APPROACHING ROAD INFRASTRUCTURE VULNERABILITY FROM A MOBILITY MANAGEMENT PERSPECTIVE. A 5 YEAR ANALYSIS OF ACCIDENT DYNAMICS IN BRASOV COUNTY

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Rezumat. *Decesele înregistrate ca urmare a accidentelor rutiere situează România în fruntea țărilor europene cu cele mai îngrijoratoare statistici, poziționând managementul mobilității într-o poziție deficitară, de cele mai multe ori motivată prin vulnerabilitatea infrastructurii rutiere. Lucrarea de față, realizată cu ajutorul statisticilor oferite de Poliția Română, analizează impactul pe care îl are calitatea carosabilului la nivelul producerii accidentelor în determinarea gravității vătămării corporale a participanților la eveniment. Studiul prezentat este realizat pe o perioadă de 5 ani pe raza județului Brașov.*

Abstract. *Recorded fatalities as a result of road accidents place Romania at the top of the European countries with the most worrying statistics, situating the mobility management in a deficient position, often motivated by the vulnerability of the road infrastructure. The present paper, conducted with the statistics provided by the Romanian Police, analyzes the impact of road quality on the occurrence of accidents in determining the severity of injuries to participants. This study was carried out over a period of 5 years in Brasov County.*

Keywords: road safety, traffic accidents, mobility management, road infrastructure

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1. Introduction

Mobility has become a fundamental element in modern society, resulting in the development of the car fleet at both macro and household level. Thus, while two decades ago a family owned one car that served all the needs of its members, today the trend is for each member with a car licence to use their own vehicle. This evolution in the structure of the automobile fleet has led to an increase in the number of accidents, as the development of road infrastructure has not kept pace with the overpopulation of vehicles [21].
In these conditions, mobility management is all the more important as Romania, being a European member, has undertaken to reduce the number of accidents by 50% by 2030 and to eliminate them by 2050 [20]. Given this major objective, the analysis of factors related to the occurrence of accidents becomes an extremely important process in road safety management.
This paper aims to analyse the relationship between the severity of accidents, respectively the degree of personal injury of the participants and the quality of the road at the time of the impact.

2. Literature review and hypothesis development

The scientific literature [4,19,23,24] has examined the causes of accidents through various studies, considering various factors involved, whether controllable, such as the quality of markings, street lighting or roadway integrity, or unpredictable, such as weather conditions. In terms of meteorological factors, studies [16,19] show an increase in accidents of up to 85% in rainy or snowy conditions. High wind conditions or reduced visibility due to strong sunshine have also been analyzed in the literature, albeit in a more limited way [3,9].
In terms of controllable factors determining the vulnerability of road infrastructure, studies [6,25] show an increase in road accidents when street lighting is lacking. Also, a significant percentage of accidents are observed when road markings are absent [2,12].

2.1 The association between unmarked roads and accident severity

Lack of road markings or failure to maintain them properly contributes massively to the increase in serious accidents. The literature [5,27] shows a significant correlation between the existence of road markings and visual signs and the occurrence of accidents. It is important to define road markings and visual signs as part of the road infrastructure, so that their maintenance is seen as an integral part of the roadway and not as a separate element specific to road safety. Thus, the restoration of a longitudinal marking demonstrates the same degree of urgency as

a serious damage to the carriageway, which motivates the road manager to ensure the optimal functioning of the road from all points of view. Unfortunately, this is not the way things are seen in Romania, so that a significant percentage of roads are unsafe. However, an important step in the right direction was taken in 2024 by changing a piece of legislation linking the lack of road markings in the event of accidents resulting in casualties to the exclusive fault of the manager of the segment in question.
According to a series of studies [1,7,14] the lack of road markings contributes to increased accident rates and severity through various mechanisms, including driver confusion, reduced reaction times, and increased pedestrian risks. Road markings and visual signs provide critical information in traffic by helping drivers anticipate and react safely while driving.

