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ASSESSMENT OF INTELLIGENT TRANSPORT SYSTEM CRITERIA GROUPS FOR ROAD TRANSPORT SYSTEM EVALUATION

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Abstract. Intelligent transport systems (ITS) are increasingly used to improve the performance of road transport systems, yet their overall contribution depends on how different impact criteria are prioritised. The aim of this study is to determine the relative importance (weights) of ITS criteria groups for use in an integrated road traffic system evaluation framework. An expert survey was performed in which specialists assessed predefined ITS criteria groups representing key areas of impact. The level of expert agreement was verified using Kendall's coefficient of concordance. The results provide a consistent weighting scheme that distinguishes the criteria groups considered by experts to have the greatest influence on the contribution of ITS to the functioning of the road transport system. The proposed expert-based weighting method increases the transparency of criteria selection and supports evidence-based decision-making when comparing ITS measures, setting investment priorities, and developing monitoring indicators. The results show that

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traffic safety received the highest weight (0.224), followed by traffic management (0.188) and traffic flow efficiency (0.183). Future research will extend the framework by decomposing each impact group into sub-criteria and eliciting expert judgments at the sub-criterion level, enabling more granular weighting within groups and improving the sensitivity of the overall evaluation. In addition, the derived weights can be validated in real-world case studies and complemented with empirical performance data.

Keywords: criteria weighting, expert survey, intelligent transport systems, Kendall's method, multi-criteria evaluation, road transport system.

Introduction

The digital transformation of road transport has increased the introduction of data-driven and adaptive management methods, where intelligent transport systems (ITS) are taking on an increasingly important role. ITS solutions are deployed to support key transport system objectives, such as improved safety, more reliable traffic management, and more sustainable use of infrastructure. As ITS matures, the need for systematic and transparent evaluation systems becomes more apparent, especially when ITS measures are compared, prioritized, or integrated into broader infrastructure planning.

However, the impact of ITS is multi-faceted: the same intervention can affect several areas of activity at the same time, and the scale and importance of these impacts may vary depending on the context. For this reason, an integrated perspective is needed to structure the impact of ITS into a logical assessment framework. In this study, this logic is conceptualized through the Multidimensional ITS Impact Assessment Framework, which divides the impact of ITS into key criteria groups for system-level assessment.

This multiplicity gives rise to the main methodological challenge: integrated evaluation requires not only the identification of impact areas, but also a justified method for prioritising them. In practice, most criteria assessment systems often use default or pre-selected weights, which may not reflect system-level priorities and reduce the transparency and reliability of results. This highlights the need to separate the measurement of ITS performance and the prioritisation of the relative importance of key impact areas within a single evaluation model.

Accordingly, the aim of this study is to determine the relative importance of six principal ITS criteria groups within the integrated evaluation of road transport system performance. The study applies expert assessment and Kendall's coefficient of concordance (W), which provides a statistically robust measure of agreement and enables the derivation of consensus-based criterion weights within an ordinal ranking framework.

To achieve the research aim and ensure a structured investigation of the proposed evaluation framework, the study addresses the following research questions:

– Which ITS impact criteria groups should be considered in a systematic road transport system evaluation framework aligned with transport policy objectives?
– What are the relative weights of these criteria groups based on expert assessment?
– Is the level of expert agreement sufficient to support statistically validated criterion weights?
– What are the implications of the obtained weights for ITS planning and integrated transport system evaluation?

The contribution of this study is threefold. First, it increases conceptual clarity by clearly separating the measurement of ITS impact from the prioritization of impact areas. Second, it applies a statistically sound method based on overlap to obtain empirically validated system-level weights. Third, it demonstrates the practical relevance of structured prioritisation in a national transport system characterised by heterogeneous infrastructure conditions and strategic transport functions.

By integrating contemporary ITS research, criteria-based evaluation principles, and a national transport management perspective, this study strengthens the methodological basis for integrated road transport system evaluation and supports evidence-based ITS investment planning.

1. Literature review

The digital transformation of transport systems has fundamentally changed the way road networks are planned, managed, and evaluated. In the European Union, Intelligent transport systems (ITS) are considered the basis for sustainable mobility policy. The European Strategy for Sustainable and Smart Mobility identifies digital infrastructure and ITS deployment as key factors in improving road safety, reducing congestion, ensuring environmental sustainability, and infrastructure resilience (European Commission, 2021). The revised ITS Directive (EU 2023/2661) further sets out mandatory requirements for the deployment of interoperable ITS in all Member States, particularly in TEN-T corridors (European Commission, 2023). These changes reflect a broader shift in governance, with digital technologies being integrated into systemic transport objectives. The latest EU-level guidelines indicate that ITS assessment is becoming more structured, but comparable indicators are being introduced in stages. The European Commission proposes a gradual approach to mandatory Key Performance Indicators (KPI) reporting and to introduce deployment and financial KPIs from 2025, while leaving benefit KPIs voluntary

(European Commission, 2024). This phased model means that, in practice, many countries still lack harmonized data on benefits, so until consistent monitoring data sets are developed, it becomes even more important to set clear impact priorities at the system level.

