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MAPPING ROAD CRASH SEVERITY: GIS-BASED NETWORK SCREENING OF STATE ROADS IN VOJVODINA, SERBIA

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Abstract: Effective road safety management requires transparent methods for identifying locations where limited resources can achieve the greatest benefit. This study develops a map-centred, severity-weighted GIS framework for screening state-road sections and critical microlocations in the Autonomous Province of Vojvodina, Serbia. The analysis covered 34,212 police-recorded crashes during 2019–2023, of which 18,723 crashes located on state roads were assigned to 589 predefined sections. Crash consequences were evaluated using the Severity-Weighted Casualty Index (SWCI), with weights of 1, 13 and 99 assigned to slightly injured, seriously injured and fatally injured persons, respectively. Geocoded crashes, section-level scores and critical intersections were processed and mapped in ArcGIS Pro. The maps revealed a network-constrained distribution of crashes and geographically selective concentrations of severe outcomes in western and central Bačka, the Novi Sad–Temerin area, approaches to Zrenjanin and the Pančevo region. The ten highest-ranked sections recorded SWCI values between 610 and 923, with a mean of 757.9 and a median of 773.5. The highest value was recorded on the IB-10 section of the Pančevo–Alibunar corridor. At the microlocation level, the leading site recorded an SWCI of 222 and exceeded the second-ranked site by 69.5%, while the four highest-ranked sites accounted for 68.8% of the total SWCI among the ten selected microlocations. The differences between section- and microlocation-level patterns demonstrate the value of combining corridor and site-specific screening. Although the SWCI represents observed casualty burden rather than exposure-normalised risk, the proposed framework provides a reproducible basis for prioritising field inspections, engineering diagnosis and subsequent road safety interventions.

Keywords: Road safety; GIS; Network screening; Crash severity; Severity-weighted casualty index; Critical road sections; Vojvodina

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1. INTRODUCTION

Road safety management increasingly recognises that human error cannot be completely eliminated and that roads should therefore be designed, maintained and managed so that foreseeable mistakes are less likely to result in fatal or serious injuries. Road geometry, roadside conditions, visibility, traffic control and the surrounding environment influence operating speeds, conflict patterns, driver expectations and crash severity, making infrastructure improvement and the development of forgiving roads essential parts of a comprehensive safety strategy (AASHTO, 2010; Elvik, 2008; European Parliament and Council, 2019). For road authorities, however, identifying locations requiring intervention is also a resource-allocation problem because the number of potentially unsafe sections and intersections greatly exceeds the available financial, technical and organisational capacity. Network screening addresses this problem by reducing the road system to a manageable set of locations requiring further investigation. Hauer (1996) described such locations as "sites with promise", emphasising that a high historical crash count alone does not necessarily indicate the greatest potential for safety improvement. The selected ranking method can therefore substantially affect which locations receive priority (Cheng et al., 2005; Montella, 2010; Persaud et al., 1999).

Traffic crashes are not uniformly distributed across a road network but tend to concentrate on particular corridors, sections, intersections and other microlocations because traffic exposure, operating speeds, geometry, roadside conditions, land use and traffic-control characteristics vary spatially. Conventional tables and administrative summaries describe the overall magnitude of the problem but may conceal local concentrations and relationships between neighbouring locations. GIS enables crash records to be integrated with digital road-network data and examined as geographically referenced observations, while maps support geocoding control, reveal corridor continuity and facilitate comparison between road sections (O'Sullivan et al., 2003; Thomas, 1996). Spatial maps should therefore be regarded as analytical outputs rather than illustrations. Kernel density estimation and local spatial statistics can reveal concentrations that are difficult to recognise when thousands of crash points overlap, although conventional planar methods may incorrectly smooth values across physically disconnected roads. Network-based approaches address this limitation by constraining the analysis to the transport network and are consequently more appropriate for events occurring along linear road systems (Flahaut et al., 2003; Mohaymany et al., 2013; Xie et al., 2008). Nevertheless, hotspot locations remain dependent on the analytical method, spatial scale and evaluation criterion applied (Cheng et al., 2005; Thakali et al., 2015).