Accordingly, based on previous research, the hypothesis was developed as follows:

Hypothesis 1 Absence of road markings increases the risk of severe accidents

2.2 Road surface composition and accident severity

The composition of road surfaces has a profound impact on accident severity affecting traction, drainage and maintenance requirements. Materials such as asphalt and concrete have different levels of skid resistance especially in wet or icy conditions. Asphalt is flexible and provides good initial traction but can become soft in extreme heat, concrete is more durable but can pe slippery when wet and prone to cracking, while stone surfaces cand be uneven, providing varying levels of traction and become extremely slippery when wet or icy.
Various studies [8,11,13,17] have shown a strong correlation between the composition of pavement and high-risk accidents, discussing that when the pavement roughness increases the chances of accidents decrease.
Thus, based on previous research, we formulate the following hypothesis:

Hypothesis 2 There is a significant relationship between road surface composition and the occurrence of fatal accidents

2.3 Road adhesion and the occurrence of severe accidents

Road adhesion is a critical factor in traffic safety, varying significantly under weather conditions such as wet, dry, icy or snowy affected surface. A number of studies [10,16,26] analyze the meteorological factors involved in accidents and find a direct correlation between the reduction in friction of tires and road surfaces due to bad weather and the severity of road accidents.

Although obviously a cause of serious accidents, wet infrastructure can cause hydroplaning, snow and ice drastically reduce grip on the road making braking and avoidance maneuvers difficult, but a different perspective [22] puts dry road surfaces, a phenomenon based on speeding, at the top of the list for accidents. Unlike situations where the road is covered with snow or water, where caution is required in the driving process, dry road conditions seem to predominate in severe accidents.

Hypothesis 3 Most severe accidents occur in dry road conditions

2.4 Light conditions and severity of accidents

Lighting conditions significantly affect the severity and frequency of road accidents. Reduced visibility can affect the driver's ability to perceive and react to road hazards, leading to a greater chance of serious accidents.
Studies [15,18,28] have found that nighttime accidents often result in more severe injuries and fatalities compared to daytime accidents. This is due to factors such as reduced visual acuity, slower reaction times, and higher chances of driver fatigue or impairment.

Hypothesis 4 There is a correlation between accident severity and visibility conditions

3. Methodology

The methodology used in the present research consists in processing primary data sets provided by the Romanian Police, in order to analyze the impact of the road vulnerability on the occurrence of accidents in determining the severity of the injuries suffered by the participants. Thus, we requested the situation of accidents in Brasov County for the last 5 years and we analyzed severe accidents in relation to road markings, road composition, road adhesion and light conditions at the time of the accident. The sample consists of 1121 severe accidents, which were processed using the statistical package for social sciences in order to test the formulated hypotheses.

4. Results

To determine whether there is a correlation between the lack of road markings and the number of road fatalities, we performed a Spearman correlation test. Analyzing Table 1 we can observe the existence of a statistically significant

correlation between the lack of markings and the severity of accidents, thus validating the first hypothesis.

Table 6. Correlation between lack of markings and the severity of accidents

Correlations

			unmarked road	casualties
Spearman's rho	unmarked road	Correlation Coefficient	1.000	.083**
		Sig. (2-tailed)	.	.005
		N	1121	1121
	casualties	Correlation Coefficient	.083**	1.000
		Sig. (2-tailed)	.005	.
		N	1121	1121

**. Correlation is significant at the 0.01 level (2-tailed).

To determine whether roadway composition influences crash severity, we performed a Logit test, as shown in the table below (see Table 2).

Table 7. Correlating casualties with road composition

	road	Observed		Expected			Standardized
casualties	composition	Count	%	Count	%	Residual	Residual
0	asphalt	893.500	97.3%	893.500	97.3%	.000	.000
	concrete	3.500	0.4%	3.500	0.4%	.000	.000
	unpaved	2.500	0.3%	2.500	0.3%	.000	.000
	gravel	17.500	1.9%	17.500	1.9%	.000	.000
	cubic stone	1.500	0.2%	1.500	0.2%	.000	.000
1	asphalt	179.500	97.3%	179.500	97.3%	.000	.000
	concrete	.500	0.3%	.500	0.3%	.000	.000
	unpaved	.500	0.3%	.500	0.3%	.000	.000
	gravel	3.500	1.9%	3.500	1.9%	.000	.000
	cubic stone	.500	0.3%	.500	0.3%	.000	.000
2	asphalt	21.500	91.5%	21.500	91.5%	.000	.000
	concrete	.500	2.1%	.500	2.1%	.000	.000
	unpaved	.500	2.1%	.500	2.1%	.000	.000