From a scientific perspective, ITS are increasingly understood as social and technical systems that integrate infrastructure, digital connectivity, institutional systems, and user behaviour. Empirical studies show that ITS influence many interrelated aspects of operations.

In the field of road traffic safety, a growing body of recent evidence confirms the effectiveness of intelligent traffic control. Using CAV-enabled data analytics to support adaptive signal timing, one recent study reports substantial reductions in surrogate collision risk at signalized intersections while also improving operational performance (Lin & Wei, 2023). In parallel, a recent structured literature review on cooperative ITS (C-ITS) highlights that vehicle-to-everything connectivity (including V2I) can enhance situational awareness through information exchange and warning services, which is consistently framed as a key pathway to improved safety outcomes (Walch et al., 2025). Taken together, these findings suggest that ITS implementation contributes not only to operational optimisation but also to a measurable reduction in crash risk.

Improving operational efficiency is another area of impact that has been widely studied. From an operational reliability perspective, data-driven corridor management, particularly the prioritization and implementation of signal retiming, has been linked to improvements in corridor travel time reliability and overall delay performance (Dobrota et al., 2024). From a network-control perspective, integrated optimisation of signal timing and vehicle trajectories in mixed traffic has been proposed as a practical way to reduce intersection delay while maintaining computational feasibility for real-time use; for example, a two-level hierarchical framework jointly optimises signal timing and desired arrival times (upper level) and then computes connected and automated vehicle (CAV) trajectories (lower level), reporting substantial reductions in delay (and related operational indicators such as idling time) across different CAV penetration rates (Zou et al., 2024). At the corridor scale, system-level evaluations show that coordinated, demand-responsive traffic control can improve network performance by reducing delay, stops, and corridor travel times (Al Farabi et al., 2024). These studies jointly illustrate that ITS change network dynamics by improving adaptability and responsiveness.

Environmental sustainability is becoming an increasingly important focus in ITS research, especially when traffic management measures can deliver tangible reductions in energy use and emissions. At the intersection level, recent studies have started to pair real-time sensing with adaptive control so that environmental impacts are considered alongside delay and throughput. For instance, an adaptive signal-optimisation approach that combines thermal sensors with reinforcement learning reports improved traffic performance and frames "cost-aware" signal control as a practical route to lowering traffic-related environmental burdens (Balashov et al., 2026). Beyond intersections, connected-vehicle eco-driving solutions can extend these benefits to corridor operations, which is particularly relevant for freight movements. A recent U.S. based study presents a computationally efficient method for estimating corridor and network-level energy savings from Eco-Approach and Departure (EAD) strategies for heavy-duty trucks, and validates the method using real corridor case studies. The results show that the scale of energy savings can differ considerably from one corridor to another, while still being feasible to evaluate with limited data inputs (Wei et al., 2024).

Based on roadside air-quality measurements and data-driven evaluation, smart, adaptive traffic interventions can reduce roadside NO_2 concentrations (including peak levels), placing ITS in the broader context of climate-change mitigation and the transition to sustainable mobility (Munir et al., 2022).

Beyond safety, efficiency, and environmental outcomes, ITS influences infrastructure resilience and long-term asset management. Regarding long-term system readiness, digital infrastructure preparedness emerges as a prerequisite for supporting advanced mobility systems (Gouda et al., 2021). Recent research on bridge digital twins shows that integrating sensor-based monitoring with data acquisition, transmission, and integration workflows can support condition assessment and enable more data-driven life-cycle maintenance planning. Accordingly, ITS-enabled digital monitoring affects not only day-to-day maintenance performance but also the long-term structural sustainability of transport infrastructure by helping agencies plan interventions earlier and more efficiently (Kang et al., 2025). However, recent synthesis studies highlight a persistent comparability challenge in ITS/C-ITS evaluation: even when impacts are widely documented, studies operationalise them using different assessment logics and indicator sets. Walch with other researchers note that impact assessment plays a central role whereby the approaches and methods used can differ significantly, and that the literature varies in the impact categories and KPIs used to quantify the impacts (Walch et al., 2025). This heterogeneity complicates cross-study and cross-jurisdiction comparisons and supports the need for a consistent system-level structure of impact areas (criteria groups) before weights are elicited and results are aggregated.

Despite the scope of empirical research, ITS evaluation at the system level remains fragmented in terms of concept and methodology. Most studies focus on the quantitative assessment of individual performance indicators, without considering the relative importance of broader impact areas in an integrated assessment system. Mardani with other researchers note that multi-criteria decision-making methods are widely used in transport research, but the weighting coefficients are often predetermined rather than empirically derived (Mardani et al., 2016).

Methodological studies on multi-criteria assessment increasingly show that relying only on expert opinion (subjective weights) or only on data dispersion (objective weights) can reduce robustness and reproducibility. Therefore, hybrid weighting and clear consensus confirmation are receiving increasing attention. Dong and co-authors point to the insufficient integration of subjective and objective weighting methods and propose a system that evaluates reliability using the Kendall's coefficient of concordance for expert consensus (Dong et al., 2025). Although the context of their application is different, the conclusion can be transferred to the evaluation of the ITS system level: confirmation of expert agreement (e.g., Kendall W) strengthens the reliability of the weights obtained compared to default, ad hoc, or predefined weighting schemes. However, within ITS assessment specifically, hierarchical prioritisation of impact areas is still rarely grounded in statistically validated expert agreement.

