

ASSESSMENT OF FACTORS INFLUENCING THE NUMBER AND CONSEQUENCES OF ELECTRIC SCOOTER ACCIDENTS

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Abstract. Micromobility is gaining momentum in many countries, helping reduce congestion and pollution in the streets of major cities. The use of e-scooters has increased rapidly over the past three years, posing additional risks to road safety. Therefore, it is necessary to identify the key factors influencing the number of accidents and their consequences. The current article assesses eight e-scooter safety importance criteria, applying various methods and consulting highly qualified experts. It is noteworthy that the maximum weights of criteria determined by the ARTIW-L, ARTIW-N (Average Rank Transformation into Weight Linear and Non-Linear), and AHP (Analytic Hierarchy Process) methods are consistent. Evaluating the opinions of 15 experts using the ARTIW-L, ARTIW-N, DPW (Direct Percentage

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Weight), and AHP methods allowed for the determination of average criterion weights and the ranking of their priorities. Averaging the criteria weights calculated by the four expert evaluation methods yields the following overall priority order: Type and quality of road surface>Road or street element>Maximum power>Speed limits>Mandatory helmet use>Seasonality>Age of the road user>Educational activities. The findings highlight that the type and quality of the road surface, as well as road or street design, have the greatest impact on e-scooter safety. These insights can guide urban planners and policymakers in prioritizing infrastructure improvements and developing evidence-based safety regulations for micromobility users.

Keywords: e-scooter, expert evaluation, road safety, weights of criteria.

Introduction

Micromobility has been a widely used term for several years and typically refers to lightweight (up to 350 kg) mobile vehicles (Christoforou et al., 2021). It commonly describes smaller, lightweight vehicles powered by either electricity or human effort, such as bicycles (including e-bikes) and e-scooters (Fazio et al., 2021; Reck et al., 2021). These vehicles can be privately owned or shared, offering access whenever needed. Micromobility sharing systems are often presented as environmentally friendly and innovative transportation solutions (Reck et al., 2021).

Micromobility has a positive impact on reducing road congestion. On the other hand, it also highlights issues related to illegal behaviour and other sharing-related problems in cities (Mura et al., 2022).

The proliferation of micromobility, driven by the rise of both private and shared e-scooters and e-bikes, benefits individuals as well as urban areas. It offers real alternatives to car travel and improves public transport connections for the first and last kilometres. However, the most popular forms of micromobility also pose safety challenges in busy urban areas that are primarily dominated by cars (ITF, 2024).

In a joint report, the International Transport Forum (ITF) and the National Technical University of Athens presented a classification of micromobility vehicles based on their performance (Figure 1) (Yannis et al., 2024). The type of micromobility device is determined by its weight and speed, both of which directly influence its kinetic energy and risk of injury. Two weight ranges – up to 35 kg and between 35 and 350 kg – and two speed ranges – up to 25 km/h and between 25 and 45 km/h – have been defined, resulting in the classification of devices into four types: A, B, C, and D (Hossein Sabbaghian et al., 2023).

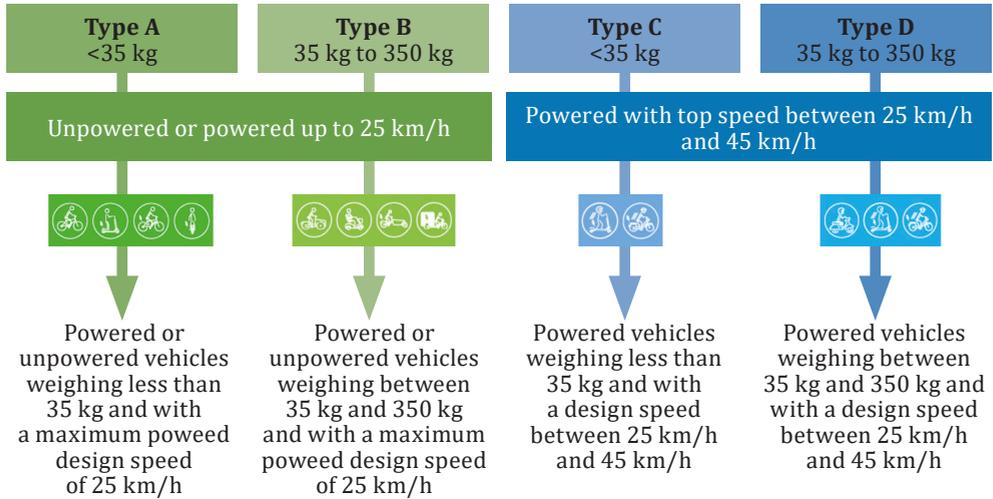


Figure 1. Micromobility definition (Yannis et al., 2024)

In the European Transport Safety Council (ETSC) report, another term is used “motorised micromobility devices” that encompasses motorised electric vehicles (including e-scooters, self-balancing unicycles, etc.) (Carson et al., 2024). The data in Table 1 show that in European countries, 20 people were killed in 2019; however, by 2023 this number had risen to 132. The number of injured persons increased accordingly from 952 in 2019 to 3145 in 2023.

The ETSC report, “Improving the Road Safety of E-Scooters (PIN Flash Report 47)”, provides an overview of the total number of fatalities and serious injuries involving by micromobility vehicles on roads between 2019 and 2023 (see Table 1).

Table 1. Total road deaths and serious injuries among micromobility vehicle users between 2019 and 2023 (Carson et al., 2024)

Country	2019		2020		2021		2022		2023	
	Deaths	Injuries	Deaths	Injuries	Deaths	Injuries	Deaths	Injuries	Deaths	Injuries
Austria	n/a	n/a	n/a	n/a	2	n/a	4	n/a	3	283
Belgium	1	8	1	26	4	56	4	97	2	n/a
Bulgaria	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2	37
Croatia	n/a	n/a	n/a	n/a	n/a	n/a	1	18	1	58
Cyprus	1	3	0	1	0	3	1	4	0	1
Czechia	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5	22
Denmark	1	8	0	15	0	18	0	19	n/a	n/a
Estonia	0	n/a	0	n/a	0	28	1	60	0	53
Finland	0	n/a	1	n/a	2	n/a	2	n/a	2	n/a
France	10	158	7	211	24	413	35	604	44	671
Germany	n/a	n/a	n/a	n/a	5	787	10	1099	21	1084
Great Britain	n/a	n/a	1	106	10	329	11	356	6	n/a
Greece	n/a	n/a	n/a	n/a	n/a	n/a	1	n/a	n/a	n/a
Hungary	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ireland	0	3	1	17	0	24	1	33	3	35
Israel	3	136	3	142	9	218	8	283	4	339
Italy	n/a	n/a	n/a	n/a	9	n/a	16	n/a	21	n/a
Latvia	1	n/a	2	1	1	13	1	25	0	15
Lithuania	0	1	2	3	1	10	0	6	2	12
Luxemburg	n/a	n/a	0	0	0	4	0	6	n/a	n/a
Malta	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Netherlands	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Norway	n/a	0	2	4	1	14	5	20	0	13
Poland	n/a	n/a	n/a	n/a	n/a	n/a	3	164	n/a	n/a
Portugal	0	3	0	2	0	8	0	15	3	19
Romania	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Serbia	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Slovakia	0	1	0	1	0	9	3	15	1	12
Slovenia	0	1	0	3	0	16	2	30	0	29
Spain	n/a	n/a	n/a	n/a	9	172	8	312	10	341
Sweden	1	616	0	717	4	2238	4	3052	n/a	n/a
Switzerland	2	14	0	55	0	89	3	114	2	121
Total	20	952	20	1304	81	4449	124	6332	132	3145

n/a – no data available or not specified.

