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APPLICATION OF MAIS3+ BASED INJURY SEVERITY IN ASSESSING ROAD NETWORK SAFETY: THE CASE OF LITHUANIAN MAIN ROADS

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Abstract. This article presents a study aimed at integrating two road safety approaches to effectively prioritise road sections requiring safety improvements. The study examines the role of injury severity assessment in evaluating the safety of road networks. It outlines the fundamental principles of the MAIS3+ methodology, discusses its relevance to road-safety analysis, and highlights its potential applications for assessing road infrastructure risk. A pilot safety assessment of the Lithuanian main road network is presented, based on the severity of traffic accident outcomes classified according to the MAIS3+ criterion. Furthermore, the study addresses the challenges of linking hospital and police data and provides recommendations to improve data integration.

Keywords: injury, injury severity, MAIS3+, road network, safety.

Introduction

Road traffic fatalities and injuries remain a major public health, social and economic challenge worldwide. Despite continuous improvements in road infrastructure, vehicle technology, and other measures to enhance road safety,

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progress in the European Union (EU) has been very slow, especially in recent years. According to the European Commission, in 2024, 19 940 people lost their lives in road traffic accidents across the EU (European Commission, 2025), which is only 2% fewer than in 2023. This represents insufficient progress toward achieving the EU's goals – in particular, Vision Zero by 2050 (European Commission, 2020). Additionally, the number of serious injuries, which the Valletta Declaration committed to reducing by 2030 compared to 2020, is equally concerning (Valletta Declaration on Road Safety, 2017). Assessing progress in reducing serious injuries is challenging, as not all EU countries, including Lithuania, use the MAIS3+ injury scale to determine injury severity (European Court of Auditors, 2024).

The above-mentioned EU targets for reducing road fatalities and serious injuries are to be achieved through the Safe Systems approach. This approach is designed to be resilient and forgiving by integrating safer vehicles, improved road infrastructure, enhanced regulations, and effective post-crash care (Pauer & Ötvös, 2025; Green et al., 2022; Job et al., 2022).

One of the five pillars of the Safe System approach, safer roads, requires the road environment to be designed to reduce human error, account for human injury tolerance, promote safer behaviour, and create conditions for safe travel, particularly for the most vulnerable road users. Efforts to create safer infrastructure have been undertaken and continue at various levels across the EU. The European Parliament and the Council adopted Directive (EU) 2019/1936 of 23 October 2019, amending Directive 2008/96/EC on the management of road infrastructure safety. At the national level, each EU Member State was required to adopt legislation implementing the aforementioned directive and to carry out the prescribed procedures to improve road safety.

Traditional methods of assessing road safety have long relied on aggregated accident numbers or fatality rates; however, these indicators often fail to reflect the full extent of road accident consequences, especially the burden of serious injuries. In the authors' opinion, given that the aim is to reduce the number of serious injuries, this indicator should be systematically assessed when implementing appropriate road safety management procedures. Furthermore, considering that the Valletta Declaration has required the Member States to provide injury indicators by severity level since 2018, and that all EU Member States will eventually need to comply, it would be appropriate to integrate injury severity levels, reflecting the consequences of road traffic accidents, into road safety management procedures. Such integrated approaches provide a more detailed understanding of accident mechanisms and facilitate the development of proactive rather than reactive safety management practices. Moreover, in the authors' opinion, the application of the MAIS3+ system is consistent with scientifically grounded Safe System principles (Aarts, 2023; Elvik, 2023), as improvements in road infrastructure are among the primary measures for preventing serious injuries. This makes MAIS3+ a valuable tool for evaluating road safety performance, prioritising high-risk locations, and supporting evidence-based decision-making.

1. Data and methodology

The aim of this study is to determine the level of road safety in Lithuania based on the severity of injuries sustained in road accidents. This represents a broader application of the MAIS3+ injury scale, i.e., the determination of injury severity is used not only to describe road accident statistics but also in a wider context, namely, to address tasks related to improving road safety on specific roads.

This study consists of three stages. In the first stage, injury severity is determined using the MAIS3+ injury scale. In the second stage, road accident data are linked with injury severity score data. In the final stage, the network of main roads is classified into safety categories or levels based on the severity of injuries sustained by road users. The main stages of the study are presented in Figure 1.