This shortcoming reveals a key difference between impact measurement and impact prioritization. Although safety improvements, efficiency increase, environmental impact, infrastructure sustainability, and monitoring capabilities can be measured separately, their systemic importance in an integrated assessment system requires a structured prioritization. Without clear weightings based on expert consensus, the evaluation of multiple criteria risks treating fundamentally different areas of activity as equally important, which may lead to misguided strategic investment decisions.

The relevance of this methodological study is particularly evident in a national context characterised by a heterogeneous road network and limited financial resources. Lithuania is precisely such a case. Located along the North-South TEN-T corridor, including the Via Baltica route, Lithuania experiences intense transit flows while maintaining an extensive regional road network. In recent years, ITS deployment has expanded with the introduction of traffic monitoring systems, enforcement technologies, and dynamic information solutions (Lithuanian Ministry of Transport and Communications, 2024). However, official assessments show that there is no unified methodological system in place to prioritise ITS impact areas in an integrated road transport assessment model (Kurk Lietuvai, 2024).

Given Lithuania's dual function as a transit corridor and a regionally structured network, determining the relative strategic importance of safety, efficiency, environmental sustainability, infrastructure maintenance, traffic management, and monitoring capabilities becomes a critical management issue. Although Lithuanian researchers have studied the factors influencing ITS development (Okunevičiūtė-Neverauskienė et al., 2021), a systematic expert-based prioritization of ITS criteria groups has not yet been carried out.

2. Multidimensional ITS impact assessment framework

The authors' experience gained from performing ITS-related research and road transport system assessments, together with a structured analysis of international scientific literature, professional contacts, and discussions with experts in the fields of road transport infrastructure, traffic management, safety, and environmental assessment, as well as a review of relevant strategic and regulatory documents, has made it possible to systematise the main areas in which ITS contribute to the functioning of the road transport system.

Based on this analysis, the study developed a multidimensional ITS impact assessment system, which divides the research area into six main groups of criteria (A–F): traffic safety (group A), traffic flow efficiency (group B), environmental impact (group C), infrastructure condition and maintenance (group D), traffic management (group E), and traffic monitoring (group F) (Figure 1). It is important to note that these groups are not treated as a single set of impact indicators but rather reflect functionally different but interrelated system-level areas operating at different analytical levels. Groups A–C primarily cover results-oriented aspects of operations, reflecting the measurable results of ITS implementation (safety, efficiency, and environmental impact). Group D examines the level of sustainability of assets and infrastructure, linking ITS to long-term infrastructure operation and life cycle optimisation. Groups E and F cover operational and auxiliary levels: traffic management (E) reflects real-time control and intervention mechanisms, while traffic monitoring (F) provides the data basis necessary for both operational decision-making and reliable impact assessment.

This layered structure reflects the systemic logic of ITS operation: monitoring enables control, control actions influence traffic operations, operational changes affect safety, efficiency, and environmental outcomes, and long-term system performance depends on infrastructure condition and maintenance strategies, thus supporting an integrated assessment without oversimplifying fundamentally different areas. In this framework, each main group is further linked to representative sub-elements (future research areas in Figure 1), indicating potential measurable elements in the area and providing a coherent structure for further prioritization.

To determine the relative importance of the six main criteria groups in the integrated ITS assessment model, their structured descriptions were presented to a panel of experts, who ranked the groups from 1 (most important) to 6 (least important), without assigning equal ratings. The ratings obtained were analysed using Kendall's coefficient of concordance to assess expert agreement and obtain statistically validated weights for the main criteria groups, establishing a hierarchical basis for further stages of multidimensional ITS impact assessment.

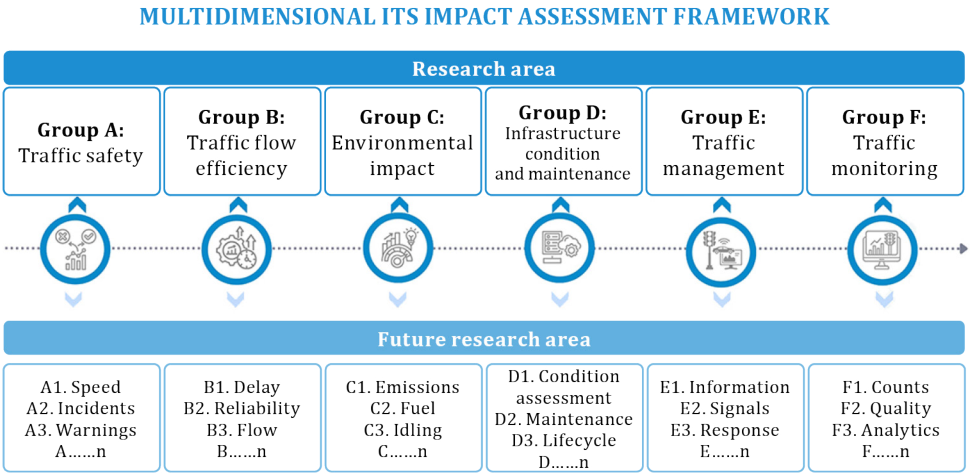

Figure 1. Multidimensional framework of ITS criteria groups for road transport system evaluation