The choice of safety indicator is equally important. Ranking locations only by crash frequency assigns the same importance to events with substantially different consequences and may prioritise a section with numerous slight-injury crashes over one with fewer crashes but fatal or serious outcomes. Severity-weighted indicators address this limitation by converting casualty outcomes into a common value and assigning progressively greater importance to slight injuries, serious injuries and fatalities. This principle is consistent with consequence-sensitive approaches such as the Equivalent Property Damage Only method and enables the identification of locations where the human consequences are high even when crash frequency is not among the largest (AASHTO, 2010; Alam et al., 2023; Zahran et al., 2021). However, severity-weighted values must be interpreted as measures of the observed casualty burden rather than exposure-normalised risk. Without traffic volume, section length or another measure of exposure, they do not estimate the probability that an individual road user will be involved in a crash. Historical rankings may also be affected by random variation and regression to the mean, particularly when locations are selected after an unusually severe period. Where detailed traffic and roadway data are available, safety performance functions and Empirical Bayes methods provide more reliable

estimates by combining site-specific crash histories with the expected performance of comparable facilities (Hauer, 1996; Persaud et al., 1999). Severity-weighted GIS mapping should therefore be treated as a transparent first-stage screening procedure rather than a substitute for exposure-based modelling, field inspection or engineering diagnosis.

The spatial unit selected for screening also affects both the ranking and its practical interpretation. Different segment lengths and microlocation definitions can split one crash concentration or combine separate problems, thereby producing different hotspot configurations (Thomas, 1996; Montella, 2010; Zahran et al., 2021). Road-section analysis is suitable for identifying corridor-level patterns and supporting investigations of alignment, operating speed, roadside hazards, access density and general infrastructure condition. Microlocation analysis focuses on intersections, junctions, access points and other spatially restricted environments where crashes may be associated with particular conflicts, visibility limitations or traffic-control arrangements. Applying both levels creates a more complete screening framework: section-level mapping identifies broader parts of the network with an elevated severity burden, whereas microlocation analysis isolates specific sites requiring detailed examination. A high-scoring section containing a critical microlocation may require both a local junction study and a wider corridor assessment, while a high-scoring microlocation located on a moderately ranked section should not be overlooked because aggregation can dilute a sharply concentrated local problem.

Accordingly, this study aims to identify and spatially represent state-road sections and critical microlocations with the greatest recorded severity burden in Vojvodina during 2019–2023. Geocoded crash records were integrated with 589 predefined state-road sections and evaluated using a severity-weighted casualty indicator that assigns progressively greater importance to slightly injured, seriously injured and fatally injured persons. The analysis maps the distribution of crashes on the state-road network, calculates and classifies severity-weighted values for individual sections, ranks the ten sections with the highest values and identifies critical intersections and other microlocations requiring detailed safety investigation. The principal contribution is a transparent, map-centred screening framework that connects individual crash records, casualty severity and official road units with clearly defined spatial priorities. By combining section- and microlocation-level results, the approach provides road authorities with an operational basis for selecting locations for field inspection, engineering diagnosis and subsequent road safety intervention while maintaining a clear distinction between observed severity burden and statistically estimated crash risk.

2. METHODOLOGY

2.1. Study area and data

A retrospective GIS-based network screening study was conducted for the state-road network of the Autonomous Province of Vojvodina, northern Serbia. Vojvodina is a predominantly lowland region crossed by a hierarchically organised network of class IA, IB, IIA and IIB state roads. The network connects major urban centres, agricultural areas, industrial zones and international transport corridors and includes road sections with different traffic functions and operating conditions. The observation period covered five complete calendar years, from 1 January 2019 to 31 December 2023.

Crash data were obtained from the Road Traffic Safety Agency of the Republic of Serbia. The Agency's integrated database contains police-recorded information on crashes, participants, vehicles, casualty consequences and geocoded crash locations, together with identifiers from the official state-road reference system (Road Traffic Safety Agency of the Republic of Serbia, 2026). The initial regional database contained 34,212 reported crashes of all types. The records

were subsequently filtered according to their association with the state-road network. Following spatial assignment and data-quality control, 18,723 crashes located on state roads were retained for the network screening analysis. Crashes that occurred on local roads, urban streets not belonging to the state-road network or other transport surfaces outside the defined study network were not included in the section-level analysis.

The digital state-road network was represented by 589 predefined analysis sections. Each section was associated with a unique road and section identifier, road category, spatial geometry and corresponding start and end nodes. The use of predefined road sections ensured compatibility between the crash database, the official state-road reference system and the resulting priority list. However, because the definition and length of spatial units can influence aggregated crash values, the section-based results were interpreted as network-screening indicators rather than as estimates independent of the selected spatial segmentation (Thomas, 1996).