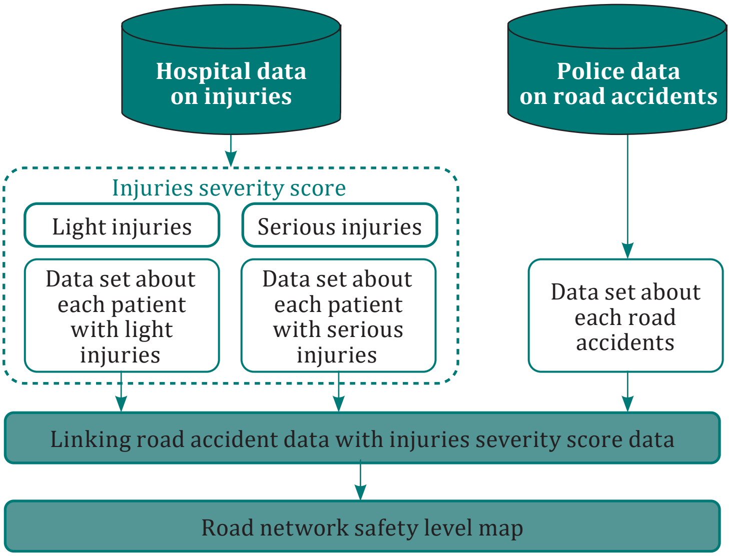

Figure 1. The main stages of the study

1.1. Data sources

The study uses two data sources: 1) hospital data and 2) police data.

The primary source of hospital data is the Hospital Discharge Register (HDR), which includes all hospitalisations due to diseases and injuries from all hospitals in the country. In Lithuania, all hospitals report these data to the Institute of Hygiene, which monitors the health status of the Lithuanian population, oversees healthcare performance indicators, and prepares official medical statistics. Data on road traffic injuries recorded in the HDR (V00-V89) were analysed for the period 2021–2022. The patient dataset contains the following information:

- date of opening/closing of the treatment record;
- date of birth;
- gender;
- type of admission to hospital (by ambulance or other means);
- patient status (alive/deceased);
- date of death or discharge;
- type of treatment (inpatient/emergency department/outpatient);
- external cause codes;
- injury diagnoses: primary diagnosis code and secondary diagnosis codes.

The second data source consists of police-registered road accident data. In most countries, police records represent the primary source of information on road accidents. This dataset includes information on accident circumstances, road users involved, and vehicles. In Lithuania, the Transport Competence Agency is the public institution currently responsible for processing, monitoring, and statistically analysing road accident data. In some cases, the publicly available data from this institution are highly aggregated (e.g., age of road accident participants is presented as ranges, such as 31–40), which creates challenges when linking the data in subsequent stages of the study.

1.2. Methodology

1.2.1. MAIS3+

As mentioned above, in the first stage of the study, injury severity is determined as minor or serious according to the MAIS3+ injury scale. A serious injury is defined as a road accident participant (patient) with a score of 3 or more on the Maximum Abbreviated Injury Scale (MAIS3+). The Abbreviated Injury Scale (AIS) and its derivative, the MAIS (Maximum AIS), constitute an anatomically based, consensus-derived coding system, developed by the Association for the Advancement of Automotive Medicine to classify and describe injury severity. AIS is one of the most common anatomical scales for traumatic injuries and allows injuries to be ranked according to severity. It is a globally accepted trauma classification system that ranges from 1 (minor injury) to 6 (untreatable injury). As an individual may sustain more than one injury, the Maximum Abbreviated Injury Scale (MAIS) represents the highest AIS score among all recorded injury diagnoses for that person (ETSC, 2021). The MAIS score ranges from 1 to 6, with levels 3–6 classified as serious injuries (MAIS3+). An AIS severity code of 9 is used to describe injuries for which insufficient information is available for more detailed coding.

In this study, the MAIS3+ injury scale was applied according to the guidelines established in the European SafetyCube project (Perez et al., 2016, 2019), using hospital data (Figure 2).