Group A (Q1). Traffic safety. This group includes the impact of ITS on road user safety by analysing changes in traffic accident risk, frequency, and severity of accidents. It covers ITS measures designed to prevent incidents by applying traffic accident risk reduction measures and creating a safer traffic environment. The concept is based on the assumption that ITS can improve traffic safety through two complementary mechanisms: behavioural adaptation, such as compliance with speed limits and safer manoeuvring, and risk reduction in road user behaviour, including earlier threat detection, timely warnings, and better situational awareness. The evaluation system, therefore, covers both final safety outcomes, such as the frequency and severity of traffic accidents and incidents, and intermediate indicators reflecting the outcomes of road safety activities and the occurrence of safety-critical situations.

Group B (Q2). Traffic flow efficiency. This group assesses how ITS affect traffic flow efficiency and stability, i.e., how smoothly and predictably traffic moves in road transport corridors. It focuses primarily on congestion-related disruptions, such as additional travel time, delays, and frequent acceleration and deceleration. The group also assesses the reliability of travel conditions, i.e., the consistency of travel times from day to day, which is important for both road users planning their journeys and companies managing the network. ITS are expected to improve traffic flow by enabling faster and more accurate control actions (e.g., adaptive signal control or dynamic speed management) and by limiting the spread of disruptions (e.g., incidents or sudden slowdowns) in transport corridors.

Group C (Q3). Environmental impact. This group assesses how ITS affect the environment by examining how changes in traffic are reflected in fuel/energy consumption and pollutant emissions. When ITS help traffic flow more smoothly by reducing the number of stops and starts, excessive acceleration and braking, and idling vehicles typically consume less fuel and emit fewer air pollutants and greenhouse gases. Beyond these direct operational effects, ITS can contribute to environmental protection by improving travel planning, coordinating traffic management, and reducing congestion, thereby lowering overall emissions in the road transport corridor and surrounding areas. At the same time, some ITS measures may redistribute traffic in space or time (e.g., by encouraging route changes), leading to decreases in emissions at one location and increases at another. For this reason, the assessment takes into account not only the total amount of emissions, but also their spatial distribution, especially in areas where the impact is greatest (e.g., densely populated urban corridors, intersections, or areas near busy transport corridors).

Group D (Q4). Infrastructure condition and maintenance. Group D assesses how ITS contribute to assessing infrastructure condition and pavement deterioration, and to coordinating maintenance and renovation operations. The group examines ITS measures that support data-driven asset management by improving infrastructure condition monitoring and by planning and prioritizing maintenance decisions. In practical terms, this includes solutions for controlling overweight vehicles, which help reduce accelerated pavement deterioration, as well as methods that can reduce maintenance and repair needs by identifying problems earlier and applying more preventive measures. In addition, the group is examining how ITS can improve the planning and execution of road works, including schedules that reduce disruption and technologies that reduce the impact of work zones on traffic (e.g., improved information provision, dynamic traffic management, and safer, more efficient work zone operations).

Group E (Q5). Traffic management. Group E assesses how ITS improve daily traffic management by providing real-time monitoring, information provision, and traffic condition control. Essentially, this group focuses on how the transport system can be actively managed, for example, by informing road users, adjusting control settings, and implementing operational measures to ensure safe and efficient traffic flow. The group examines the entire chain of operations: situation awareness, i.e., how quickly and accurately the system detects current conditions and communicates them to operators and road users; control actions, i.e., what control measures are applied (e.g., signal synchronization adjustments, dynamic speed control, lane or ramp control, routing guidelines); and system response, i.e. whether these actions reduce congestion, improve compliance, and help the network recover more quickly from disruptions such as incidents, peak demand, or roadwork. This group is particularly relevant for coordinated schemes, whose effectiveness depends not only on the availability of control infrastructure, but also on the speed of response, the quality of implementation, and the compliance of road users with the instructions provided.

Group F (Q6). Traffic monitoring. Group F focuses on traffic monitoring capabilities, which are essential for both the effective operation of ITS and the reliable assessment of their impact. In practical terms, this group assesses whether the transport system has adequate data to understand what is happening on the road network in real time and to evaluate how conditions change after the deployment of ITS measures. The basic assumption is that any assessment is only as reliable as the monitoring on which it is based: if traffic conditions and dynamics are not monitored accurately and consistently, conclusions about the impact of ITS become unclear. Accordingly, the group covers three closely related aspects. First, it examines data availability and coverage, i.e., whether the observations provide sufficient representation of traffic conditions in key corridors and nodes across the spatial and temporal dimensions. Second, it examines data quality, including accuracy, completeness, continuity, and long-term stability (e.g., calibration and comparability over time). Third, it assesses analytical utility, i.e., the ability to convert raw measurements into operationally useful information, e.g., anomaly and incident detection, traffic condition assessment, performance reports, and short-term forecasts that support operators in their decision-making.