In Lithuania, 827 traffic accidents, involving e-scooters, were recorded from 2019 to 2023, resulting in five fatalities and 639 injuries. An analysis of traffic accidents in Lithuania between 2019 and 2022 shows a 2.8-fold increase in accidents, involving e-scooters. After several years of growth, the number of injured e-scooter users decreased in 2023 to 173, compared to 184 in 2022 (Juodvalkienė et al., 2024).

E-scooters are used primarily in urban areas where motor vehicles typically have priority, leaving little room for other road users. Such conditions can make e-scooter trips unpleasant or even dangerous, thereby limiting their safe and sustainable use. Additionally, the design of e-scooters leaves users physically unprotected due to the absence of a safety zone, putting them at risk of serious injury in the event of a collision with a vehicle (Karpinski et al., 2022). The lack of dedicated infrastructure for e-scooters can also lead to conflicts with pedestrians, as scooter users are often forced to navigate between the pavement and roadway.

There are many factors contributing to e-scooter accidents, with the primary ones being regulated differently across countries (see Table 2). There are still no uniform safety standards for micromobility devices at the EU level (Carson et al., 2024).

The data in Table 2 demonstrate that European countries impose different micromobility requirements, reflecting the evolving role of e-scooters as a mode of travel. Helmet requirements and age limits also vary across countries. The overall risk of e-scooter accidents varies unevenly across countries. In some, it has increased significantly (e.g., Denmark and Switzerland), while in others, it has decreased (e.g., Austria and Italy). The overall risk reduction associated with e-scooters can partly be attributed to an increased emphasis on road safety and improvements in traffic culture. The significant risk reduction in Italy can be attributed to recent mandatory improvements in e-scooter features, including front and rear brakes and turn indicators (yellow flashing lights front and rear). These improvements are required for all new e-scooters entering the market from October 2022. Notably, these safety improvements have contributed to a 25.7% overall reduction in e-scooter accident risks across all countries (Yannis et al., 2024).

Table 2. Shared e-scooter risk and e-scooter safety regulations across European countries
(Yannis et al., 2024)

Shared e-scooter casualties requiring medical treatment per million trips				E-scooter safety regulations						
Country	Year		YoY% change	Min age, y/o	Max speed, km/h	Max power, W	Ride on pavements?	Drink-ride limit	Helmet required	Mandatory insurance
	2021	2022								
Austria	4.1	1.5	-63.6	12	25	600	No ¹	0.8	<12 m.	No
Belgium	7.1	7	-1.8	16	25	n/a	No	Same as car	No	No
Bulgaria	n/a	n/a	n/a	16	25	n/a	Yes ¹	n/a	<18	No
Cyprus	v	n/a	n/a	14	20	n/a	Yes ¹	0.5	Yes	No
Czech Republic	9.2	15.6	69.3	n/a	25	250	>10 y/o	No	<18	No
Denmark	8.6	14.8	72.3	15	20	n/a	No	Same as mopeds	Yes (>Jan 2022)	Yes
Finland	5	2.9	-41.6	No	25	1000	No	No	Yes – as bikes	No
France	9	12.1	34.8	12	25	n/a	No ¹	Forbidden to ride	Recommended	Yes
Germany	4.3	4	-7.7	14	20	500	No ¹	Same as car	No	Yes
Greece	n/a	n/a	n/a	15	25	n/a	Yes ¹	No	Yes	No
Italy	12.1	4.4	-63.3	14	20 ²	500	No	NA	<18	No ⁵
Norway	3.2	2.7	-17.5	12	20	n/a	No	Same as cars	<15	No
Poland	4.9	4.5	-8.0	10	20	n/a	Yes ¹	Forbidden to ride	No	No
Portugal	22.3	25	12.0	No	25	1000	>10 y/o	Same as cars	No	No
Slovenia	n/a	n/a	n/a	14 ⁴	25	NA	No	0.5	<18	No
Spain	22.4	14.8	-34.1	14-16	25	1000	No	Same as cars	Yes (>March 2022)	No ⁵
Sweden	5.2	5.3	0.5	n/a	20	250	n/a	n/a	<15 – as bikes	n/a
Switzerland	2.2	4.4	100.3	16 ³	20	500	No ¹	Same as cars	No	No
JK	31.9	20.6	-35.5	16	25	500 (trials)	No	Same as cars	No	Trial ⁵
Cumulative			-25.7							

¹ "local" authorities can make exceptions (e.g., if there is no cycling lane, travel speed up to 6 km/h, if the road speed limit is <30 km/h or <50 km/h, riders aged 14–16 should ride only on bicycle lanes etc.); ² 6 km/h in pedestrian areas; ³ 14 with a moped license; ⁴ 12 with a cycling licence; ⁵ required by sharing providers.

The EU Regulation (2013) applies to two-, three-, and four-wheel vehicles, but exempts self-balancing vehicles and vehicles without seats. Therefore, e-scooter users are not bound by this Regulation. This implies that national authorities should implement flexible regulations to rapidly adapt to emerging mobility solutions (Aba & Esztergár-Kiss, 2024).

The widespread use of micromobility vehicles has presented new challenges for urban infrastructure planners, compelling them to integrate vehicles of varying sizes, meet diverse safety requirements, and incorporate new technologies into city streets (Olabi et al., 2023).

Establishing clear traffic rules, including minimum age limits, mandatory helmets, prohibitions on passenger riding, and guidelines specifying where and when scooters may be used, can reduce collision risks and injury severity. Improving infrastructure for vulnerable road users, including e-scooter riders, positively impacts their overall safety (Carson et al., 2024). Limiting maximum speed and acceleration, along with enforcing technical standards for lighting and braking systems, can further improve vehicle safety.

Travel by e-scooter inherently involves interactions with other road users. Existing infrastructure in many countries is insufficient for current e-scooter volumes, forcing users onto streets, cycle paths, or pedestrian walkways that lack adequate quality or capacity to accommodate additional vehicles. This increases congestion and, consequently, collision potential between e-scooters and other road users, such as pedestrians, cyclists, and cars (Zhang et al., 2024). Studies reveal that vibrations experienced by e-scooter riders on urban surfaces can be effectively dampened through improved scooter design, enhancing rider comfort (Karpenko et al., 2025). Insights from this research could improve road infrastructure design to better accommodate micromobility and ensure user safety and comfort (Karpenko et al., 2025). The impact on traffic safety at major junctions often focuses on intersections where traffic flows converge (Mura et al., 2022), as well as on micro-vehicle and pedestrian traffic (Maiti et al., 2022; Valero et al., 2020). The interaction of the wheels with pavement types also influences micromobility safety (Ružinskas & Sivilevičius, 2017).

Training and skill development are essential, as many road safety issues stem from user inexperience, inadequate protective equipment, and insufficient driving skills (Zhang et al., 2024).

Therefore, specific infrastructure guidelines are needed to integrate e-scooters into urban traffic networks safely and effectively.