Spatial data preparation and analysis were performed in ArcGIS Pro (Esri, Redlands, California, USA). Source crash-point coordinates were stored in the World Geodetic System 1984 coordinate reference system (WGS 84; EPSG:4326). The Agency's public Web GIS service displays spatial data in WGS 84 Web Mercator Auxiliary Sphere (EPSG:3857). Source coordinates were retained in WGS 84 for data exchange, tabular presentation and reporting, while ArcGIS Pro handled coordinate transformations, map projection and spatial processing. The GIS workflow included harmonisation of road and crash attributes, verification of coordinate validity, comparison of crash locations with the state-road network, spatial assignment of crashes to road sections and visual plausibility checks. GIS-based visual inspection was used to identify records positioned outside the expected road environment and to verify the consistency of the spatial join. The use of GIS for integrating crash points with a linear road network is consistent with established spatial road safety applications (Anderson, 2009; Mohaymany et al., 2013; O'Sullivan & Unwin, 2003).

The spatial assignment linked each eligible crash point to the corresponding state-road section. Crash records and casualty outcomes were then aggregated for each of the 589 sections over the complete five-year observation period. All years were assigned equal importance, and no temporal weighting was applied. For each section, the aggregated database contained the total number of crashes and the numbers of slightly injured persons, seriously injured persons and fatalities. The unit used in the severity calculation was the number of casualties, rather than the number of crashes containing a particular casualty category. Consequently, a crash involving multiple injured or killed persons contributed the corresponding number of casualties to the section total.

Figure 1 presents the spatial distribution of the 18,723 geocoded crashes assigned to the state-road network. The point map was used both as an analytical representation of crash concentration and as a visual quality-control layer. Although point mapping preserves the original crash locations, areas with a large number of overlapping observations can be difficult to interpret. The subsequent section-level aggregation was therefore used to transform individual crash points into comparable network units. This approach provides a direct connection between the spatial distribution of recorded crashes and the road sections that can be subjected to detailed inspection and treatment planning (Flahaut et al., 2003; Zahran et al., 2021).

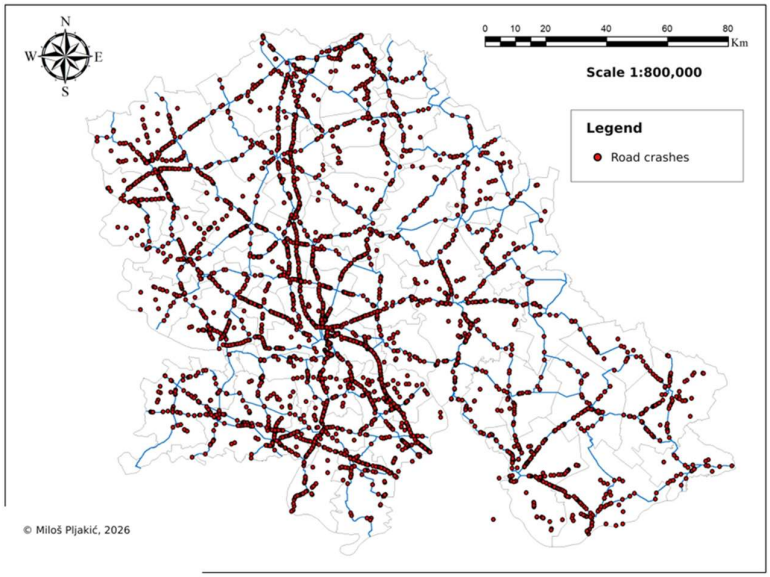


Fig. 1. Geocoded crashes on the state-road network of Vojvodina, 2019–2023.

To account for differences in the severity of casualty outcomes, a Severity-Weighted Casualty Index (SWCI) was calculated for each road section. The indicator followed the severity-weighting procedure applied in the source study and assigned weights of 1, 13 and 99 to slightly injured persons, seriously injured persons and fatalities, respectively. For a road section (s), the SWCI was calculated as:

$$SWCI(s) = \sum c \in s\,[SI(c) + 13 \cdot SEI(c) + 99 \cdot FAT(c)] \quad (1)$$

where:

- $SWCI_s$ – the Severity-Weighted Casualty Index for section s;
- c – an individual crash assigned to section s;
- SI – the number of slightly injured persons in crash c;
- SEI – the number of seriously injured persons in crash c; and
- FAT – the number of fatalities in crash c.