3. Research methodology

To determine the relative importance of the main criteria groups defined in the multidimensional ITS impact assessment system, an expert assessment was carried out using Kendall's coefficient of concordance (W). Kendall's method was chosen because of its suitability for analysing ordinal data and assessing the degree of agreement among several experts when ranking alternatives or criteria.

The Kendall method was used for the evaluation, according to which the criteria groups were ranked on a scale of one to six. A total of 20 questionnaires were completed and their data used for the evaluation.

Individually interviewed experts (hereafter referred to as E1–E20) provided their assessments of the importance of the main groups of criteria (hereafter referred to as Q1–Q6) for the impact of ITS on the road traffic system, using their personal expertise, experience, qualifications, and intuition. These assessments are presented in Table 1. The evaluation values for each group were determined using a 6-point scale. If the evaluated component is deemed the least important ITS impact on the road traffic system, then it is assigned 6 points, and if the component is considered the most important, it is assigned 1 point, with the points for the other components allocated accordingly. Each rating could only be used once, thus ensuring a complete, non-duplicative rating of all criteria groups by each expert.

The experts were selected for the assessment of the main criteria groups based on their work experience (no less than five years), position at their workplace (division level and higher) and academic degrees (Master degree and higher) in fields related to the research. The expert group consisted of specialists from Lithuania with professional expertise in innovation, ITS, communications, road infrastructure and road network management, traffic safety, environmental protection, research, and transport policy making. The survey involved experts from government institutions, infrastructure management organizations, the academia, and the ITS technology development field. Although all experts represented Lithuanian institutions, a substantial proportion possessed international experience through participation in international ITS and transport-related projects, expert activities abroad, contributions to international scientific and professional conferences, and teaching and research activities in the fields of intelligent transport systems and road transport management. A total of twenty questionnaires were sent for expert evaluation, describing in detail the main groups of criteria identified by the authors.

Table 1. Ranks of the groups of criteria assigned by each expert (Source: Authors, 2026)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20
Q1	1	1	4	5	2	1	1	5	1	3	4	4	2	1	1	1	1	2	4	2
Q2	5	3	5	3	3	2	2	4	2	5	5	5	4	3	3	2	2	1	3	1
Q3	6	4	6	6	4	6	4	6	6	6	6	6	6	6	2	5	3	5	1	6
Q4	3	5	3	4	1	3	5	3	5	1	2	3	1	5	6	3	6	4	2	4
Q5	2	2	2	1	5	4	3	1	3	2	3	1	3	2	4	6	4	3	5	5
Q6	4	6	1	2	6	5	6	2	4	4	1	2	5	4	5	4	5	6	6	3

Kendall's coefficient of concordance is widely recognized as a reliable statistical method for assessing the degree of agreement among experts when analysing ordinal ratings. This method was first introduced by Kendall as a measure of rank correlation designed to assess the consistency of different experts' opinions when they evaluate the same set of alternatives (Kendall, 1970). The methodological framework of rank correlation analysis was later further developed by Kendall and Gibbons, who extended its application to more complex expert evaluation situations involving multiple evaluators and rated variables (Kendall & Gibbons, 1990). When there are more than two participants in expert groups, Kendall's coefficient of concordance (W) is typically used to assess the overall level of agreement among group members. The coefficient ranges from 0 (no agreement) to 1 (perfect agreement), allowing researchers to determine whether expert assessments are consistent enough to proceed with analysis and decision-making procedures. Since expert surveys in transport system studies are typically based on ordinal rankings rather than precise quantitative measurements, Kendall's W coefficient is considered particularly suitable for analysing such data structures (Mardani et al., 2016). The use of Kendall's W in large-scale expert evaluations has been discussed by Zavadskas, Peldschus, and Kaklauskas, who emphasise its importance in ensuring the consistency and reliability of expert rankings (Zavadskas et al., 1994). Subsequent research by Zavadskas and Vilutienė further confirms the suitability of Kendall's W for similar expert-based analyses (Zavadskas & Vilutienė, 2006). Similarly, Palevičius and co-authors applied Kendall's coefficient of concordance (W) to evaluate the consistency of expert judgements in determining the relative importance of assessment criteria within a multi-criteria decision-making framework for the development of autonomous travel (Palevičius et al., 2020). In addition, Ginevičius highlights the flexibility of Kendall's W and its practical applicability across a range of contemporary research contexts (Ginevičius, 2011). The latest transport-related research once again confirms the practicality of Kendall W in structuring and confirming expert ratings in the context of road transport technology assessment (Kondratovič et al., 2024). Given that the Kendall method is specifically designed for ordinal data, it is particularly well suited to the present study. Moreover, the method is conceptually straightforward and computationally transparent, which facilitates its application in practical evaluations (Jakimavičius et al., 2016).