Ensuring safe e-scooter use requires analysing factors affecting both users and non-users, including perceptions and personal factors influencing e-scooter usage decisions (Pourfalatoun et al., 2023).

Helmets, speed, alcohol consumption, and riding experience are critical road safety factors for e-scooters. Lower driving speeds contribute significantly to improved safety (Zhang et al., 2024).

The Parties agree that micromobility solutions require separate regulation from other types of vehicles. The top priority is to incorporate speed limits into regulations and promote infrastructure improvements (Aba & Esztergár-Kiss, 2024).

Hossein Sabbaghian (2023) claims that research on road safety in micromobility has provided valuable insights into how infrastructure improvements, road surface quality, traffic patterns, and operational conditions affect user safety. These conclusions can help establish safer micromobility networks and enhance infrastructure design and maintenance, thus ensuring user well-being. More comprehensive and reliable accident data are required to better understand micromobility safety and develop effective safety measures (Hossein Sabbaghian et al., 2023).

Identifying, ranking, and conducting a cluster analysis of the criteria determining micromobility safety can help pinpoint where researchers should concentrate their efforts to achieve the greatest impact in this field (Hossein Sabbaghian et al., 2023).

The aim of this article is to identify the key factors influencing both the frequency and consequences of e-scooter accidents and to assess their significance using multiple-criteria decision-making (MCDM) methods. Specifically, the article evaluates eight safety criteria for e-scooters based on the opinions of highly qualified experts, employing the ARTIW-L, ARTIW-N, DPW, and AHP methods to determine the average weights of the criteria and establish their priority rankings.

The paper hypothesizes that the safety of electric scooter traffic is influenced by many factors, whose significance varies and remains insufficiently studied.

By applying experts' experience and knowledge, the significance of the criteria can be evaluated using multiple-criteria decision-making methods.

1. Methodology and data sample

The significance of the criteria, expressed as subjective normalized weights, can be determined using various methods (algorithms). While none of these approaches holds a theoretical advantage over the others, they all adhere to the same principle: the most important criterion is assigned the highest relative weight. In addition, the sum of the weights of all criteria must equal one, i.e., the weights are normalised (Sivilevičius & Martišius, 2023).

To ensure the robustness of the research, four multiple-criteria decision-making (MCDM) methods were used. Initially, the Kendall rank correlation method (Kendall & Gibbons, 1990) was used to assess the consistency of the expert team's opinions. Linear (ARTIW-L: Average Rank Transformation into Weight-Linear)

and non-linear (ARTIW-N: Average Rank Transformation into Weight-Non-Linear) methods were employed to calculate the normalized relative weights of criteria (Maskeliūnaitė & Sivilevičius, 2021). The experts also provided percentage-based importance estimates for the criteria, which were normalized using the DPW (Direct Percentage Weight) method. The research also employs the Analytic Hierarchy Process (AHP) method (Saaty, 1980); however, some experts found it challenging to complete the pairwise comparison matrix while maintaining transitivity and avoiding contradictions. If necessary, the matrices were slightly adjusted until their consistency ratio (*C.R.*) was less than 0.1.

1.1. Methods for transforming rank averages into weights

The ARTIW-L and ARTIW-N methods were selected to determine the weights of criteria because they are both simple and accurate, enabling weights to be calculated directly from the average of the ranks. The average rank for each criterion ($i = 1, 2, \dots, m$) is calculated based on the rankings provided by the n experts ($j = 1, 2, \dots, n$) involved in the research:

$$\bar{R}_i = \frac{\sum_{j=1}^n R_{ij}}{n}, \quad (1)$$

where: R_{ij} – the rank assigned by the j -th expert to the i -th criterion; n – the number of experts.

The subjective normalized weight of each criterion is calculated using the linear method for transforming rank averages into weights (ARTIW-L):

$$\omega_i^{\text{ARTIW-L}} = \frac{(m+1) - \bar{R}_i}{\sum_{i=1}^m \bar{R}_i}, \quad (2)$$

where: \bar{R}_i – the average rank of the i -th criterion; m – the number of criteria describing the study object.

The weights (ω_i) of criteria, calculated using the ARTIW-L method, are linearly correlated with the average ranks \bar{R}_i of the criteria.

The normalized weights ω_i of criteria can be calculated using an alternative method for transforming rank averages \bar{R}_i into weights. The criterion weights $\omega_i^{\text{ARTIW-L}}$ derived from Equations (3) and (4) exhibit a non-linear inverse correlation with the criterion rank averages \bar{R}_i . Accordingly, this approach is designated as the ARTIW-N method.

Using the ARTIW-N method, the ratio of the most important criterion characterised by the lowest average rank $\min_i \bar{R}_i$, to the average ranks \bar{R}_i : of all other i -th criteria is calculated:

$$u_i = \frac{\min_i \bar{R}_i}{\bar{R}_i}. \quad (3)$$

After normalizing each criterion value u_i , their subjective significance (weights) ω_i is calculated as follows:

$$\omega_i^{\text{ARTIW-N}} = \frac{u_i}{\sum_{i=1}^m u_i}. \quad (4)$$

The weights of criteria $\omega_i^{\text{ARTIW-N}}$ calculated using the ARTIW-N method exhibit an inverse, non-linear relationship with the average ranks of the corresponding criteria. This correlation indicates that the importance assigned to the most and least significant criteria is amplified, whereas the importance of moderately ranked criteria is reduced.

For aggregated expert opinions, expressed as ranks, scores, or weights, to be considered valid, it is essential to verify their consistency and non-contradictory nature. The average can only be regarded as a reasonable solution if the experts' assessments are sufficiently consistent and not contradictory. For this purpose, Kendall's coefficient of concordance W (Kendall & Gibbons, 1990) is calculated, indicating the consistency of expert opinions. Its value ranges from 0 to 1:

$$W = \frac{12S}{n^2(m^3 - m)} = \frac{12S}{n^2m(m^2 - 1)}, \quad (5)$$

For each m -th criterion, the sum S of the squared deviations of the rank $\sum_{j=1}^n R_{ij}$ sums from the average rank is calculated:

$$S = \sum_{i=1}^m \left[\sum_{j=1}^n R_{ij} - \frac{1}{2}n(m+1) \right]^2. \quad (6)$$

The calculated value of W is compared with its minimum value, W_{\min} taking into account the chosen significance level α ($\alpha = 0.05$ or the stricter $\alpha = 0.01$) and the degrees of freedom $\nu = m - 1$:

$$W_{\min} = \frac{\chi_{\nu, \alpha}^2}{n(m-1)}, \quad (7)$$

where $\chi_{\nu, \alpha}^2$ – Pearson's chi-square statistic. Typically, a significance level of $\alpha = 0.05$ is selected. The critical value $\chi_{\nu, \alpha}^2$ is obtained from a mathematical statistics table (Montgomery et al., 2007).

To verify the consistency of expert opinions, a random variable is calculated based on classic methodology (Kendall & Gibbons, 1990):

$$\chi^2 = Wn(m-1) = \frac{12S}{nm(m+1)}. \quad (8)$$

When it is determined that $W > W_{\min}$ and $\chi^2 > \chi_{\nu, \alpha}^2$, it becomes possible to calculate how many times the results obtained from the survey data (expert

opinions) exceed the critical values. For this purpose, the coefficient of compatibility is calculated (Sivilevičius & Martišius, 2023):

$$k_c = \frac{W}{W_{\min}} = \frac{\chi^2}{\chi_{\nu, \alpha}^2}. \quad (9)$$

When the experts are in agreement, $k_c > 1$. Conversely, if $k_c < 1$, this indicates significant disagreement among the experts.