The weights reflect the relative severity of casualty outcomes: a serious injury contributes 13 times and a fatality 99 times the value of a slight injury, while crashes without casualties contribute zero. This approach prioritises sections with severe outcomes even when crash counts are relatively low, consistent with severity-weighted network screening methods (AASHTO, 2010; Alam & Tabassum, 2023).

The SWCI is a dimensionless, additive screening indicator of cumulative severity and should not be interpreted as a crash rate or individual risk measure because traffic exposure and section length were not included. It was therefore used only for initial prioritisation, recognising that observed rankings may be affected by exposure differences, random variation and regression to the mean (Hauer, 1996; Persaud et al., 1999).

All 589 sections were ranked by SWCI and mapped in five predefined classes: 0–63, 63.1–173, 173.1–319, 319.1–547 and 547.1–923, using a green-to-red scale. These fixed classes reproduce the source analysis and were not statistically optimised. Continuous values and ranks were retained because sections near class boundaries may have similar severity levels.

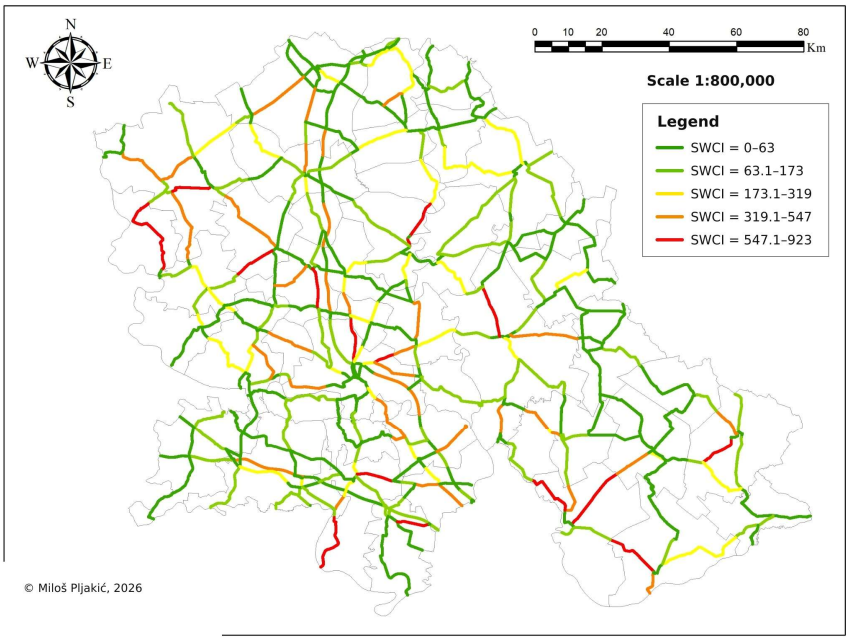


Fig. 2. Severity-Weighted Casualty Index (SWCI) by state-road section. © Miloš Pljakić, 2026.

Figure 2 shows the spatial distribution of severity-weighted risk across the state-road network. It was used to identify high-value corridors and compare neighbouring sections. The ten sections with the highest SWCI values were selected for detailed investigation. However, the ranking indicates screening priorities rather than causal differences in safety and should be followed by statistical validation and site investigation (Cheng & Washington, 2005; Montella, 2010; Persaud et al., 1999).

Critical intersections and other microlocations were assessed using the same casualty weights of 1, 13 and 99. The predefined microlocations were ranked by SWCI, and the ten highest-ranked sites were retained. Their WGS 84 coordinates were reported to support field inspection and integration with road-infrastructure data.

The analysis was descriptive and screening-oriented; no inferential tests, safety performance functions or Empirical Bayes adjustments were applied. The maps therefore represent the observed severity burden during 2019–2023 and identify locations requiring further investigation. Final intervention decisions should also consider field observations, traffic exposure, crash characteristics, road-user groups, road geometry and operating conditions.

3. RESULTS

3.1. Spatial pattern of crashes and severity

The crash map reveals a network-constrained pattern rather than an even regional distribution. Dense, nearly continuous chains of crash points follow the main north–south and east–west corridors, with particularly visible concentrations around Novi Sad and the southern urban belt, and along the approaches to Sombor, Zrenjanin, Pančevo and the northern border area. Sparse interior spaces largely correspond to areas outside the main state-road alignments. This pattern confirms that administrative aggregation alone would conceal the corridor structure relevant to engineering action.

