



WASPAS Multi-Criteria Decision-Making Method for Assessment Effectiveness and Performance Intelligent Transportation Systems Alternatives

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Abstract

The assessment of Intelligent Transportation Systems (ITS) plays a vital role in understanding their effectiveness, efficiency, and impact on transportation networks. This abstract provides an overview of the criteria for assessing ITS and highlights the importance of a comprehensive and multidimensional approach. The requirements discussed include safety, efficiency, mobility, environmental impact, user satisfaction, cost-effectiveness, scalability and interoperability, data security and privacy, technological reliability and resilience, regulatory and policy compliance, equity and accessibility, system integration, innovation and future-readiness, stakeholder engagement, performance monitoring and evaluation, resilience and disaster preparedness, social and economic impact, and continuous improvement and adaptation. By considering these criteria, stakeholders can gain valuable insights into the performance and benefits of ITS, aiding in decision-making, policy development, and future planning for transportation systems. This study uses multi-criteria decision-making (MCDM) methodologies, such as the assessing attractiveness method and the weighted aggregated sum product assessment (WASPAS) method. The WASPAS method is used to rank the alternatives. We used 18 criteria and 8 alternatives to be organized. The sensitivity analysis is conducted to check the stability of the results.

Keywords: Transportation System; Multi-Criteria Decision Making; WASPAS; Assessment.

1. Introduction

The transportation landscape is transforming profoundly, ushered in by the advent of Intelligent Transportation Systems (ITS). In an era where urbanization, population growth, and technological innovation intersect, ITS emerges as a comprehensive framework intertwining cutting-edge technologies with transportation infrastructure to enhance mobility, safety, and efficiency in the movement of people and goods[1]–[3].

At its core, Intelligent Transportation Systems represent a convergence of various technological disciplines, including telecommunications, data analytics, artificial intelligence, and sensor technologies. This integration empowers transportation networks with real-time data collection, analysis, and dissemination, fostering informed decision-making and optimization across the entire spectrum of transportation[4]–[6].

The foundational pillars of ITS encompass a diverse array of applications, each geared towards addressing specific challenges prevalent in traditional transportation systems. These applications range from advanced traffic management and vehicle-to-infrastructure communication to intelligent parking solutions, connected and autonomous vehicles, and integrated public transportation systems[7], [8].

The transformative potential of ITS extends beyond the optimization of traffic flow. It encompasses holistic approaches to safety enhancement, pollution reduction, energy conservation, and infrastructure resilience. By leveraging data-driven insights and intelligent algorithms, ITS endeavours to mitigate congestion, reduce travel times, enhance safety measures, and pave the way for sustainable transportation systems[9], [10].

Moreover, the evolution of Intelligent Transportation Systems is inherently linked to societal shifts, urban planning paradigms, and the changing expectations of a tech-savvy populace. As cities and regions grapple with growing transportation demands and environmental concerns, ITS is a catalyst for reimagining transportation ecosystems, promoting multimodal connectivity, and fostering inclusive, accessible mobility solutions[11]–[13].

This study used the multi-criteria decision making (MCDM) methodology to analysis the effectiveness and performance of the ITS. This study used the WASPAS method to rank the alternatives[14], [15].



Figure 1: The WASPAS methodology for ranking the alternative in intelligent transportation.

2. Suggested Methodology

This section introduces the WASPAS method to give the best alternative to the intelligent transportation system. The suggested methodology has many stages, like building the decision matrix between criteria and options of transportation systems, computing the weights of criteria by the average method, and ranking the alternatives by the WASPAS method[16], [17]. The "weighted aggregated sum product assessment" (WASPAS) approach was developed by Zavadskas et al. [18]and has shown to be a useful MCDM tool across various areas[19], [20]. Due to its straightforward computation that produces accurate results when rating or choosing individual options based on how well they perform against competing criteria, it is widely used and increasing[21]–[24]. The steps of the suggested methodology are shown in Figure 1.

Step 1. Building the decision matrix

$$A = \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \dots & a_{mn} \end{bmatrix} \tag{1}$$

Step 2. Compute the weights of criteria

The criteria weights are computed by the average method.

Step 3. Normalize the decision matrix.