Considering that this study is based on expert ranks according to ITS criteria groups, Kendall's coefficient of concordance is an appropriate methodological choice. This method allows for statistical verification of the degree of expert agreement without losing the ordinal nature of the ranking data. In addition, this method is conceptually transparent and simple to calculate, making it easy to apply in practical expert assessments.

Kendall concordance coefficient is linked with the sum of rank of each factor Rj and with regard to experts:

$$R_j = \sum_{i=1}^{n} R_{ij}, \; j = 1,2,\ldots,m. \tag{1}$$

The mean rank of each factor $\overline{R}$ is obtained dividing the sum of ranks assigned thereto by number of factors:

$$\overline{R} = \frac{\sum_{j=1}^{m} R_j}{m}, \tag{2}$$

where R_{ij} – the rank given by expert i to factor j; n – the number of experts (i = 1, 2, ..., n); m – the number of factors (j = 1, 2, ..., m).

The difference between sum of ranks R_{ij} and constant quantity $1/2\,n(m+1)$ is calculated for each criterion:

$$\sum_{i=1}^{n} R_{ij} - \frac{n(m+1)}{2}. \tag{3}$$

The square of the difference between sum of ranks R_{ij} and constant quantity $1/2\,n(m+1)$ is calculated:

$$\left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2}n(m+1)\right]^2. \tag{4}$$

Upon calculation as per Equations (1)–(4), the next step is to calculate the concordance coefficient W:

$$W = \frac{12S}{n^2(m^3 - m)}. \tag{5}$$

Significance of concordance coefficient and compatibility of expert evaluation of factor groups is determined by χ^2:

$$\chi^2 = \frac{12S}{nm(m+1)}. \tag{6}$$

Min value of the concordance coefficient $W_{\min}$ is calculated using Equation (7):

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

where $\chi^2_{\nu,\alpha}$ – Pearson critical statistics, which value is found in the table (Montgomery, 2009), taking the degree of freedom $\nu = m - 1$ and significance level α.

4. Results

To assess the consistency of expert assessments, Kendall's coefficient of concordance (W) was calculated. The statistical significance of the obtained coefficient of concordance was tested using the chi-square (χ^2) test. The results of the concordance analysis are presented in Table 2.

Table 2. Results of Kendall's concordance analysis (Source: Authors, 2026)

Statistic indicator	Value
Number of experts (*n*)	20
Number of criteria groups (*m*)	6
Kendall's coefficient of concordance (*W*)	0.247
Chi-square statistic (χ^2)	24.7
Degrees of freedom ($m-1$)	5
Significance level (*p*-value)	< 0.05

The calculated value of Kendall's coefficient of concordance was $W = 0.247$, indicating a low-to-moderate level of agreement among the experts. The corresponding chi-square statistic was $\chi^2 = 24.7$, with $m - 1$ degrees of freedom, and the obtained p-value < 0.05, confirming that the agreement among experts is statistically significant. Therefore, the expert rankings can be considered sufficiently consistent and suitable for determining the weights of the ITS criteria groups.

The assessments of 20 experts showed that the most important criterion for evaluating the impact of ITS on the road transport system was traffic safety (Q1), which had a weight of 0.224. Traffic management (Q5) was ranked second in importance (0.188), followed by traffic flow efficiency (Q2) (0.183). The weights of all criteria groups are shown in Figure 2.

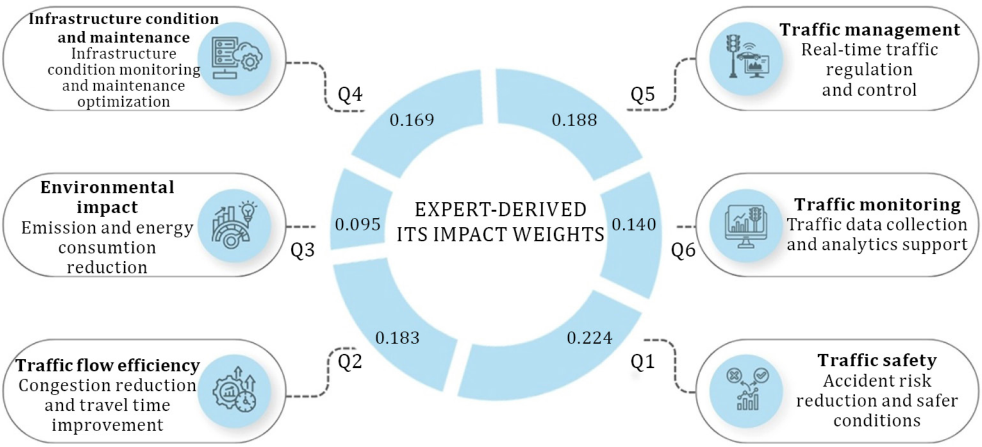

Figure 2. Determined weights for each group of criteria

Conclusions

This study identified and evaluated six main groups of criteria describing the impact of ITS on the road transport system and determined their relative importance using Kendall's coefficient of concordance based on expert assessment. The results provide a structured and empirically based prioritization of ITS impact dimensions, suitable for further multi-criteria analysis.