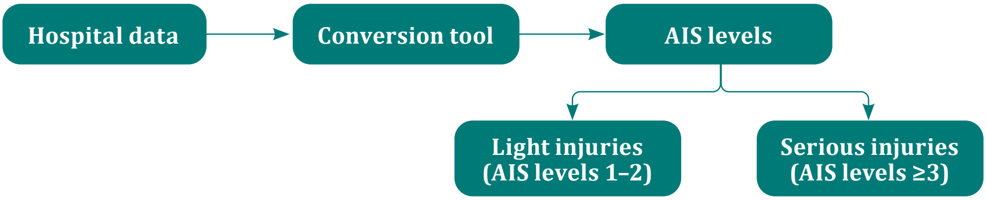

Figure 2. Workflow for classifying road injury severity according to the MAIS3+ injury scale using hospital data

1.2.2. Linking road accident data with injury severity score data

To enable broader use of injury severity data, it is necessary to link these data to specific road traffic accidents. The main benefit of such data linkage is the maximisation of available data sources. Furthermore, this process provides insight into the completeness of both police and hospital data and allows for identification, and potentially the reduction, of selection bias and underreporting (Perez et al., 2016; 2019). Such data linkage makes it possible not only to determine the proportion of serious and minor injuries, but also to:

– conduct a more detailed analysis of road traffic accidents according to selected criteria (e.g., road category, type of accident, etc.);
– assess the safety level of the road network based on injury severity criteria;
– prioritise road traffic safety improvement measures and interventions, etc.

To combine data from different databases, common variables must be available in both datasets. The most accurate method for linking records is using a personal identification number; however, this variable is often unavailable in one or both databases due to data protection and privacy requirements. After analysing the datasets and identifying common variables, the following variables were used in this study to link the records:

– date of the road accident/date of hospitalization;
– location of the road accident/healthcare facility that admitted the road accident victim;
– age (years);
– gender.

1.2.3. Determining the safety level of the road network

The European Commission revised EU Directive 96/2008/CE through the adoption of EU Directive 1936/2019, in which network-wide road safety assessments – one of several road infrastructure safety management procedures – received particular emphasis. In 2023, the Directorate-General for Mobility and Transport of the European Commission published the Network Wide Road Safety Assessment: Methodology and Implementation Handbook to provide the Member States with a methodological framework for conducting effective network-level road safety assessments (Bonera et al., 2024; European Commission et al., 2023). This methodology comprises two assessment approaches: proactive and reactive, resulting in the classification of the road network into five safety classes (European Commission et al., 2023).

The reactive methodology is based on the assessment of road accident data on fatal and injury accidents over at least the previous three years. The methodology indicates that, in the medium to long term, once a common definition of injury severity is applied across the EU, it will be possible to consider only accidents involving serious injuries (MAIS3+) and fatalities. Currently, accident risk is assessed using the standard rate formula (Equation (1)):

$$AR = \frac{N \times 10^6}{365.25 \times AADT \times y \times L}, \quad (1)$$

where:
N – number of accidents on the road or road section during the analysis period;
$AADT$ – average annual daily traffic on the road or road section, vehicles/day;
y – analysis period, years;
L – length of the road or road section, km.

In this study, a pilot accident rate calculation was performed (Equation (2)), incorporating injury severity as determined according to the MAIS3+ injury scale. For this purpose, weighting factors were introduced: 5 for fatal road accidents; 3 for accidents with serious injuries; and 1 for accidents involving minor injuries. These weighting factors are applied in Lithuania and are established in national legal acts regulating the procedure for conducting network-wide road safety assessments (Transport Competence Agency, 2022).

$$AR = \frac{(N_f \times w_f) + (N_s \times w_s) + (N_l \times w_l) \times 10^6}{365.25 \times AADT \times y \times L}, \tag{2}$$

where:
N_f – number of fatal accidents on the road or road section during the analysis period;
N_s – number of accidents involving serious injuries on the road or road section during the analysis period;
N_l – number of accidents involving minor injuries on the road or road section during the analysis period;
w_f – weighting factor for fatal accidents (5);
w_s – weighting factor for accidents involving serious injuries (3);
w_l – weighting factor for accidents involving minor injuries (1);
$AADT$ – average annual daily traffic on the road or road section, vehicles/day;
y – analysis period, years;
L – length of the road or road section, km.

The calculation of the accident rate enables the assessment of road traffic accident risk on a specific section, taking into account the number of recorded accidents, the severity of their consequences, and traffic intensity. The accident rate thus becomes an important component of the analytical framework, supporting data-driven decision-making to reduce the number of road traffic accidents and mitigate their consequences.