The normalization decision matrix is computed by the cost and profit criteria

$$T_{ij} = \frac{a_{ij}}{\max_i(a_{ij})} \quad (2)$$

$$T_{ij} = \frac{\min_i(a_{ij})}{a_{ij}} \quad (3)$$

Step 4. Compute the additive relative importance

$$d_{ij} = T_{ij} \times w_j \quad (4)$$

Step 5. Compute the multiplicative relative importance

$$e_{ij} = \prod_{j=1}^n (T_{ij})^{w_j} \quad (5)$$

Step 6. Compute the value of joint generalize factor

$$G = \frac{1}{2} \left(\sum_{j=1}^n T_{ij} \times w_j + \prod_{j=1}^n (T_{ij})^{w_j} \right) \quad (6)$$

Step 7. Order the alternatives

3. Criteria Selection

Criteria that are often considered when evaluating the effectiveness and performance of Intelligent Transportation System (ITS)[25]–[28]:

1. **Safety:** Assessing the impact of ITS on safety is a fundamental criterion. It evaluates whether the system reduces accidents, minimizes the severity of collisions, and improves overall road safety. Critical indicators for safety assessment may include accident rates, reduction in fatalities and injuries, and the effectiveness of safety features like collision avoidance systems.
2. **Efficiency:** Efficiency is a crucial aspect of ITS assessment. It evaluates the system's ability to improve traffic flow, reduce congestion, and optimize transportation operations. Criteria for efficiency assessment may include travel time reduction, increased average speeds, improved roadway capacity utilization, and reduction in fuel consumption and emissions.
3. **Mobility:** Mobility assessment examines how it enhances the accessibility and availability of transportation options for individuals and communities. It involves evaluating the impact of ITS on reducing travel delays, improving multimodal connectivity, and providing real-time information on transportation options. Critical indicators for mobility assessment may include travel time reliability, accessibility to public transportation, and integration of different modes of transportation.
4. **Environmental Impact:** The environmental impact assessment of ITS focuses on its ability to reduce carbon emissions, improve air quality, and support sustainable transportation practices. Criteria for the ecological evaluation may include reductions in greenhouse gas emissions, fuel consumption, and pollutant levels. Additionally, the review may consider promoting eco-friendly transportation modes and integrating renewable energy sources.
5. **User Satisfaction:** User satisfaction is an essential criterion for evaluating the success of ITS. It involves gathering feedback and opinions from users, such as drivers, passengers, and pedestrians, regarding their experience with the system. User satisfaction assessment may utilize surveys, interviews, or user feedback platforms to evaluate aspects such as ease of use, reliability of information, and overall user experience.

6. **Cost-effectiveness:** Assessing the cost-effectiveness of ITS is crucial to determine its economic viability and sustainability. This criterion involves evaluating the benefits gained from the system and the costs incurred for its implementation, operation, and maintenance. Cost-effectiveness assessment may consider factors such as the return on investment, cost savings due to reduced congestion or accidents, and the system's long-term financial sustainability.
7. **Scalability and Interoperability:** Scalability and interoperability are essential criteria when assessing the potential for widespread adoption and integration of ITS. It involves evaluating the system's ability to accommodate increasing demands, handle diverse data and technologies, and seamlessly integrate with existing transportation infrastructure and systems.
8. **Data Security and Privacy:** As ITS relies on collecting and processing vast amounts of data, assessing the security and privacy of this data is critical. The evaluation includes examining the measures to protect sensitive information, prevent unauthorized access, and ensure compliance with data protection regulations.
9. **Technological Reliability and Resilience:** Assessing the reliability and resilience of ITS technologies is crucial to ensure consistent performance and minimal disruptions. It involves evaluating the system's ability to handle unexpected events, such as equipment failures, adverse weather conditions, or cyber-attacks, and recover quickly while minimizing the impact on transportation operations.
10. **Regulatory and Policy Compliance:** ITS assessment may also consider the system's compliance with relevant regulatory and policy frameworks. This includes evaluating whether the system meets legal requirements, adheres to industry standards, and aligns with transportation policies and guidelines set by regulatory authorities.
11. **Equity and Accessibility:** Assessing the equity and accessibility aspects of ITS involves evaluating whether the system provides equal opportunities and benefits to all segments of the population. It considers factors such as the availability of transportation options for underserved communities, affordability of ITS services, and inclusive design considerations for individuals with disabilities or limited mobility. Evaluating equity and accessibility ensures that ITS implementation does not exacerbate transportation disparities.
12. **System Integration:** System integration is an essential criterion for assessing ITS effectiveness. It involves evaluating the level of integration and interoperability between different components and subsystems within the transportation network. This includes assessing the seamless exchange of data and information between various ITS applications and infrastructure, such as traffic management systems, public transportation systems, and traveller information services.
13. **Innovation and Future Readiness:** Assessing the innovation and future readiness of ITS considers the system's ability to adapt and incorporate emerging technologies and trends. It evaluates whether the ITS infrastructure and components are designed to accommodate future advancements, such as connected and autonomous vehicles, electric mobility, and innovative city initiatives. This criterion ensures that it remains relevant and practical despite technological advancements and changing transportation needs.
14. **Stakeholder Engagement:** Stakeholder engagement is crucial for ITS implementation and operation success. Assessing stakeholder engagement involves evaluating the level of involvement, collaboration, and feedback from various stakeholders, including government agencies, transportation operators, industry partners, and the public. This criterion ensures that the perspectives and needs of different stakeholders are considered, fostering a sense of ownership and support for the ITS system.
15. **Performance Monitoring and Evaluation:** Performance monitoring and evaluation criteria involve establishing metrics and indicators to track the ongoing performance of ITS. It includes collecting and analysing data to measure the system's performance against predefined goals and objectives. Regular evaluation helps identify areas for improvement, measure the effectiveness of implemented measures, and inform decision-making for future enhancements or expansions of the ITS system.