	gravel	.500	2.1%	.500	2.1%	.000	.000
	cubic stone	.500	2.1%	.500	2.1%	.000	.000
3	asphalt	1.500	42.9%	1.500	42.9%	.000	.000
	concrete	.500	14.3%	.500	14.3%	.000	.000
	unpaved	.500	14.3%	.500	14.3%	.000	.000
	gravel	.500	14.3%	.500	14.3%	.000	.000
	cubic stone	.500	14.3%	.500	14.3%	.000	.000
4	asphalt	1.500	42.9%	1.500	42.9%	.000	.000
	concrete	.500	14.3%	.500	14.3%	.000	.000
	unpaved	.500	14.3%	.500	14.3%	.000	.000
	gravel	.500	14.3%	.500	14.3%	.000	.000
	cubic stone	.500	14.3%	.500	14.3%	.000	.000

Thus, we correlated the number of casualties resulting from accidents to determine the severity of the event in relation to the composition of the road. As can be seen in the table, in the case of accidents with 0 to 2 casualties, more than 90% of them occurred in normal conditions, on an asphalt road composition. For accidents with a higher degree of severity, involving more than 3 victims, the proportion of accidents changes, with about 40% of accidents occurring on asphalt. We can thus conclude that the severity of accidents is influenced by the type of road composition, validating the second hypothesis.

To determine whether the majority of accidents happen on dry roadways, we conducted a Logit test. Analyzing the data in Table 3 we can observe the following: in terms of serious non-fatal accidents, 73.3% occurred on a dry road and 21.7% on a wet road. In the case of serious accidents with one fatality, 65.9% occurred on dry pavement conditions and 30.9% on wet pavement conditions. In case of accidents with 2 fatalities, 50% of the accidents occurred in dry asphalt conditions and in case of accidents with 3 fatalities, only 30% of the accidents occurred on a dry road surface. In accidents with 4 fatalities, only 10% of accidents occurred on dry asphalt, with the majority of high severity accidents occurring on a vulnerable road surface in terms of grip. Analyzing the statistics in Table 3 we can conclude that most serious accidents do not occur in dry road conditions, thus invalidating the third hypothesis.

Table 8. Correlating casualties with road grip

		Observed		Expected			Standardized	
Casualties	road grip	Count	%	Count	%	Residual	Residual	Deviance
0	others	1.500	0.2%	1.500	0.2%	.000	.000	.000
	slippery	9.500	1.0%	9.500	1.0%	.000	.000	.000
	frozen	3.500	0.4%	3.500	0.4%	.000	.000	.000
	muddy	6.500	0.7%	6.500	0.7%	.000	.000	.000
	icy	4.500	0.5%	4.500	0.5%	.000	.000	.000
	wet	199.500	21.7%	199.500	21.7%	.000	.000	.000
	dry	674.500	73.3%	674.500	73.3%	.000	.000	.000
	snow	20.500	2.2%	20.500	2.2%	.000	.000	.000
1	others	.500	0.3%	.500	0.3%	.000	.000	.000
	slippery	.500	0.3%	.500	0.3%	.000	.000	.000
	frozen	.500	0.3%	.500	0.3%	.000	.000	.000
	muddy	1.500	0.8%	1.500	0.8%	.000	.000	.000
	icy	.500	0.3%	.500	0.3%	.000	.000	.000
	wet	57.500	30.9%	57.500	30.9%	.000	.000	.000
	dry	122.500	65.9%	122.500	65.9%	.000	.000	.000
	Snow	2.500	1.3%	2.500	1.3%	.000	.000	.000
2	others	.500	2.0%	.500	2.0%	.000	.000	.000
	slippery	.500	2.0%	.500	2.0%	.000	.000	.000
	frozen	1.500	6.0%	1.500	6.0%	.000	.000	.000
	muddy	.500	2.0%	.500	2.0%	.000	.000	.000
	Icy	.500	2.0%	.500	2.0%	.000	.000	.000
	Wet	8.500	34.0%	8.500	34.0%	.000	.000	.000
	Dry	12.500	50.0%	12.500	50.0%	.000	.000	.000
	Snow	.500	2.0%	.500	2.0%	.000	.000	.000
3	others	.500	10.0%	.500	10.0%	.000	.000	.000
	slippery	.500	10.0%	.500	10.0%	.000	.000	.000
	frozen	.500	10.0%	.500	10.0%	.000	.000	.000
	muddy	.500	10.0%	.500	10.0%	.000	.000	.000
	Icy	.500	10.0%	.500	10.0%	.000	.000	.000
	Wet	.500	10.0%	.500	10.0%	.000	.000	.000