2. Results

To demonstrate the applicability of the MAIS3+ injury scale results in a broader context, data on serious and minor injuries were used to classify Lithuanian main roads into road safety categories.

The main road network in Lithuania consists of 21 roads with a total length of 1751.29 km. Those roads carry the highest traffic volumes in the country. The average annual daily traffic on these roads ranges from approximately 4000 to 24 000 vehicles per day, and the road traffic accident density is 0.622 accidents per kilometre.

In this study, two primary data sources were used: the police registers and data from the Institute of Hygiene, which collect information on road accidents and injured persons, respectively. Injury data collected by the Institute of Hygiene were used to assess the severity of road-user injuries using the MAIS3+ injury scale (Figure 2), while police data were used to link individual injuries to specific road accidents. This approach enables: (i) a more detailed analysis of road accident statistics than is typically possible, and (ii) the use of these data in a broader context to address road safety issues (e.g., determining safety levels on various roads). It is important to note that this is the first time in Lithuania that data from these sources have been used in such a context, and that the primary purposes for which these datasets are collected differ significantly. Therefore, the identification of significant discrepancies between the datasets is not unexpected.

The Institute of Hygiene was found to record significantly more injuries than the police (see Table 1). Discrepancies between the datasets may be related to the fact that certain injuries are not documented at the time of the accident or immediately thereafter, as some road users do not report the accident to the police. An accident participant may seek medical attention later, when symptoms become more pronounced or more discomforting. In such cases, the accident is not reported to the police and, therefore, is not officially registered or included in police statistics. However, the fact that medical assistance is sought indicates that these injuries are captured in the healthcare statistics of the Institute of Hygiene. Such cases highlight the importance of institutional data integration and the need to improve mechanisms for recording road traffic accidents and associated injuries.

Table 1. Data from the Institute of Hygiene and police on road users injured in road accidents, 2021–2022

	Data from the Institute of Hygiene	Police data
2021	7128	3211
2022	7735	3375

For further calculations, the required hospital dataset was compiled. In the first stage of dataset preparation, only injuries sustained in road traffic accidents were selected. For this purpose, the ICD-10 variable “External causes of morbidity and mortality” was used (codes V00–V89, covering road traffic accidents). It should be noted that the V00–V89 code range consists of 9 code groups (Figure 3). According to the results of this study, the largest proportion of injuries falls within the groups V40–V49 “Car occupant injured in road accident” and V10–V19 “Pedal cyclist injured in road accident”, accounting for 34.78% and 33.90% of all injuries, respectively (Figure 3).

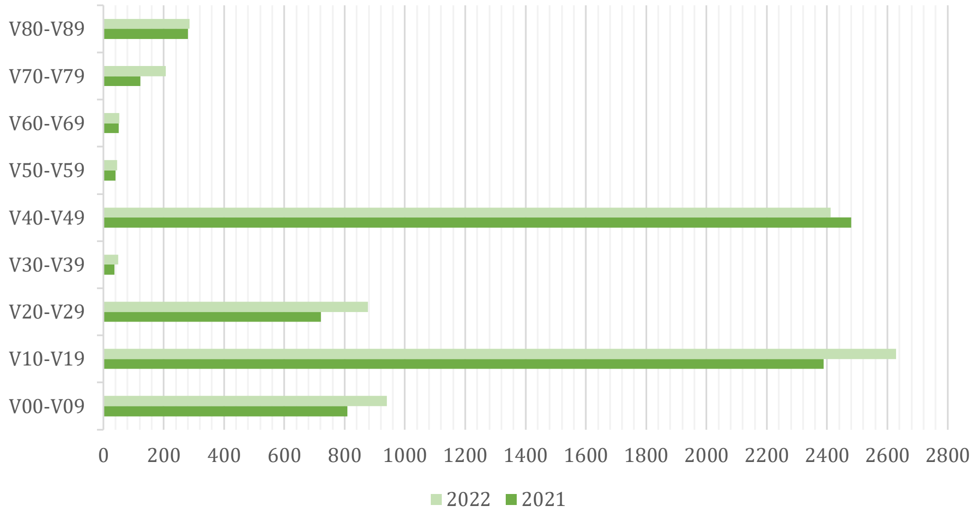

Figure 3. Number of injuries by ICD-10 external cause code groups

In the second stage, ICD-10 diagnosis codes were converted to AIS codes. This process was carried out using a conversion tool developed by the Association for the Advancement of Automotive Medicine (AAAM) for the European Commission. It is the official tool recommended and freely distributed by the DG MOVE (Directorate-General for Mobility and Transport) of the European Commission. The conversion from ICD codes to AIS codes is performed using mapping tables. In the case of ICD-10 classification mapping, the table contains 16 508 records. Of these:

