presents the distribution of crashes in relation to pavement skid resistance on DN6, and Figure 31 illustrates the influence of weather conditions on crash occurrence on DN6. Straight sections concentrate most crashes (51.72%), while curves account for 44.83% and intersections for only 3.45%. These values reflect the difficulty drivers have in adjusting speed on winding sections, as well as reduced attention on straight segments. Most crashes occur on dry pavement (57.47%), followed by wet pavement conditions (40.23%), while "other" situations are minimal (2.30%). These differences suggest that excessive confidence under favorable conditions leads to risk underestimation. Crashes occur mainly under normal weather conditions (70.11%), followed by rain (26.44%) and snow (3.45%). The high frequency under normal conditions indicates that driver behavior, rather than adverse weather, is the dominant factor.

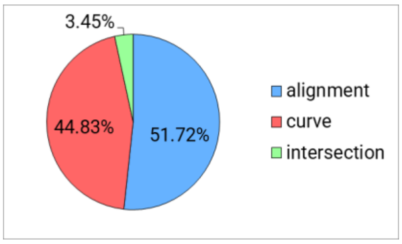


Figure 29. Percentage of the total number of crashes (2021-2024) by road geometry on DN6

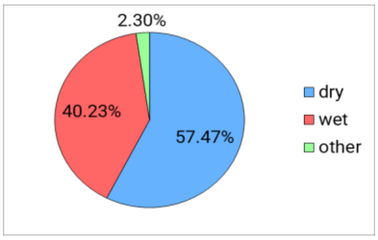


Figure 30. Percentage of the total number of crashes (2021-2024) by pavement skid resistance on DN6

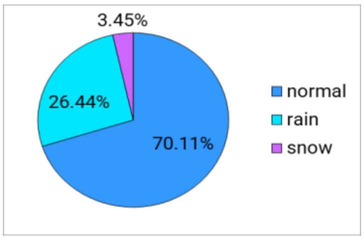


Figure 31. Percentage of the total number of crashes (2021-2024) by weather conditions on DN6

Figure 32 summarizes the main causes that generated crashes on DN6.

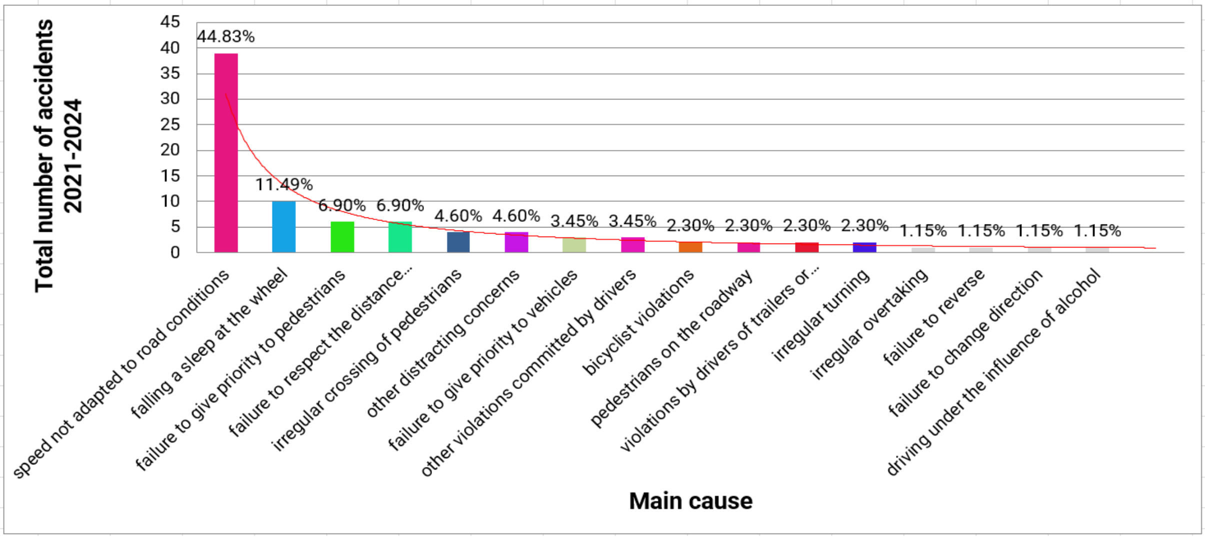


Figure 32. Percentage of the total number of crashes (2021–2024) by primary cause on DN6

The very high share of excessive or inappropriate speed (44.83%) and driver fatigue or falling asleep at the wheel (11.49%) shows that loss of vehicle control is the dominant crash mechanism, while the remaining causes (mostly below 7%) occur infrequently and have a marginal impact on the overall distribution.

Figure 33 presents the distribution of crashes in relation to the pavement structural condition of DN6 sections, and Figure 34 illustrates the distribution of crashes according to the level of pavement distress on DN6.