The severity-weighted map changes the emphasis from where crashes are numerous to where casualty consequences are most burdensome. Most of the network remains in the two green classes, but yellow and orange links form discontinuous corridor clusters. The highest red class is spatially selective and appears on isolated links in western Vojvodina, central Bačka, the Novi Sad–Temerin area, north of Zrenjanin and southeast of Pančevo. This fragmentation is operationally important: it favours targeted diagnosis of individual sections while also indicating several corridors where neighbouring links require coordinated review.

3.2. Highest-ranked road sections

All ten leading sections fall in the highest map class. Their SWCI values range from 610 to 923, with a mean of 757,9 and a median of 773,5. The first-ranked IB-10 section is 51,3% above the tenth-ranked IB-21 section, yet the top five remain comparatively close (796–923). The ranking therefore does not indicate one isolated problem only; it identifies a portfolio of corridors with similarly elevated severity burdens. Four of the ten are class IB roads, five are class IIA roads and one is a class IIB road.

Table 1. Ten highest-ranked state-road sections, 2019–2023.

Rank	Road / section	Section or corridor	SWCI
1	IB-10 / 01001	Pančevo–Alibunar corridor	923
2	IIA-107 / 10701	Sombor–Apatin–Bogojevo corridor	873
3	IB-14 / 01401	Pančevo–Kovin–Bela Crkva corridor	808
4	IIA-113 / 11302	Vrbas–Zmajevo	803
5	IIA-100 / 10015	Sirig–Temerin–Novi Sad approach	796
6	IIA-131 / 13101	Čenta–Jabučki Rit	751
7	IB-13 / 01311	Melenci–Zrenjanin	719
8	IIA-110 / 11001	Kula–Odžaci/Ratkovo	669
9	IIB-318 / 31801	Prhovo–Šimanovci interchange	627
10	IB-21 / 02137	Hrtkovci–AP boundary toward Šabac	610

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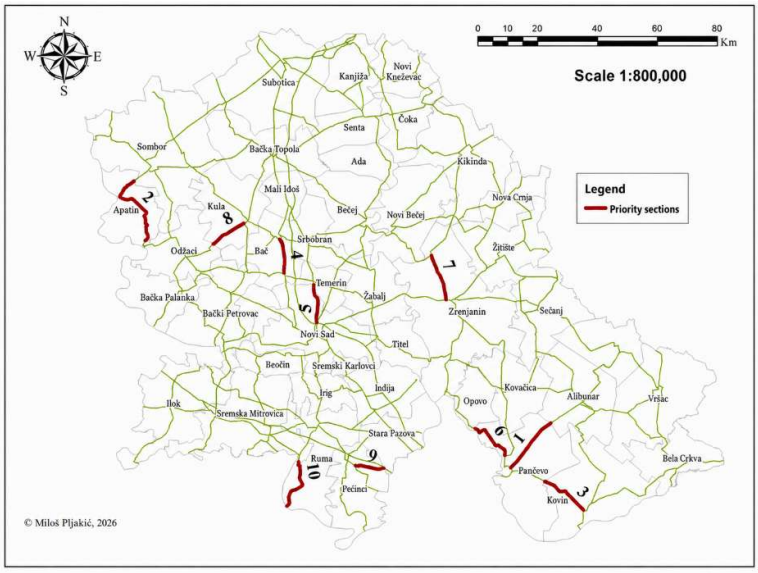
ranking therefore does not indicate one isolated problem only; it identifies a portfolio of corridors with similarly elevated severity burdens. Four of the ten are class IB roads, five are class IIA roads and one is a class IIB road.