- 2323 diagnoses are classified as serious injuries (e.g., S06.33 Contusion and laceration of the cerebrum, unspecified);
- 9700 as minor injuries (e.g., S01.1 Open wound of the eyelid and periocular area); and
- 4485 as injuries of unknown severity (e.g., S00.35 Superficial foreign body of the nose) where it cannot be determined whether the injury is minor or serious.

The results of the conversion are presented in Figure 4. According to the Institute of Hygiene, not all participants in road traffic accidents were assigned injury diagnosis codes. In 2021, injury codes were not assigned to three road users, and in 2022, this number increased to 21. Additionally, cases assigned AIS code 9 (“unknown”) should be noted, as it is not possible to determine whether these injuries are serious or minor. In 2021, 164 such cases were recorded, while in 2022, this number decreased to 144.

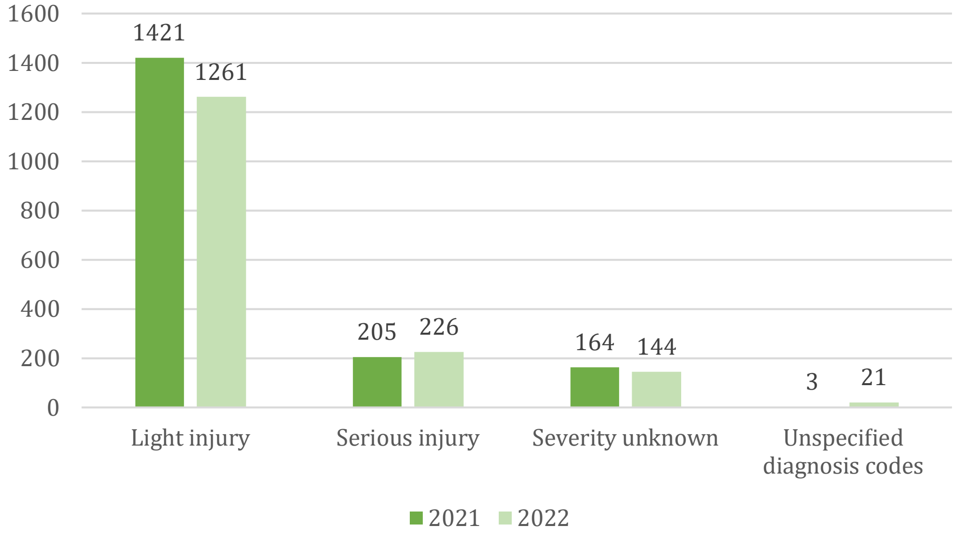

Figure 4. Results of the conversion of injuries into serious and minor injury categories

After completing these steps, the stage of determining injury severity could be considered finalized. However, to enable broader application of these data in road safety engineering, it is necessary to link each injury to a specific road traffic accident. Therefore, in the third stage, the injuries identified in the second stage are merged with road traffic accident data based on predefined criteria. As mentioned in Subsection 1.2.2, the following variables are used to link the records:

– date of the road accident/date of hospitalization;
– location of the road accident/healthcare facility that admitted the road accident victim;
– age (years);
– gender.

Although data from 2021 and 2022 were analysed in this study, only 2022 data were used during data linkage. This decision was necessitated by changes in the structure of publicly available road traffic accident data in Lithuania introduced in 2022. One change relevant to this study is that publicly available reports no longer contain information on the gender of road users involved in traffic accidents. Furthermore, instead of reporting the exact age of road users, as in previous datasets, age is now presented in eight predefined groups: 0–6, 7–17, 18–25, 26–35, 36–45, 46–54, 55–64 and 65 years and older. As a result, it was not possible to link traffic accidents with injury data for 2022 using the predefined linkage variables.