The results show that traffic safety (Q1) is the most important group of criteria (Q1 = 0.224). This confirms that, in the opinion of experts, the main objective of ITS implementation is to reduce the risk, frequency, and severity of traffic accidents. Therefore, safety-related results are considered the key performance indicator in the detailed evaluation system.

The second and third most important groups – traffic management (Q5 = 0.188) and traffic flow efficiency (Q2 = 0.183) – emphasise the importance of operational efficiency and real-time system reactions. Experts highlighted ITS's ability to improve network management, reduce congestion, stabilise traffic conditions, and increase travel time reliability. Their close weights indicate that operational management and traffic flow efficiency are closely related dimensions of ITS effectiveness.

The infrastructure condition and maintenance (Q4 = 0.169) was rated as having medium importance, indicating recognition of ITS's contribution to data-driven asset management, pavement preservation, and the optimisation of maintenance measures. Although these long-term infrastructure benefits are not as obvious as the effects on safety or congestion reduction, they remain an important component of the system's sustainable development.

Traffic monitoring (Q6 = 0.140) was rated as a facilitating but secondary aspect. The results show that monitoring functions – data availability, quality assurance, and analytical capabilities – are primarily valued as prerequisites for effective ITS operation rather than as direct impact outcomes. Reliable monitoring ensures the validity and credibility of performance assessment, but is not in itself the ultimate goal of the system.

The lowest weight was assigned to environmental impact (Q3 = 0.095). Although ITS measures can contribute to reducing emissions and increasing energy efficiency by ensuring smoother traffic flow, environmental benefits are considered indirect and context-dependent, compared with the direct improvements in safety and performance.

The obtained weighting distribution indicates that the greatest importance was assigned to traffic safety, traffic management, and traffic flow efficiency. Together, these three criteria groups account for approximately 60% of the total weight, suggesting that experts place greater emphasis on the direct operational outcomes of ITS than on supporting dimensions such as environmental impact, monitoring, and infrastructure-related aspects. In general, the expert-based weighting structure reveals a clear hierarchy of priorities: safety and performance dominate the assessment of ITS impacts, while infrastructure sustainability, monitoring capabilities, and environmental performance play a complementary role. These results provide a theoretically and methodologically grounded basis for developing an integrated multi-criteria evaluation model, ensuring that subsequent decision-making processes reflect the priorities identified by experts and the system-level engineering objectives. The proposed weighting framework may therefore contribute to more transparent prioritisation of ITS measures and support evidence-based transport planning and investment decisions.

Future research should extend the framework by decomposing criteria groups into sub-criteria and validating the weights through empirical case studies.

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Author contributions

All authors contributed equally to this work. JR developed the project idea, analysed the data, conducted the expert survey, led the development of the methodology, and contributed to drafting the manuscript. OV developed the quantitative and qualitative data collection model, created the graphs and figures, prepared the tables, outlined the conclusions and recommendations, and contributed to drafting the manuscript. VP performed the weighting calculations and the multi-criteria analysis. VV analysed the data and contributed to revising the draft and improving the final manuscript. All authors discussed the results and commented on the manuscript. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

The authors declare no conflict of interest.

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

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to improve the language, grammar, and readability of the text. All AI-generated suggestions were critically reviewed, edited, and verified by the authors. The authors take full responsibility for the final content of the manuscript.

REFERENCES

Al Farabi, A., Mohebifard, R., Niroumand, R., Hajbabaie, A., Hadi, M., & Elefteriadou, L. (2024). Integrated corridor management by cooperative traffic signal and ramp metering control. *Computer-Aided Civil and Infrastructure Engineering*, *39*(16), 2439–2456. https://doi.org/10.1111/mice.13199

Balashov, A., Ponomaryova, O., Balashova, Y., & Tregub, O. (2026). Adaptive traffic signal optimization with thermal sensors and reinforcement learning. *Results in Engineering*, *29*, Article 108601. https://doi.org/10.1016/j.rineng.2025.108601

Dobrota, N., Cesme, B., Fisher, C., Mead, P., Tahmasebi, M., & Shastri, A. (2024). Data-driven statewide prioritization of corridors for signal retiming projects. *International Journal of Transportation Science and Technology*, *16*, 260–275. https://doi.org/10.1016/j.ijtst.2024.02.005

Dong, Z., Yang, J., Yuan, R., Su, G., & Lei, M. (2025). A game-theoretic Kendall's coefficient weighting framework for evaluating autonomous path planning intelligence. *Automation*, *6*(4), Article 85. https://doi.org/10.3390/automation6040085

European Commission. (2021). *Sustainable and Smart Mobility Strategy – putting European transport on track for the future*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789

European Commission. (2023). *Directive (EU) 2023/2661 on the framework for the deployment of Intelligent Transport Systems (ITS Directive)*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023L2661

European Commission. (2024). *Intelligent transport systems – Key performance indicators for the EU*. https://transport.ec.europa.eu/document/download/93ba8375-0ac0-477d-b6a9-9deca6b5b01d_en?filename=Guidance_document-ITS_KPI_for_the_EU.pdf