1.2. Direct method of percentage weights

This method is most commonly used in practice. The DPW method is as transparent and logically sound as the method based on ranking indicators (rank correlation), yet it provides considerably higher accuracy. For the direct method of percentage weighting, the weights assigned to all evaluation criteria by the experts must sum to 100%. When percentage estimates are available, they are converted into fractions by dividing by 100. Criteria are easier to assess directly in percentage terms if they have previously been ranked, as lower ranks correspond to higher weights. For each i -th criterion, the sum $\sum_{j=1}^n p_{ij}$ of the percentage weights p_{ij} assigned by all n experts ($j = 1, 2, \dots, n$) is calculated, along with their normalized weights ω_i^{DPW} :

$$\omega_i^{\text{DPW}} = \frac{\sum_{j=1}^n p_{ij}}{100n}, \quad (10)$$

where p_{ij} – the weight, expressed as a percentage, assigned to the i -th criterion by the j -th expert; n – the number of experts.

The weights of criteria ω_i^{DPW} calculated by the DPW method are indirectly correlated with their average ranks \bar{R}_i . This non-linearity typically arises from the amplified significance attributed to the most important criteria.

1.3. Analytical Hierarchy Process method

The Analytical Hierarchy Process (AHP) method enables the comparison of criteria based on their importance, assigning each a quantitative priority relative to the others. This priority is expressed as the intensity (level) of importance between the two criteria. The foundation of the method is a square pairwise comparison matrix A , in which the expert compares all criteria (factors, indicators) C_i and C_j ($i, j = 1, 2, \dots, m$) (Jateikienė, 2016; Sivilevičius & Martišius, 2023). Here m represents the number of criteria being compared, for example, the factors affecting the number of e-scooter traffic incidents and their consequences. A five-level Saaty scale (1-3-5-7-9) is used for comparing the criteria, and intermediate pairwise evaluation values (2-4-6-8) can also be employed.

The AHP method is convenient because it allows the expert to compare the factors influencing the number or consequences of e-scooter accidents pairwise, rather than all at once. The comparison of criteria becomes straightforward and reliable only when the expert understands the method well. The square matrix clearly illustrates how much more important one element is compared to another. This method enables a qualitative (linguistic/verbal) evaluation of factors or criteria to be converted into a quantitative (numerical) assessment.

The outcome of a pairwise comparison of criteria is a square matrix

$$\mathbf{A} = \left\| a_{ij} \right\| (i, j = 1, 2, \dots, m).$$

When comparing the importance of factors C_i and C_j , which influence the number and consequences of e-scooter accidents, their relative importance is expressed by the ratio of estimates $\omega_1, \omega_2, \dots, \omega_n$:

$$a_{ij} = \frac{\omega_i}{\omega_j}, (i, j = 1, 2, \dots, m), \quad (11)$$

indicating, how many times more important the i -th safety criterion C_i is compared to the j -th safety criterion C_j , $a_{ij} = 1/a_{ji}$.

The elements of Matrix \mathbf{A} (using integers and fractions on a nine-point scale) must be completed according to the following requirements: $a_{ij} = 1$, when the compared criteria are of equal importance with respect to the research object (i.e., the elements on the main diagonal, where each criterion is compared with itself), then $a_{ij} = 3$, when criterion C_i is slightly more important than criterion C_j ; $a_{ij} = 5$, when C_i is much more important than C_j ; $a_{ij} = 7$, when C_i is very significantly more important than C_j ; $a_{ij} = 9$, when C_i is absolutely more important than C_j (Podvezko & Sivilevičius, 2013).

The elements a_{ij} of matrix \mathbf{A} can be interpreted as the ratio of the values of criteria C_i and C_j after these values have been normalized; that is, as the ratio of the criteria weights. A square matrix based on a pairwise comparison of criteria by one expert is given as follows (where i represents rows and j represents columns).

The expert assigns a level of importance from 1 to 9 when comparing the two criteria with respect to the research object. It is convenient to first rank the criteria; then, the most important criterion is compared sequentially with the second, third, and all subsequent criteria in order of importance until the final (m -th) criterion is reached (resulting in the most important criterion's row being filled with integers). Subsequently, the second most important criterion is compared with the remaining criteria in the same sequential order (the row corresponding to the second criterion is filled with $m - 1$ integers and one fractional value), and so on.

It is crucial to ensure that the pairwise comparison matrix completed by the expert is consistent, reflecting a non-contradictory logic throughout its construction. A review of scientific publications indicates that matrices are not always filled in correctly. The essential condition for consistency is the transitivity

of the importance relationships among the matrix elements: if element A is more important than B, and B is more important than C, then A must be more important than C. In practice, the transitivity condition facilitates the identification of matrix elements that do not meet this requirement. Such elements should be corrected, or the matrix should be excluded from the research (Jateikienė, 2016).

The most accurate approximate method for determining the weights (ω_i) of the object criteria is an algorithm that calculates the geometric means of the products of the elements in each row of the pairwise comparison matrix a_{ij} (Podvezko, 2009; Saaty, 1980).

The eigenvector is a numerical value representing the normalized relative importance of criteria ω_i^{AHP} , calculated from the formula:

$$\omega_i^{\text{AHP}} = \frac{\sqrt[n]{\prod_{j=1}^n a_{ij}}}{\sum_{i=1}^n \sqrt[n]{\prod_{j=1}^n a_{ij}}}. \quad (12)$$

The weights ($\sum_{i=1}^n \omega_i = 1.0000$) for each criterion have been calculated, allowing for a quantitative comparison of the significance of each criterion for the subject, as determined by a single expert.

The consistency of the pairwise comparison matrix **A** is evaluated by calculating a maximum eigenvalue λ_{\max} . The arithmetic mean of all criteria for the object is obtained by dividing the sum of the products for each criterion $\sum_{j=1}^m a_{ij}\omega_i$ by the corresponding test vector value ω_i calculated for that criterion (Ai et al., 2022; Stanujkic, 2016):

$$\lambda_{\max} = \frac{1}{n} \times \sum_{i=1}^n \frac{\sum_{j=1}^m a_{ij}\omega_i}{\omega_i}. \quad (13)$$

Saaty (1980) found that for an m -th-order inverse symmetric matrix, the maximum eigenvalue satisfies $\lambda_{\max} \geq m$. Ideally, when the pairwise comparison matrix is perfectly consistent and its column elements are proportional, $\lambda_{\max} = m$. The consistency of the matrix is demonstrated by the difference $\lambda_{\max} - m$ relative to the order $m \times m$ of matrix **A**. The Consistency Index (*C.I.*) is calculated as follows:

$$C.I. = \frac{\lambda_{\max} - m}{m - 1}. \quad (14)$$

The consistency of the pairwise comparison matrix **A** completed by the expert improves as the *C.I.* value decreases. The *C.I.* of a perfectly consistent matrix is close to zero. A matrix with a *C.I.* of 0 is extremely rare in practice, even when its elements fully satisfy the transitivity condition. The degree of consistency of the inverse

symmetric matrix is quantified by comparing the calculated *C.I.* with the Random Index (*R.I.*), which is determined for randomly generated matrices of the same order on a scale corresponding to 1–3, 5, 7–9 (Saaty & Ozdemir, 2003), as shown in Table 3.