Given these constraints and acknowledging that a one-year dataset does not capture interannual variability, the results obtained should be interpreted as a methodological demonstration rather than a fully representative safety assessment.

At this stage, using 2021 data, it was possible to link the records of 1119 road users who were registered by both the Police and the Institute of Hygiene as having been involved in road traffic accidents. This accounts for 62.44% of all analysed cases. It should be noted that this result is relatively strong, given that, to date, no systematic mechanism has been established in Lithuania for determining injury severity level. The available data have not been systematically analysed, the relevant legal framework has not been comprehensively reviewed, and no fully standardised or integrated databases or formalised procedures have been established to enable data linkage across institutions. Consequently, this pilot data-linkage exercise highlights existing gaps in data collection and integration. The findings may therefore serve as a basis for improving data collection practices within both the Police and the Institute of Hygiene. Furthermore, the literature analysis shows that even in countries where the MAIS3+ injury scale has been applied for several years and unified personal identifiers are used for data linkage, matching rates of approximately 80% are typically achieved (Folla et al., 2019; Howard & Linder, 2014; Nunn et al., 2018).

In the final stage of the study, the safety level of the road network was evaluated according to the severity of road accidents. The equal interval method (Li & Shan, 2022) was applied to classify road sections, in which the full range of accident rates was divided into five equal-width intervals (Equation (3)). This approach provides a transparent, objective, and reproducible framework for assessing the safety of road sections and enables consistent comparison of accident levels across the full range of observed values. Such classification is particularly appropriate when the accident rate is used as a relative indicator, no universally accepted critical threshold values exist, and the assessment aims to support the identification of high-risk sections, priority setting, or strategic planning.

$$\text{Interval width} = \frac{AR_{\max} - AR_{\min}}{k}, \quad (3)$$

where:
$AR_{\max}$ – maximum accident rate value;
$AR_{\min}$ – minimum accident rate value;
k – number of selected classes (in this case – 5).

The calculated accident rates for the analysed main roads ranged from 0 to 0.56. To ensure an objective assessment of road safety, accident rates were classified into five categories using interval thresholds derived from the equal-interval method. Each category was assigned a corresponding safety class, ranging from 1 (very safe roads) to 5 (very dangerous roads). For example, roads with an accident rate not exceeding 0.11 are classified as very safe, whereas those with rates between 0.48 and 0.56 are classified as very dangerous. This classification enables a systematic assessment of road conditions and supports the prioritization of safety improvement measures (see Table 2).

Table 2. Classification of road safety classes by accident rate

Road Safety classes		Accident rate	
		from	to
1	Very high safety roads	0.0	0.11
2	High safety roads	0.12	0.23
3	Medium safety roads	0.24	0.35
4	Low safety roads	0.36	0.47
5	Very low safety roads	0.48	0.56

Following a comprehensive analysis of accident indicators, each of Lithuania's national highways was assigned to one of five road safety classes. This classification was based on AIS injury scores, the number of fatalities, average annual daily traffic (AADT), road length, and the calculated accident rate. Figure 5 presents a map of Lithuania's national highways categorised by the calculated accident rate and corresponding safety classes (1–5). On the map, the classes are distinguished by different colours, ranging from green (Class 1 – safest) to red (Class 5 – most hazardous). Table 3 presents the distribution of the main roads by safety class.