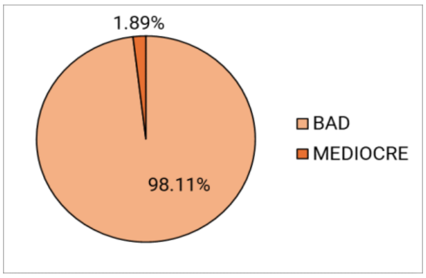


Figure 33. Percentage of the total number of crashes (2021–2023) by pavement structural condition on DN1

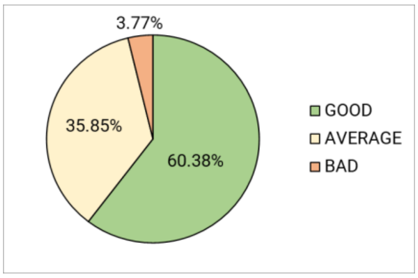


Figure 34. Percentage of the total number of crashes (2021–2023) by pavement distress level on DN1

Almost all crashes are associated with sections in poor pavement structural condition (98.11%). This proportion highlights the structural vulnerability of DN6 and its impact on road safety. Most crashes occur on sections with slight pavement distress (60.38%), while severe distress accounts for only a minimal share. This pattern indicates that obvious defects encourage more cautious driving, whereas slight defects are often overlooked.

2.7. National Road DN 7

Figure 35 illustrates how road geometry influences the distribution of crashes on DN7, Figure 36 presents the distribution of crashes according to pavement skid resistance on DN7, and Figure 37 shows the influence of weather conditions on crash occurrence on DN7.

Straight sections account for more than half of all crashes (50.61%), while curves represent 37.65%, indicating difficulties in speed adaptation on segments with variable trajectory. Intersections (10.12%) and bridges (1.62%) contribute much less.

Crashes are more frequent on dry pavement (68.02%), followed by wet pavement (29.55%), while “other” conditions are marginal (2.43%). This distribution indicates that, under good conditions, drivers tend to adopt higher speeds, which increases risk.

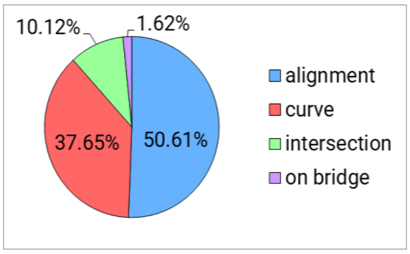


Figure 35. Percentage of the total number of crashes (2021-2024) by road geometry on DN7

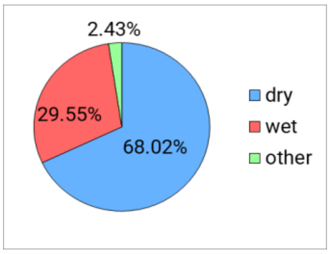


Figure 36. Percentage of the total number of crashes (2021-2024) by pavement skid resistance on DN7

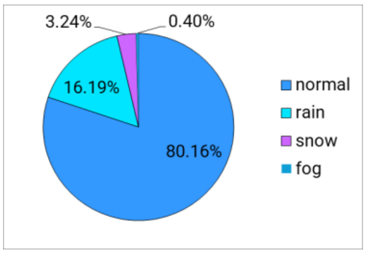


Figure 37. Percentage of the total number of crashes (2021-2024) by weather conditions on DN7

Normal weather dominates crash occurrence (80.16%), while rain accounts for 16.19%, snow for 3.24%, and fog for only 0.40%. The prevalence of crashes in normal weather shows that human factors—not meteorological ones—primarily determine risk on DN7.

Figure 38 highlights the main causes of crashes on DN7.