Table 3. Dependence of *R.I.* values on the order of the matrix (number of criteria) *m*

Matrix order (<i>m</i>)	3	4	5	6	7	8	9	10	11	12	13	14	15
<i>R.I.</i>	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The ratio between the Consistency Index (*C.I.*) and the Random Index (*R.I.*) of a matrix is called the Consistency Ratio (*C.R.*), reflecting the degree of consistency of the pairwise comparison matrix **A**:

$$C.R. = \frac{C.I.}{R.I.} \quad (15)$$

A matrix is considered consistent if its calculated Consistency Ratio (*C.R.*) is less than or equal to 0.1 (10%) (Saaty, 1980).

1.4. Average of the criteria weights from the four MCDM methods

The arithmetic mean of the criteria weights, calculated using the four MCDM methods, is determined by the following formula, with equal weighting assigned to each method:

$$\bar{\omega}_i = \frac{\sum_{k=1}^r \omega_{ik}}{r} = \frac{\omega_i^{\text{ARTIW-L}} + \omega_i^{\text{ARTIW-N}} + \omega_i^{\text{DPW}} + \omega_i^{\text{AHP}}}{4}, \quad (16)$$

where ω_{ik} – the weight of the *i*-th criterion calculated by the *k*-th MCDM method ($k = 1, 2, \dots, r$); *r* – the number of methods used in the research ($r = 4$).

This value is likely to approximate the population mean, which would be obtained by surveying a large number of experts regarding the weights of criteria calculated using any of the four MCDM methods employed in the research (Sivilevičius & Martišius, 2023).

The sample range, also known as the dataset range (interval) $\Delta\omega_i$, for the weights of each criterion determined by different methods, is calculated using the following formula:

$$\Delta\omega_i = \omega_{i\max} - \omega_{i\min}, \quad (17)$$

where $\omega_{i\max}$ and $\omega_{i\min}$ – are the maximum and minimum weights, respectively, for criterion *i*, as determined by the four different MCDM methods used in the research.

1.5. Determining the minimum number of experts

When employing expert methods to evaluate the significance of criteria, a key question arises: How many experts are minimally required? In practice, the commonly applied rule – that the number of experts must be equal to or exceed the number of criteria – is mathematically unsound. There is also a widespread assumption that the sample size required for a study should be $n \geq 30$, although this is not universally justified. In some cases, this number may be sufficient (if there is slight variation in expert opinion), while in others, it may be inadequate. The reliability of panel assessments depends on both the number of experts and the depth of their expertise (Maskeliūnaitė & Sivilevičius, 2021).

What is the minimum number of experts required to achieve the desired accuracy? The minimum number of experts n_{\min} can be calculated using the sample size formula (Navikas et al., 2016):

$$n_{\min} = \frac{t^2 \times \sigma_R^2}{\Delta_R^2}, \quad (18)$$

where $t = 1.96$ (Montgomery et al., 2007); σ – the standard deviation of the ranks provided by the panel; Δ – the required precision, representing the maximum allowable difference between the panel's mean rank for a criterion and the population mean.

The pooled standard deviation σ_R is calculated under the assumption that all criteria σ_R^2 have equal variances (i.e., their variances do not differ significantly from one another).

Since the same number of experts rate each criterion, the Cochran's test (G_c) can be applied to assess the homogeneity of variances, provided that the data follow a normal distribution (Sachs, 1972).

Essentially, this method calculates the ratio of the maximum variance to the total sum of variances. This statistic (G_c) must be lower than the critical value (G_{kr}) (as provided in the tables (Sachs, 1972)). G_{kr} depends on $\alpha = 0.05$, the number of criteria (m) and the number of experts ($n - 1$).

$$G_c = \frac{\max \sigma_{R_i}^2}{\sum_{i=1}^m \sigma_{R_i}^2}. \quad (19)$$

We have found that the variances of the criteria ranks are equal, as confirmed by Cochran's test. This permits us to calculate the average variance for the entire set of criteria:

$$\bar{\sigma}_{R_i}^2 = \frac{\sum_{i=1}^m \sigma_{R_i}^2}{m}. \quad (20)$$

Standard deviation: $\sigma_{R_i} = \sqrt{\overline{\sigma_{R_i}^2}}$. The accuracy of the result is calculated as follows:

$$\Delta_R = \sqrt{\frac{t^2 \sigma_R^2}{n}}. \quad (21)$$

2. Results and analysis

2.1. Key factors influencing the number and consequences of e-scooter accidents

A literature review has resulted in the development of a framework comprising eight factors (criteria) that influence both the frequency and the consequences of e-scooter accidents.

To identify the factors influencing both the frequency and consequences of e-scooter accidents, an expert questionnaire based on eight criteria was developed. The eight criteria enable a comprehensive assessment of the factors influencing both the frequency and consequences of e-scooter accidents. The questionnaire was adapted to evaluate the significance of the criteria using ranks, percentage weights, and the Analytic Hierarchy Process (AHP) method, which involves completing a pairwise comparison matrix. The questionnaire was submitted to 15 experts. The current research compares these criteria, assigning them ranks and percentage weights (see Table 4).

2.2. Ranking the significance of factors

Each of the 15 experts participating in the current research, drawing on their personal knowledge, expertise, experience, and intuition, completed the questionnaire by assigning ranks to the criteria (see Table 5), providing percentage weights, and filling out a pairwise comparison matrix for the factors.

Table 4. Factors influencing the frequency and severity of e-scooter accidents

Criterion Identifier	Safety Criterion	Description of the Criterion
A	Road or street element	E-scooters travel on various types of infrastructure, including single-level intersections, cycle and pedestrian paths, street carriageways, and yard exits. Intersections require increased attention due to a higher likelihood of interactions with other road users. Shared-use paths (such as cycle-pedestrian paths and carriageways) pose risks due to limited space. Exits from yards can be hazardous due to limited visibility.
B	Educational activities	Educational activities include information campaigns, training sessions, and social communication aimed at developing safe behaviour skills. Training programs for children and young people promote responsible behaviour, while public awareness messages on social networks raise awareness of safe practices. This helps foster a responsible public attitude toward traffic and reinforces the importance of adhering to city regulations.
C	Speed limits	Urban speeds should be adjusted to suit both traffic volume and available infrastructure. It is recommended to reduce speeds in areas where there is increased pedestrian presence (e.g. footpaths, cycle paths, intersections) and other vehicles. Speed limits tailored to specific zones help reduce collision risks and enhance stability and control, especially in high-risk areas.
D	Seasonality	Different seasons produce varying conditions for e-scooter traffic. In winter, snow and ice make it challenging to control the scooter. Summer can pose a risk of overheating, while autumn and spring characterized by rain, leaves on the road, and temperature fluctuations – also impact safety. Air temperature and rainfall influence braking distances and skid risk, which is particularly important in urban areas.
E	Maximum power	The e-scooter power directly influences its speed and acceleration, both critical safety factors. E-scooters with higher power, especially when operated by inexperienced riders, can be more challenging to control in urban environments requiring frequent speed adjustments. A maximum power limit ensures that scooters are easier to steer and brake.
F	Mandatory helmet use	Wearing a helmet helps reduce the likelihood of head injuries in the event of an accident. E-scooters reach speeds sufficiently high to render collisions with other road users or objects dangerous. Mandatory helmet use ensures users are better protected, reducing injury severity particularly in urban environments.
G	Type and quality of road surface	The type of surface (e.g., asphalt, concrete, cobblestones) affects scooter stability. Smooth surfaces, such as asphalt, provide greater safety and comfort, whereas concrete and cobblestone, which may feature cracks or irregularities, are less suitable. Pavement damage (such as potholes and cracks) increases the risk of accidents and necessitates regular maintenance.
H	Age of the road user	Minimum age restrictions ensure that users have the necessary skills to safely operate e-scooters. Children and adolescents often lack sufficient knowledge of traffic regulations and the required operational skills; therefore, establishing a minimum age limit helps reduce risks associated with inexperienced or risk-taking scooter users.