Ginevicius, R. (2011). A new determining method for the criteria weights in multi-criteria evaluation. *International Journal of Information Technology & Decision Making*, *10*(6), 1067–1095. https://doi.org/10.1142/S0219622011004713

Gouda, M., Chowdhury, I., Weiß, J., Epp, A., & El-Basyouny, K. (2021). Automated assessment of infrastructure preparedness for autonomous vehicles. *Automation in Construction*, *129*, Article 103820. https://doi.org/10.1016/j.autcon.2021.103820

Jakimavičius, M., Burinskienė, M., Gusarovienė, M., & Podviezko, A. (2016). Assessing multiple criteria for rapid bus routes in the public transport system in Vilnius. *Public Transport*, *8*(3), 365–385. https://doi.org/10.1007/s12469-016-0146-7

Kang, C., Walker, M., Bartels, J.-H., Marzahn, G., & Marx, S. (2025). Digital twin technologies for bridge lifecycle management – Literature insights and a pilot study on the Nibelungen Bridge. *Results in Engineering*, *28*, Article 108288. https://doi.org/10.1016/j.rineng.2025.108288

Kendall, M. G. (1970). *Rank correlation methods* (4th ed.). Griffin London.

Kendall, M. G., & Gibbons, J. D. (1990). *Rank correlation methods* (5th ed.). Oxford University Press.

Kondratovič, V., Palevičius, V., Čygas, D., Rimkuvienė, J., & Smirnovs, J. (2024). Assessment of the road ecosystem for autonomous vehicles. *The Baltic Journal of Road and Bridge Engineering*, *19*(4), 119–135. https://doi.org/10.7250/bjrbe.2024-19.651

Kurk Lietuvai. (2024). *Intelektinių transporto sistemų plėtros galimybės Lietuvoje*. https://kurklt.lt/projektai/intelektiniu-transporto-sistemu-pletros-galimybes-lietuvoje

Lin, W., & Wei, H. (2023). CAV-enabled data analytics for enhancing adaptive signal control safety environment. *Accident Analysis & Prevention*, *192*, Article 107290. https://doi.org/10.1016/j.aap.2023.107290

Lithuanian Ministry of Transport and Communications. (2024). *Analysis of the ITS situation in Lithuania*. https://sumin.lrv.lt/public/canonical/1725452082/11438/Intelektinių%20transporto%20sistemų%20situacija%20Lietuvoje.pdf

Mardani, A., Zavadskas, E. K., Khalifah, Z., Jusoh, A., & Md Nor, K. (2016). Multiple criteria decision-making techniques in transportation systems: a systematic review of the state of the art literature. *Transport*, *31*(3), 359–385. https://doi.org/10.3846/16484142.2015.1121517

Montgomery, D. C. (2009). *Design and analysis of experiments* (7th ed.). John Wiley & Sons, Inc.

Munir, S., Luo, Z., Dixon, T., Manla, G., Francis, D., Chen, H., & Liu, Y. (2022). The impact of smart traffic interventions on roadside air quality employing machine learning approaches. *Transportation Research Part D: Transport and Environment*, *110*, Article 103408. https://doi.org/10.1016/j.trd.2022.103408

Okunevičiūtė-Neverauskienė, L., Novikova, M., & Kazlauskienė, E. (2021). Factors determining the development of intelligent transport systems. *Business, Management and Economics Engineering*, *19*(2), 229–243. https://doi.org/10.3846/bmee.2021.15368

Palevičius, V., Ušpalytė-Vitkūnienė, R., Damidavičius, J., & Karpavičius, T. (2020). Concepts of development of alternative travel in autonomous cars. *Sustainability*, *12*(21), 8841. https://doi.org/10.3390/su12218841

Walch, M., Schirrer, A., & Neubauer, M. (2025). Impact assessment of cooperative intelligent transport systems (C-ITS): A structured literature review. *European Transport Research Review*, *17*, Article 11. https://doi.org/10.1186/s12544-024-00702-9

Wei, Z., Hao, P., Kailas, A., Amar, P., Palmeter, K., Levin, L., Orens, S., Barth, M. J., & Boriboonsomsin, K. (2024). Computationally efficient approach for evaluating eco-approach and departure for heavy-duty trucks. *Transportation Research Record, 2678*(12), 2033–2045. https://doi.org/10.1177/03611981241254112

Zavadskas, E. K., Peldschus, F. & Kaklauskas, A. (1994). *Multiple criteria evaluation of projects in construction*. Technika.

Zavadskas, E. K., & Vilutienė, T. (2006). A multiple criteria evaluation of multi-family apartment block's maintenance contractors: I–Model for maintenance contractor evaluation and the determination of its selection criteria. *Building and Environment*, *41*(5), 621–632. https://doi.org/10.1016/j.buildenv.2005.02.019

Zou, Y., Zheng, F., Liu, C., & Liu, X. (2024). Integrated optimization of traffic signals and vehicle trajectories for mixed traffic at signalized intersections: A two-level hierarchical control framework. *Transportation Research Part C: Emerging Technologies, 169*, Article 104884. https://doi.org/10.1016/j.trc.2024.104884