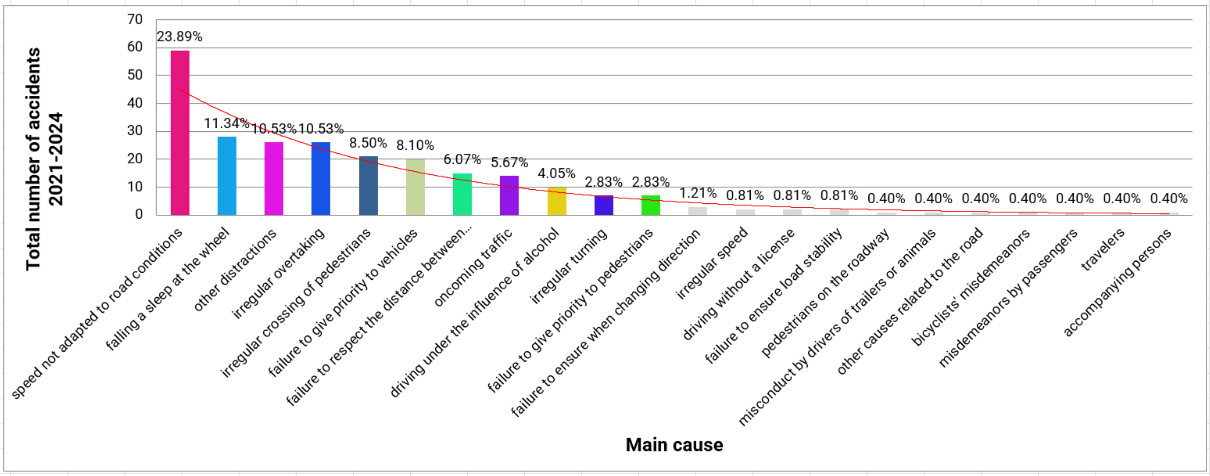


Figure 38. Percentage of the total number of crashes (2021–2024) by primary cause on DN7

The high proportions associated with excessive or inappropriate speed (23.89%) and falling asleep at the wheel (11.33%), followed by other frequent violations such as inattention (9.53%) and performing dangerous maneuvers (10.53%), show that most crashes are generated by loss of control and attention-related errors, while the remaining causes (below 8%) occur sporadically and have only a marginal influence on the overall distribution.

Figure 39 presents the distribution of crashes according to the pavement structural condition of DN7 sections, and Figure 40 shows the influence of pavement distress level on crash distribution on DN7.

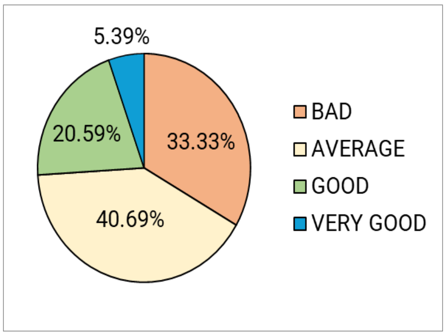


Figure 39. Percentage of the total number of crashes (2021–2023) by pavement structural condition on DN1

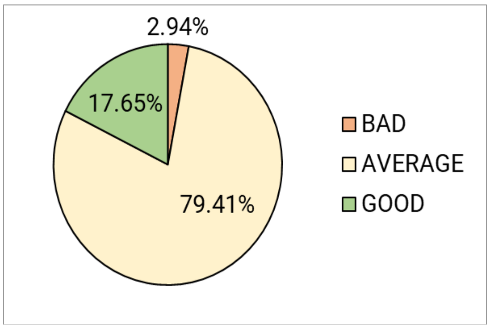


Figure 40. Percentage of the total number of crashes (2021–2023) by pavement distress level on DN1

Most crashes are associated with sections in medium (40.69%) and poor (33.33%) pavement structural condition. This distribution reflects the impact of moderate structural deficiencies, which are often underestimated by drivers. The majority of crashes occur on sections with medium pavement distress (79.41%), while severe distress has only a minor impact. This indicates that moderate defects are most frequently underestimated, generating higher risks during driving.

3. CONCLUSIONS

The analysis of road crashes on DN1–DN7 shows that, regardless of the specific characteristics of each road, several converging trends define the overall profile of road risk at the national level.

Crashes are predominantly concentrated on straight sections (in many cases over 60–70%), indicating that seemingly simple, linear segments are associated with reduced vigilance and higher travel speeds. Transitions between straight sections and curves also represent sensitive points due to late speed adjustment.On all analyzed roads, dry pavement is associated with the highest share of crashes (generally over 70%). The explanation is behavioral: drivers feel safer, reduce caution, and increase speed, which heightens the likelihood of errors. Between 60% and 80% of crashes occur under normal weather conditions, while rain or fog account for smaller proportions. This consistent pattern across all roads confirms that crash risk is shaped not by adverse weather, but rather by excessive driver confidence and reduced vigilance under conditions perceived as safe.

Failure to yield (to pedestrians and vehicles), jaywalking, and excessive or inappropriate speed dominate the causative structure on all roads. In many cases, these causes account for over 40–50% of the total. This highlights the necessity of behavioral interventions—educational, punitive, or regulatory—to reduce crash risk.

On DN2, DN5, and DN6, sections classified as being in “poor” pavement structural condition concentrate between 50% and 100% of crashes, emphasizing the critical role of structural capacity and pavement integrity. Roads with extensive deficiencies require prompt interventions to reduce risk. In most cases, crashes are more frequent on sections with moderate distress, as drivers tend to underestimate these defects. Severe distress, although technically more critical, leads to more cautious driving and lower speeds.

The combination of straight alignment, dry pavement, normal weather, and human error (failure to yield, excessive or inappropriate speed) represents the pattern that generates the majority of crashes across all analyzed roads.

Crashes on DN1–DN7 are driven primarily by driver behavior under infrastructure and environmental conditions perceived as “favorable,” where vigilance decreases and speed increases, while poor pavement structural condition and moderate pavement distress further amplify the vulnerability of the affected sections.

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