Table 5. Significance of factors influencing the number and consequences of e-scooter accidents in rank order

Expert $j = 1, 2, \dots, n$	Factor (criterion), $(j = 1, 2, \dots, m)$										Sum
	A	B	C	D	E	F	G	H			
E1	1	7	3	8	4	5	2	6	36		
E2	6	8	2	7	1	3	4	5	36		
E3	3	6	4	7	2	8	1	5	36		
E4	2	3	7	1	5	8	4	6	36		
E5	1	8	3	7	2	6	4	5	36		
E6	6	7	2	4	1	8	3	5	36		
E7	1	7	4	8	3	6	2	5	36		
E8	2	8	6	4	3	5	1	7	36		
E9	1	7	2	8	3	6	4	5	36		
E10	6	8	2	7	4	3	1	5	36		
E11	2	7	4	8	1	5	3	6	36		
E12	4	1	2	3	7	6	5	8	36		
E13	4	2	7	8	1	3	6	5	36		
E14	1	5	8	4	3	6	2	7	36		
E15	6	8	1	3	7	4	2	5	36		
$\sum_{j=1}^n R_{ij}$	46	92	57	87	47	82	44	85	540		
$\bar{R}_i = \frac{\sum_{j=1}^n R_{ij}}{n}$	3.07	6.13	3.80	5.80	3.13	5.47	2.93	5.67	36		
$\sum_{j=1}^n R_{ij} - \bar{R}$	-21.5	24.5	-10.5	19.5	-20.5	14.5	-23.5	17.5	0		

Expert $j = 1, 2, \dots, n$	Factor (criterion), $(j = 1, 2, \dots, m)$										Sum
	A	B	C	D	E	F	G	H			
$\left(\sum_{j=1}^n R_{ij} - \bar{R}\right)^2$	462.25	600.25	110.25	380.25	420.25	210.25	552.25	306.25	3042		
ARTIW-L method: $\omega_j = \frac{(m+1) - \bar{R}_i}{\sum_{i=1}^m \bar{R}_i}$	0.1648	0.0796	0.1444	0.0889	0.1630	0.0981	0.1685	0.0926	1.000		
Priority $u_j = \frac{\min \bar{R}_i}{\bar{R}_i}$	2	8	4	7	3	5	1	6	36		
	0.9565	0.4783	0.7719	0.5057	0.9362	0.5366	1.0000	0.5176	5.7029		
ARTIW-N method $\omega_j = \frac{u_j}{\sum_{i=1}^m u_i}$	0.1677	0.0839	0.1354	0.0887	0.1642	0.0941	0.1754	0.0908	1.000		
Priority	2	8	4	7	3	5	1	6	36		
Standard deviation $\sigma = \sqrt{\frac{\sum_{j=1}^n (R_{ij} - \bar{R})^2}{n-1}}$	2.0862	2.3258	2.2104	2.3664	1.9952	1.7265	1.5337	0.9759	-		

A minimum number of experts must be established to ensure that the results are accurate:

$$G_c = \frac{\max \sigma_{R_i}^2}{\sum_{i=1}^m \sigma_{R_i}^2} = \frac{2.37^2}{2.09^2 + 2.33^2 + 2.21^2 + 2.37^2 + 2^2 + 1.73^2 + 1.53^2 + 0.98^2} = \frac{5.6169}{30.5922} = 0.1836.$$

Given: $G_{kr}(0.05; 8; 14) = 0.2584$. $G_c = 0.1836 < G_{kr} = 0.2584$: variances are equal.

We have found that the variances of the eight criteria ranks are equal (according to Cochran's test). This enables us to calculate the overall average variance for the eight criteria:

$$\bar{\sigma}_{R_i}^2 = \frac{\sum_{i=1}^m \sigma_{R_i}^2}{m} = \frac{30.5922}{8} = 3.824.$$

Standard deviation:

$$\sigma_{R_i} = \sqrt{\bar{\sigma}_{R_i}^2} = \sqrt{3.824} = 1.9555.$$

$$\Delta_R = \sqrt{\frac{t^2 \sigma_R^2}{n}} = \sqrt{\frac{1.96^2 \times 1.9555^2}{15}} = 0.9896.$$

The precision of the result (Δ_R) is 0.9896, which is below the threshold of 1, based on interviews with 15 experts.

$$n_{\min} = \frac{t^2 \times \sigma_R^2}{\Delta_R^2} = \frac{1.96^2 \times 1.9555^2}{0.98996^2} = 15.000.$$

A minimum of 15 experts is required to ensure the accuracy of the current study.

To calculate W , the sum of the squares of the deviations S , is determined. This sum comprises

$$\sum_{j=1}^n R_{ij} \text{ and } \bar{R}.$$

The average rank for each criterion (criteria $i = 1, 2, \dots, m$; experts $j = 1, 2, \dots, n$):

$$\bar{R} = \frac{1}{2}n(m+1) = \frac{1}{2}15(8+1) = 67.5,$$

and sum of the squared deviations:

$$S = \sum_{i=1}^m \left[\sum_{j=1}^n R_{ij} - \frac{1}{2}n(m+1) \right]^2 = 3042.$$

Concordance coefficient:

$$W = \frac{12S}{n^2(m^3 - m)} = \frac{12 \times 3042}{15^2(8^3 - 8)} = 0.3219.$$

The minimum value of the concordance coefficient W_{\min} , at a significance level of $\alpha = 0.05$, given the degrees of freedom is $\nu = m - 1 = 8 - 1 = 7$:

$$W_{\min} = \frac{\chi_{\nu, \alpha}^2}{n(m-1)} = \frac{\chi_{0.05, 7}^2}{15(8-1)} = \frac{14.067}{105} = 0.134.$$

Pearson's criterion statistic is calculated:

$$\chi^2 = Wn(m-1) = 0.3219 \times 15 \times (8-1) = 33.80,$$

or, equivalently, for verification purposes:

$$\chi^2 = \frac{12S}{nm(m+1)} = \frac{12 \times 3042}{15 \times 8 \times (8+1)} = 33.80.$$

The consistency coefficient indicates that the experts' opinions are consistent and non-contradictory:

$$k_c = \frac{W}{W_{\min}} = \frac{\chi^2}{\chi_{\alpha, \nu}^2} = \frac{0.3219}{0.134} = \frac{33.80}{14.067} = 2.40.$$

The results indicate that the panel of 15 experts is in agreement regarding the significance of the factors influencing both the frequency and consequences of e-scooter accidents.