16. **Resilience and Disaster Preparedness:** Resilience and disaster preparedness criteria assess the ability of ITS to withstand and respond to unforeseen events, natural disasters, or disruptions. It involves evaluating the system's redundancy, backup systems, and emergency response capabilities. Assessing resilience ensures the ITS system can quickly recover from disruptions and provide vital transportation services during critical situations.
17. **Social and Economic Impact:** Assessing the social and economic impact of ITS involves evaluating the broader effects of the system on society and the economy. It includes measuring the system's contribution to job creation, economic growth, and improved quality of life for individuals and communities. This criterion helps demonstrate the value and benefits of ITS beyond the immediate transportation aspects.
18. **Continuous Improvement and Adaptation:** ITS assessment should consider the potential for continuous improvement and adaptation over time. It involves evaluating the system's flexibility and the capacity to incorporate feedback, lessons learned, and emerging best practices. This criterion ensures that ITS evolves and stays relevant as transportation needs and technologies advance.

Intelligent Transportation Systems (ITS) have become essential to modern transportation networks. However, some alternative approaches and technologies can complement or offer alternatives to ITS[29]–[31].

1. **Sustainable Transportation Solutions:** Instead of solely optimizing existing transportation infrastructure through ITS, alternative approaches prioritize sustainable transportation options. This may include promoting walking, cycling, and public transportation and supporting infrastructure development for electric vehicles and alternative fuel sources. By reducing reliance on private cars and prioritizing environmentally friendly modes of transportation, these alternatives aim to mitigate traffic congestion, reduce emissions, and improve overall sustainability.
2. **Mobility as a Service (MaaS):** MaaS is an emerging concept that combines various transportation modes and services into a single, integrated platform. It offers travellers a seamless experience by providing access to multiple transportation options through a single app or service. MaaS platforms typically integrate public transit, ride-sharing, bike-sharing, and other mobility services, providing users with convenient and flexible travel options. MaaS aims to improve transportation efficiency, reduce congestion, and enhance user experience.
3. **Shared Mobility Solutions:** Shared mobility services, such as ride-sharing, car-sharing, and bike-sharing, provide alternatives to traditional private vehicle ownership. These services allow individuals to access on-demand transportation without needing personal vehicle ownership. By maximizing the utilization of existing vehicles and promoting resource sharing, shared mobility solutions can reduce traffic congestion, parking demands, and environmental impact.
4. **Active Traffic Management:** Active Traffic Management (ATM) focuses on dynamically managing traffic flow and congestion through various strategies, such as variable speed limits, dynamic lane assignment, and real-time incident management. ATM aims to optimize traffic flow and reduce congestion by actively monitoring and controlling traffic conditions. It can improve transportation efficiency and reduce travel times without requiring extensive infrastructure investments.
5. **Smart Parking Solutions:** Smart parking systems leverage technology, including sensors and real-time data, to help drivers locate available parking spaces more efficiently. These systems provide real-time information about parking availability, guiding drivers to empty parking spots and reducing the time spent searching for parking. Innovative parking solutions can help alleviate congestion and reduce emissions associated with vehicles circling for parking.
6. **Active Transportation Infrastructure:** Active transportation infrastructure focuses on creating safe and accessible infrastructure for walking and cycling. This includes the development of bike lanes, pedestrian-friendly streets, and dedicated infrastructure for non-motorized modes of transportation. By promoting active

transportation, these alternatives aim to reduce reliance on vehicles for short trips, improve public health, and enhance the livability of cities.