	Dry	1.500	30.0%	1.500	30.0%	.000	.000	.000
	Snow	.500	10.0%	.500	10.0%	.000	.000	.000
4	others	.500	10.0%	.500	10.0%	.000	.000	.000
	slippery	.500	10.0%	.500	10.0%	.000	.000	.000
	frozen	.500	10.0%	.500	10.0%	.000	.000	.000
	muddy	.500	10.0%	.500	10.0%	.000	.000	.000
	Icy	.500	10.0%	.500	10.0%	.000	.000	.000
	Wet	1.500	30.0%	1.500	30.0%	.000	.000	.000
	Dry	.500	10.0%	.500	10.0%	.000	.000	.000
	snow	.500	10.0%	.500	10.0%	.000	.000	.000

In order to test for a correlation between accident severity and visibility conditions we performed a Spearman correlation test. Analyzing the data in Table 4, we can observe a significant correlation between the two variables. Also, the correlation is negative, demonstrating that in conditions of reduced visibility, accident severity increases. Thus, we validated the 4th hypothesis.

Table 9. Correlation between visibility conditions and the severity of accidents

Correlations

			casualties	visibility conditions
Spearman's rho	casualties	Correlation Coefficient	1.000	-.104**
		Sig. (2-tailed)	.	.000
		N	1121	1121
	visibility conditions	Correlation Coefficient	-.104**	1.000
		Sig. (2-tailed)	.000	.
		N	1121	1121

**. Correlation is significant at the 0.01 level (2-tailed).

5. Conclusions

Specialists estimate that 98% of accidents occur due to the human factor. This also means that there is potential for action aimed at reducing casualties, and that

the European target of eliminating road traffic fatalities by 2050 is not an unattainable goal.

This paper analyzed a number of factors that determine the vulnerability of road infrastructure, namely road composition, the existence of road markings, light conditions and road adhesion at the time of accidents. As far as the first 3 factors are concerned, they are fully controllable through effective public policies, enforcement legislation, road safety audits and efficient traffic management. As for road adhesion, which is due to weather phenomena, they are rarely totally unpredictable and once the precedent exists, various intelligent solutions can be used to mitigate the effects of a similar event.

Romania is by far at the bottom of the ranking when it comes to good practices in terms of efficient mobility management, having the highest number of victims per million inhabitants. But even from this position, recent years have shown an upward trend in infrastructure development, with more kilometers of motorway being built and problematic road sections being upgraded. But from building new roads to eliminating accidents in the next 25 years is an idealistic vision to say the least, and many steps in the right direction are needed. Many effective steps.

6. Acknowledgement

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7. Limitations and future research

Infrastructure vulnerability encompasses many aspects that need to be analyzed in order to establish effective management policies. Those presented in this paper need to be further correlated with other factors such as: lack of automation of railway level crossings, lack of proper vegetation clearing that is affecting visibility, lack of effective measures to prevent animals from crossing the road, etc.

At the same time, as new sections of road have been built and continue to be built, the problem of missing or inadequate markings may be at least partially solved by reducing the importance of one of the factors analyzed.

Last but not least, the recent change in legislation regarding the serious sanctioning of the road manager in case of accidents with casualties due to infrastructure problems has the potential to solve, in the short to medium term, the problems raised in this paper.

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