The weights for each criterion are calculated using the ARTIW-L (Equation (2)) and ARTIW-N (Equations (3) and (4)) methods, with the resulting priorities presented in Table 5. While the priorities of the criteria are identical across both MCDM methods, the weights w_i assigned to each criterion differ. The highest weights are assigned to criterion G ($\omega_G^{\text{ARTIW-L}} = 0.1685$, $\omega_G^{\text{ARTIW-N}} = 0.1754$), which reflects the type and quality of the carriageway surface for e-scooters. The weights for criterion A ($\omega_A^{\text{ARTIW-L}} = 0.1648$, $\omega_A^{\text{ARTIW-N}} = 0.1677$), indicating a road or street feature, are slightly lower, placing it in second position. Criterion B ($\omega_B^{\text{ARTIW-L}} = 0.0796$, $\omega_B^{\text{ARTIW-N}} = 0.0839$), assessing educational activities, is considered the least important by the experts. Criterion D ($\omega_D^{\text{ARTIW-L}} = 0.0889$, $\omega_D^{\text{ARTIW-N}} = 0.0887$), which evaluates the seasonality of the year, is also considered to be of low importance.

2.3. Determining the significance of the factors by percentage weights

The percentage weights assigned to the expert criteria are calculated using the DPW method (Equation (10)). The weights and priorities of the criteria w_i are presented in Table 6.

Table 6. Significance of the factors affecting the number and consequences of e-scooter accidents in percentage weights

Expert $j = 1, 2, \dots, n$	Factor (criterion), ($i = 1, 2, \dots, m$)								Suma
	A	B	C	D	E	F	G	H	
E1	24	7	15	6	12	10	18	8	100
E2	7.2	4.4	22	5.8	24	15.2	13	8,4	100
E3	16.7	8.3	13.9	5.6	19.4	2.8	22.2	11.1	100
E4	20	17	3	25	11	1	14	9	100
E5	22	4	17	5	19	9	13	11	100
E6	8.3	5.6	19.4	13.9	22.2	2.8	16.7	11.1	100
E7	25	5	13	2	16	9	20	10	100
E8	20	1	5	14	18	15	25	2	100
E9	20	4	18	2	16	13	15	12	100
E10	8.3	2.8	19.4	5.6	13.9	16.7	22.2	11.1	100
E11	15	9	13	8	18	12	14	11	100
E12	12	25	18	14	7	8	10	6	100
E13	15	20	3	1	30	19	5	7	100
E14	25	8	3	11	19	7	22	5	100
E15	8	3	27	15	5	13	19	10	100
DPW method $\sum_{j=1}^n p_{ij}^{DPW}$	246.5	124.1	209.7	133.9	250.5	153.5	249.1	132.7	1500
\bar{p}_i	16.4333	8.2733	13.9800	8.9267	16.7000	10.2333	16.6067	8.8467	100.0000
ω_i^{DPW}	0.1647	0.0809	0.1401	0.0894	0.1673	0.1025	0.1664	0.0886	1.0000
Priority	3	8	4	6	1	5	2	7	36
Standard deviation	6.4680	7.1202	7.4610	6.4988	6.4146	5.3372	5.3576	2.8188	-

The weights and prioritization of the criteria determined by the DPW method differ from those obtained using the ARTIW-L and ARTIW-N methods. The highest weights are assigned to criterion E (maximum power, kW) – $\omega_E^{DPW} = 0.1673$; and criterion G (type and quality of the road surface) – $\omega_G^{DPW} = 0.1664$. The least important criteria are criterion H (age of road users) and criterion B (educational activity), both receiving the lowest weights $\omega_H^{DPW} = 0.0886$ and $\omega_B^{DPW} = 0.0809$.

2.4. Determining the significance of factors using the AHP method

The normalized criterion weights ω_i^{AHP} and consistency ratios (C.R.) were calculated using the AHP method, based on the pairwise comparison matrices completed by each expert (see Table 7). All matrices were found to be consistent (C.R. < 0.1).

2.5. Comparison of the weights of criteria determined by the MCDM methods

The maximum weights determined by both the AHP method and the ARTIW-L/ARTIW-N methods correspond to criteria A and G ($\bar{\omega}_A^{\text{AHP}} = 0.1908$, $\bar{\omega}_G^{\text{AHP}} = 0.1858$). According to the AHP method, criteria H and B receive the lowest weights ($\bar{\omega}_H^{\text{AHP}} = 0.0599$, $\bar{\omega}_B^{\text{AHP}} = 0.0726$).

The average of the weights assigned to the criteria using the four expert evaluation methods yields the following priority ranking: G>A>E>C>F>D>H>B (Figure 2).

Table 7. Significance of factors influencing the number and consequences of e-scooter accidents, as determined by the AHP method

Expert $j = 1, 2, \dots, n$	Factor (criterion), ($i = 1, 2, \dots, m$)								Consistency Ratio (C.R.)
	A	B	C	D	E	F	G	H	
E1	0.3201	0.0294	0.1635	0.0207	0.1176	0.0633	0.2432	0.0422	0.0361
E2	0.0608	0.0273	0.2237	0.0341	0.3104	0.1668	0.1036	0.0733	0.0244
E3	0.1749	0.0563	0.1282	0.0408	0.1908	0.0289	0.2919	0.0882	0.0414
E4	0.2195	0.1381	0.0304	0.3941	0.0533	0.0239	0.1017	0.0389	0.0611
E5	0.3105	0.0211	0.1680	0.0259	0.2414	0.0533	0.0989	0.0809	0.0682
E6	0.0533	0.0357	0.2355	0.1052	0.3030	0.0191	0.1641	0.0841	0.0720
E7	0.3040	0.0331	0.1133	0.0215	0.1602	0.0528	0.2430	0.0720	0.0404
E8	0.2410	0.0166	0.0456	0.1022	0.1486	0.0731	0.3489	0.0239	0.0816
E9	0.3328	0.0420	0.1860	0.0342	0.1487	0.0639	0.1164	0.0761	0.0209
E10	0.0432	0.0190	0.2199	0.0375	0.1112	0.1758	0.3156	0.0779	0.0509
E11	0.2195	0.0378	0.1162	0.0216	0.2902	0.0896	0.1715	0.0537	0.0573
E12	0.1036	0.3279	0.2305	0.1562	0.0397	0.0433	0.0677	0.0311	0.0207
E13	0.1019	0.2204	0.0283	0.0145	0.3629	0.1585	0.0470	0.0666	0.0796
E14	0.3348	0.0620	0.0190	0.1042	0.1738	0.0378	0.2418	0.0267	0.0617
E15	0.0425	0.0217	0.3662	0.1488	0.0277	0.0973	0.2321	0.0636	0.0779
AHP method $\sum_{j=1}^n \omega_{ij}^{\text{AHP}}$	2.8624	1.0884	2.2743	1.2615	2.695	1.1474	2.7874	0.8992	15.0001
$-\text{AHP}$ ω_i	0.1908	0.072	0.1516	0.0841	0.1786	0.0765	0.1858	0.0599	1.0000
Priority	1	7	4	5	3	6	2	8	36
Standard deviation	0.1147	0.0894	0.0974	0.0985	0.1040	0.0519	0.0951	0.0221	-