7. **Intelligent Freight Management:** Intelligent Freight Management systems focus on optimizing the movement of goods and freight within the transportation network. These systems use advanced technologies, such as logistics optimization algorithms, real-time tracking, and data analytics, to improve freight efficiency, reduce delivery times, and minimize environmental impact. Intelligent Freight Management solutions can enhance supply chain operations and reduce congestion caused by freight transportation.
8. **Smart City Initiatives:** Smart city initiatives encompass various technologies and approaches that leverage data and connectivity to improve urban living. These initiatives integrate multiple systems, including transportation, energy, and public services, to enhance efficiency, sustainability, and quality of life. Innovative city initiatives may incorporate elements of ITS but often extend beyond transportation to address broader urban challenges.

4. Results and Discussion

In this section, we introduce the results obtained by the WASPAS method. We used 18 criteria and 8 alternatives.

Step 1. Building the decision matrix by using the scale between 1 to 9.

Step 2. Compute the weights of criteria by the average method as shown in Figure 2.

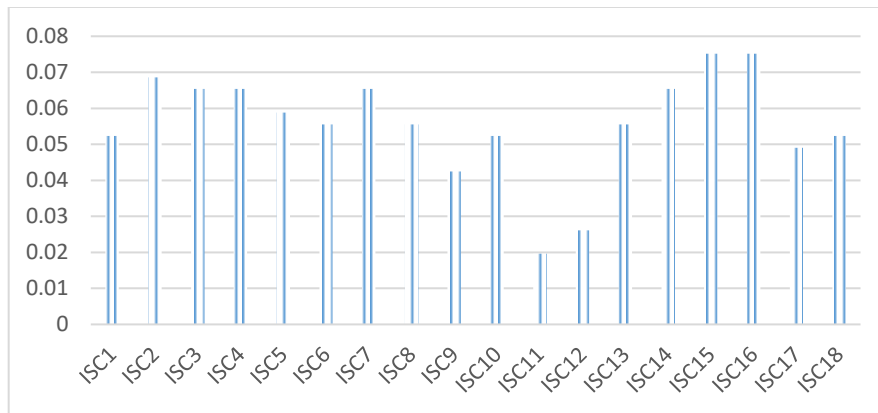


Figure 2: The weights of intelligent transportation systems criteria.

Step 3. Normalize the decision matrix by Eqs. (2 and 3) as shown in Table 1.

Table 1: The normalization decision matrix.

	ISC ₁	ISC ₂	ISC ₃	ISC ₄	ISC ₅	ISC ₆	ISC ₇	ISC ₈	ISC ₉	ISC ₁₀	ISC ₁₁	ISC ₁₂	ISC ₁₃	ISC ₁₄	ISC ₁₅	ISC ₁₆	ISC ₁₇	ISC ₁₈
ISA ₁	0.555556	0.666667	1	0.888889	0.777778	0.444444	0.625	0.555556	0.222222	0.666667	0.375	0.25	0.555556	0.777778	0.888889	1	0.666667	0.555556
ISA ₂	0.444444	1	0.666667	0.888889	0.555556	0.444444	0.875	0.555556	0.222222	0.555556	0.125	0.375	0.666667	1	0.888889	0.555556	0.444444	0.555556

	ISA ₈	ISA ₇	ISA ₆	ISA ₅	ISA ₄	ISA ₃
	0.777778	0.555556	0.888889	1	0.888889	0.777778
	0.888889	0.777778	0.888889	0.777778	1	0.666667
	1	0.888889	0.777778	0.666667	0.888889	0.555556
	0.888889	1	0.888889	1	1	0.444444
	0.555556	0.888889	1	0.888889	0.444444	0.666667
	0.333333	1	0.222222	0.777778	1	1
	0.25	0.25	0.625	0.5	1	1
	0.555556	0.666667	0.666667	0.555556	1	0.777778
	0.666667	0.444444	0.333333	0.666667	0.666667	1
	1	0.555556	0.555556	0.222222	0.333333	0.555556
	1	0.875	0.5	0.625	0.25	0.25
	0.875	1	0.625	0.75	0.125	0.375
	0.888889	1	0.777778	1	0.444444	0.666667
	0.666667	0.666667	0.888889	0.888889	0.555556	0.444444
	1	0.444444	1	0.555556	0.888889	0.777778
	0.444444	0.555556	0.666667	0.111111	1	1
	0.555556	0.222222	1	0.666667	0.555556	0.555556
	0.444444	0.222222	0.555556	0.888889	1	0.666667