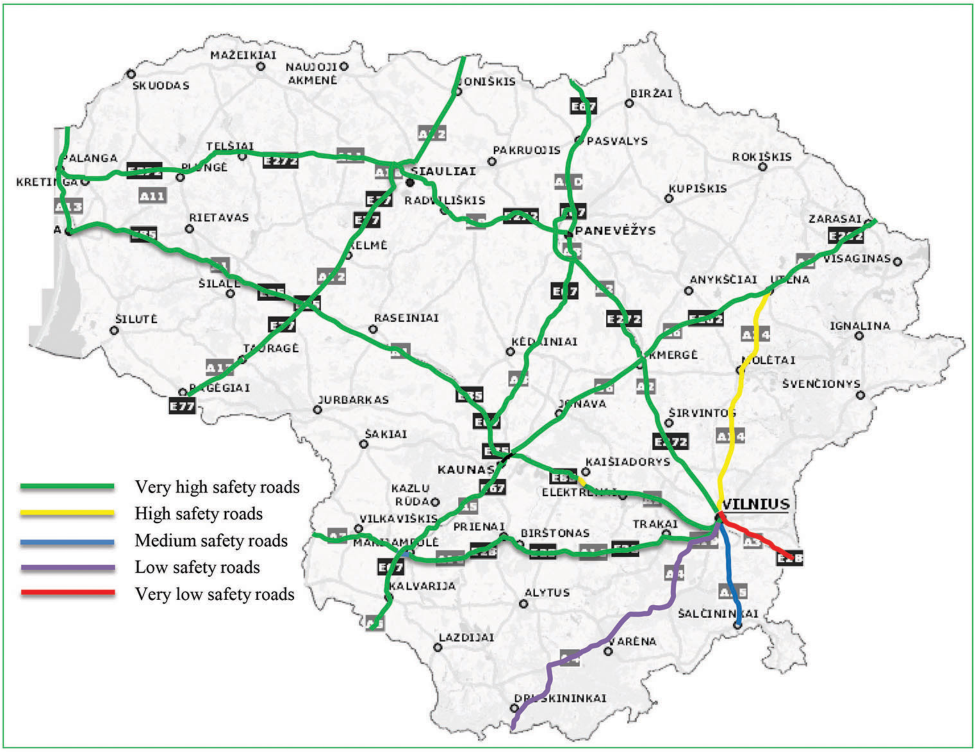

Figure 5. Map of accident rate classification for national highways (Mikavičienė, 2025)

Table 3. Distribution of road safety classes by total road length

Road Safety classes		Length, km	%
1	Very high safety roads	1461.193	83.44
2	High safety roads	85.002	4.85
3	Medium safety roads	38.212	2.18
4	Low safety roads	140.588	8.03
5	Very low safety roads	26.262	1.50
Total:		1751.257	100.00

The results presented in Table 3 indicate that 83.44% of Lithuanian main roads are classified as very high safety roads; however, these findings warrant further discussion.

First, it should be noted that the calculations were based on only one year of road accident data (the reasons for not using a larger data sample are discussed above).

A single-year dataset may not adequately capture the actual safety performance of road networks. Consequently, this study is primarily designed to demonstrate the proposed methodology, assess the quality of the recorded data, and identify the existing data limitations.

Second, it should be emphasised that the analysis was limited to Lithuanian main roads, which accounted for approximately 24% of all road accidents recorded in Lithuania in 2021. Furthermore, the accident rate calculation is based on the number of traffic accidents and the severity of their outcomes, rather than on the absolute number of fatalities or injured persons. Official accident statistics indicate that fewer traffic accidents were recorded on Lithuanian main roads in 2021 than the average for 2018–2020.

In summary, this study demonstrates that the MAIS3+ injury scale can be applied beyond its conventional use in road safety statistics, extending to broader road safety engineering and network assessment tasks. However, the results should not be interpreted as a defensive evaluation of Lithuania's main roads, as more precise assessments require higher-quality data and a longer observation period. The limitations related to data quality and availability were discussed in a previous section of the paper.

Conclusions and Recommendations

1. Reducing not only fatalities but also serious injuries in road traffic accidents is essential, as severe non-fatal injuries impose substantial social and economic impact, including long-term healthcare costs, productivity losses, and reduced quality of life. Therefore, comprehensive road safety strategies should address both fatality reduction and serious injury prevention to achieve a more holistic improvement in road safety outcomes.
2. In the experimental study, national roads were classified into five road safety categories based on the calculated accident rate and the assessment of injury severity. This classification enabled the identification of roads associated with the most severe road accidents and those requiring additional safety measures.
3. The study revealed that the implementation of the MAIS3+ injury scale in Lithuania is restricted by an undeveloped data infrastructure. To apply this methodology at the national level, it is necessary to enhance data collection systems, strengthen interinstitutional cooperation, and ensure compatibility with international data standards. Effective implementation of the MAIS3+ injury scale also requires the development of a standardised methodology that clearly defines procedures for data collection, analysis, and interpretation, thereby ensuring compliance with EU legislation.

Statement of the use of generative AI and AI-assisted technologies in the writing process

The authors did not use generative AI or AI-assisted technologies in the writing process.

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