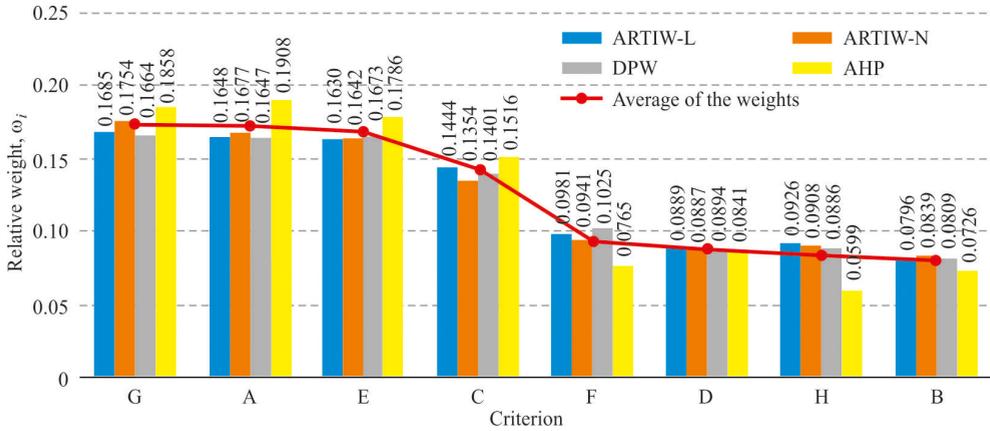


Figure 2. Significance (weights) of the factors (criteria) affecting the number of e-scooter accidents and their consequences, as determined by four different MCDM methods

Table 8. Weights, mean, and priority of the factors influencing the number and consequences of e-scooter accidents as determined by different methods

Criterion (factor) $i = 1, 2, \dots, m$	Method and weight				Average of the weights form the four methods $\bar{\omega}_i$	Priority
	ARTIW-L, $\omega_i^{\text{ARTIW-L}}$	ARTIW-N $\omega_i^{\text{ARTIW-N}}$	DPW ω_i^{DPW}	AHP ω_i^{AHP}		
A	0.1648	0.1677	0.1647	0.1908	0.1720	2
B	0.0796	0.0839	0.0809	0.0726	0.0793	8
C	0.1444	0.1354	0.1401	0.1516	0.1429	4
D	0.0889	0.0887	0.0894	0.0841	0.0878	6
E	0.1630	0.1642	0.1673	0.1786	0.1683	3
F	0.0981	0.0941	0.1025	0.0765	0.0928	5
G	0.1685	0.1754	0.1664	0.1858	0.1740	1
H	0.0926	0.0908	0.0886	0.0599	0.0830	7
Sum	1.0000	1.0000	1.0000	1.0000	1.0000	–

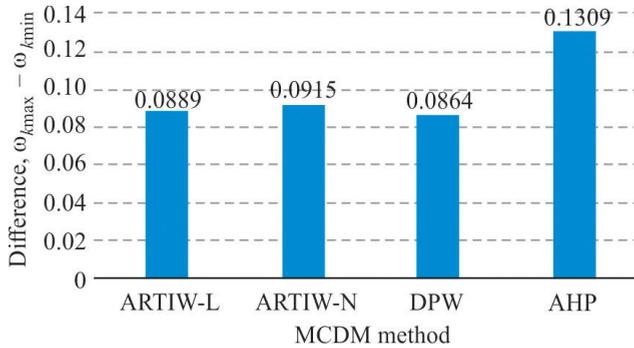


Figure 3. Differences in criteria weights calculated by different MCDM methods

$$\Delta\omega_j = \omega_{jmax} - \omega_{jmin}$$

The average of the weights for each criterion $\bar{\omega}_i$, calculated using the four MCDM methods (Equation (16)), is taken as the final result (see Table 8). It is likely that averaging the weights of criteria $\bar{\omega}_i$ across multiple methods yields a result closer to the overall expert population average than relying solely on the weight of the i -th criterion calculated using a single method. Figure 3 illustrates the differences $\Delta\omega_j$ in the weights calculated by the MCDM methods.

Conclusion and Recommendations

1. In many countries, the number of micromobility vehicles and their participation in traffic are growing rapidly, thereby creating additional road safety risks. Among all micromobility devices worldwide, e-scooters have experienced the largest increase in usage over the past three years. Therefore, by identifying and appropriately managing the key factors that influence both the frequency and consequences of e-scooter accidents, positive outcomes can be achieved.
2. The evaluation of the eight safety criteria selected for the research, conducted by fifteen experts, allowed for the determination of the significance of these criteria. The order of safety criteria priority, determined using the ARTIW-L and ARTIW-N methods, from most to least important, is as follows: type and quality of the road surface (weights 0.1685 and 0.1754); road or street element (weights 0.1648 and 0.1677); maximum power (weights 0.1630 and 0.1642); permissible speed limit (weights 0.1444 and 0.1354); mandatory helmet use (weights 0.0981 and 0.0941); age of the road user (weights 0.0926 and 0.0908); seasonality (weights 0.0889 and 0.0870); and educational activities (weights 0.0796 and 0.0839).

3. The weights and priority order of criteria calculated using the DPW method differ from those obtained using the ARTIW-L and ARTIW-N methods. The priority order of criteria determined by the DPW method is as follows: maximum power (weight 0.1673); type and quality of the road surface (weight 0.1664); road or street element (weight 0.1647); permissible speed limit (weight 0.1401); mandatory helmet use (weight 0.1025); seasonality (weight 0.0894); age of the road user (weight 0.0889); and educational activities (weight 0.0809).
4. The highest weights determined by the AHP method, similarly to the ARTIW-L and ARTIW-N methods, correspond to criteria A and G ($\omega_A^{\text{AHP}} = 0.1908$, $\omega_G^{\text{AHP}} = 0.1858$). The lowest weights identified by the AHP method correspond to criteria H and B ($\omega_H^{\text{AHP}} = 0.0599$, $\omega_B^{\text{AHP}} = 0.0726$). Averaging the criteria weights calculated by the four expert evaluation methods yields the following overall priority order: $G > A > E > C > F > D > H > B$.
5. The consistency of individual expert opinions was confirmed by the Consistency Ratio (C.R.), which was below 0.1. The consistency of the expert panel's collective opinions was evaluated using Kendall's Concordance Coefficient $W = 0.3219$, which exceeds the minimum acceptable value $W_{\min} = 0.134$.
6. As the number of micromobility vehicles, particularly e-scooters, and their involvement in traffic continue to grow rapidly, future research should analyse more thoroughly their impact on road safety and identify the most effective measures to reduce accident risks. To develop effective policies for regulating e-scooter traffic, international comparative studies assessing the effectiveness of safety measures across different countries, as well as their impact on accident reduction, would be highly beneficial.
7. The research results made it possible to identify the most important criterion, G (Type and quality of road surface), which has the greatest impact on the traffic safety of electric scooters.
8. In further research, it is necessary to examine the individual characteristics of this criterion (such as pavement type, smoothness, surface damage, etc.), which would allow for the regulation of electric scooter traffic.

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