3.3. Critical intersections and microlocations

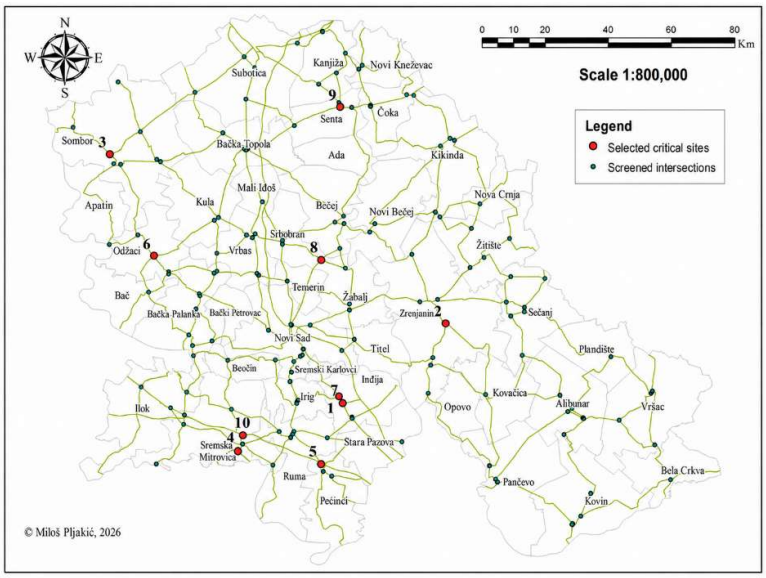
The critical-site distribution is more concentrated than the section ranking. The leading IIA-100 microlocation scored 222, which is 69,5% above the second-ranked IB-13 site and represents 26,3% of the cumulative SWCI of the ten listed sites. The first four sites together account for 68,8% of that top-ten total. Two distinct sites occur on IIA-100, two on IB-12 and two on IIA-102, indicating that route-level repetition can coexist with sharply localised severity peaks.

Table 2. Ten highest-ranked critical microlocations (coordinates in WGS 84, EPSG:4326).

Rank	Road	Route context	Longitude	Latitude	SWCI
1	IIA-100	Novi Sad–Sremski Karlovci–Inđija	20,02654	45,10986	222
2	IB-13	Zrenjanin–Čenta	20,45507	45,32032	131
3	IB-12	Subotica–Sombor	19,08021	45,78622	116
4	IB-20	Sremska Mitrovica–Bogatić	19,62261	44,95132	111
5	IIA-120	Ruma–Pećinci	19,95747	44,91750	88
6	IIA-110	Kula–Odžaci	19,27069	45,50028	48
7	IIA-100	Novi Sad–Sremski Karlovci–Inđija	20,04069	45,09158	43
8	IIA-102	Bečej–Temerin	19,94987	45,49706	29
9	IIA-102	Bačka Topola–Senta	20,01784	45,93165	28
10	IB-12	A3 connection–Sremska Mitrovica	19,64149	44,99526	27



(a) ten highest-ranked road sections



(b) ten critical intersections/microlocations

Fig. 3. Priority locations: (a) ten highest-ranked road sections; (b) ten critical intersections/microlocations.

Figure 3 provides the spatial bridge between Tables 1 and 2. The highest-ranked sections are distributed across the province, whereas the critical sites form several recognisable groups: the Sremska Mitrovica–Inđija belt, the Novi Sad–Temerin area, western Bačka, the Zrenjanin approach and northern Bačka. The map thus supports both site-specific inspection and corridor-level coordination. Numbers on the maps correspond to the ranks in Tables 1 and 2.

4. DISCUSSION AND CONCLUSIONS

This study demonstrates that severity-weighted GIS mapping can transform a large regional crash database into a transparent and operationally useful network-screening system. Of the 34,212 crashes recorded in Vojvodina during 2019–2023, 18,723 crashes located on state roads were assigned to 589 predefined sections. The comparison of the resulting maps shows that crash concentration and casualty severity do not necessarily produce the same spatial priorities. While the crash-point map is dominated by major corridors and the Novi Sad metropolitan area, the SWCI map identifies a smaller and geographically more selective group of sections with the greatest recorded severity burden. This distinction confirms that crash frequency alone may underrepresent locations where fewer crashes resulted in disproportionately serious consequences.

The highest SWCI values were distributed across western and central Bačka, the Temerin–Novi Sad area, approaches to Zrenjanin and the Pančevo region. Although these priorities are geographically dispersed, several locations form recognisable corridor groups, indicating the need for both province-wide screening and coordinated corridor-level investigation. The first-ranked IB-10 section recorded an SWCI of 923, while the remaining leading sections had relatively similar values. The top ten sections had a mean SWCI of 757.9 and a median of 773.5,

and the difference between the first- and fifth-ranked sections was only 15.9%. Consequently, the results should not be interpreted as identifying a single "worst road"; instead, they support the parallel investigation of several sections with similarly high observed burdens.

A different pattern was found at microlocation level. The leading IIA-100 site had an SWCI of 222 and exceeded the second-ranked location by 69.5%, while the first four microlocations accounted for 68.8% of the total SWCI of the ten selected sites. This concentration supports a more sequential inspection programme in which the highest-ranked microlocations receive immediate attention. The difference between the section and microlocation distributions also confirms that these two analytical scales are complementary. A high-scoring section containing a critical microlocation may indicate that a substantial share of the burden is concentrated at a junction or other specific road feature. In contrast, a high-scoring section without a dominant microlocation suggests a more dispersed problem requiring corridor-wide examination of speed, alignment, roadside conditions, overtaking opportunities and access points.

The adopted weights of 1, 13 and 99 ensure that fatal and serious outcomes have substantially greater influence than slight injuries. This approach shifts attention from the number of recorded events towards their human consequences and is consistent with severity-sensitive hotspot screening described in the literature (Alam et al., 2023; Zahran et al., 2021). The main advantage of the SWCI is its transparency: each section score can be reproduced from three casualty counts and the predefined coefficients. However, the weights represent a methodological and policy choice rather than universal values. Alternative casualty-cost or public-health weights could change the ranking, particularly where section scores are close. Sensitivity analysis should therefore be used in future applications to determine whether the leading locations remain stable under different defensible weighting schemes.

The findings are also consistent with studies showing that hotspot identification depends on the selected indicator, spatial unit and analytical method (Cheng et al., 2005; Montella, 2010). Count-based, rate-based, spatial and model-based procedures may identify different locations because they represent different dimensions of road safety. The section-based approach used here provides direct compatibility with the official road-reference system and facilitates field inspection, treatment planning and monitoring. Nevertheless, network-based spatial methods could complement the present screening by testing whether visually identified corridor concentrations represent statistically meaningful clusters rather than a consequence of the selected section boundaries (Flahaut et al., 2003; Mohaymany et al., 2013; Pljakić, 2020).

The maps should be treated as the starting point for diagnosis, not as evidence of a causal mechanism or an automatic treatment order. High SWCI values may reflect traffic exposure, operating speeds, roadside severity, road geometry, junction density, traffic composition, vulnerable-road-user presence, emergency response or combinations of these factors. Accordingly, the selected sections and microlocations should be examined through multidisciplinary field inspections integrating collision diagrams, casualty composition, traffic volumes, operating speeds, road and junction geometry, visibility, signs, markings, roadside hazards and road-user behaviour. The GIS database can then connect each priority location with photographs, diagnosed deficiencies, recommended measures, responsible institutions, estimated costs and implementation status.

Several limitations must be considered. The SWCI is a dimensionless and additive measure of observed casualty burden, not an exposure-normalised crash rate or an estimate of individual crash probability. Traffic volume, vehicle-kilometres travelled, section length and intersection entering volume were not included. Rankings may also be affected by random fluctuation and regression to the mean, particularly because a single fatal event has a large influence on the index (Hauer, 1996; Persaud et al., 1999). Police reporting, injury classification, coordinate accuracy and spatial assignment may introduce additional uncertainty, while alternative section

boundaries could split or merge crash concentrations. Furthermore, the five mapped classes are communication categories rather than statistically derived or legally defined safety thresholds. Locations immediately below and above a class boundary may have very similar severity burdens.

Future development should integrate traffic exposure, road geometry and treatment history into the same reference system. Safety performance functions and Empirical Bayes adjustment would enable estimation of expected crash frequency and potential for safety improvement while reducing the influence of regression to the mean. Rolling-period analysis should distinguish persistent, emerging and declining locations, while network kernel density and local spatial association methods could test the robustness of corridor patterns. Field findings and before–after evaluations should subsequently be incorporated into the GIS, creating a continuous cycle of screening, diagnosis, treatment and monitoring.

Within these limitations, the study provides an immediately applicable framework for directing limited road-safety resources towards locations where the recorded human consequences were greatest. Its main contribution lies in combining severity weighting with a clear map-centred workflow that retains traceability from individual crash records to ranked sections and microlocations. Used as a first-stage screening tool and followed by detailed engineering investigation, the approach can support more transparent prioritisation, better coordination among responsible institutions and more focused actions aimed at reducing fatal and serious road casualties.

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