Step 4. Compute the additive relative importance by Eqs. (4) as shown in Table 2.

Table 2: The additive relative importance.

	ISA ₃	ISA ₂	ISA ₁
ISC ₁	0.040668	0.023239	0.029049
ISC ₂	0.045752	0.068627	0.045752
ISC ₃	0.036311	0.043573	0.065359
ISC ₄	0.029049	0.058097	0.058097
ISC ₅	0.039216	0.03268	0.045752
ISC ₆	0.055556	0.024691	0.024691
ISC ₇	0.065359	0.05719	0.04085
ISC ₈	0.04321	0.030864	0.030864
ISC ₉	0.042484	0.009441	0.009441
ISC ₁₀	0.029049	0.029049	0.034858
ISC ₁₁	0.004902	0.002451	0.007353
ISC ₁₂	0.009804	0.009804	0.006536
ISC ₁₃	0.037037	0.037037	0.030864
ISC ₁₄	0.029049	0.065359	0.050835
ISC ₁₅	0.05846	0.066812	0.066812
ISC ₁₆	0.075163	0.041757	0.075163
ISC ₁₇	0.027233	0.021786	0.03268
ISC ₁₈	0.034858	0.029049	0.029049

	ISA ₄	ISA ₅	ISA ₆	ISA ₇	ISA ₈	ISA ₉	ISA ₁₀	ISA ₁₁	ISA ₁₂	ISA ₁₃	ISA ₁₄	ISA ₁₅	ISA ₁₆	ISA ₁₇	ISA ₁₈
	0.040668	0.052288	0.046478	0.029049	0.040668	0.029049	0.028322	0.019608	0.022876	0.049383	0.043573	0.075163	0.033406	0.027233	0.023239
	0.061002	0.053377	0.061002	0.053377	0.061002	0.053377	0.028322	0.019608	0.022876	0.049383	0.043573	0.075163	0.033406	0.027233	0.023239
	0.065359	0.043573	0.050835	0.058097	0.065359	0.058097	0.018519	0.01634	0.01634	0.01634	0.055556	0.041757	0.041757	0.010893	0.011619
	0.058097	0.065359	0.058097	0.065359	0.058097	0.065359	0.03268	0.030864	0.030864	0.030864	0.058097	0.058097	0.058097	0.04902	0.011619
	0.03268	0.052288	0.058824	0.052288	0.03268	0.052288	0.018519	0.01634	0.01634	0.01634	0.055556	0.041757	0.041757	0.010893	0.011619
	0.018519	0.04321	0.012346	0.055556	0.018519	0.055556	0.01634	0.01634	0.01634	0.01634	0.055556	0.041757	0.041757	0.010893	0.011619
	0.01634	0.03268	0.04085	0.01634	0.01634	0.01634	0.030864	0.030864	0.030864	0.030864	0.058097	0.058097	0.058097	0.04902	0.011619
	0.030864	0.030864	0.037037	0.037037	0.030864	0.037037	0.028322	0.019608	0.022876	0.049383	0.043573	0.075163	0.033406	0.027233	0.023239
	0.028322	0.028322	0.014161	0.018882	0.028322	0.018882	0.052288	0.019608	0.022876	0.049383	0.043573	0.075163	0.033406	0.027233	0.023239
	0.052288	0.011619	0.029049	0.029049	0.052288	0.029049	0.019608	0.019608	0.022876	0.049383	0.043573	0.075163	0.033406	0.027233	0.023239
	0.019608	0.012255	0.009804	0.017157	0.019608	0.017157	0.019608	0.019608	0.022876	0.049383	0.043573	0.075163	0.033406	0.027233	0.023239
	0.022876	0.019608	0.01634	0.026144	0.022876	0.026144	0.022876	0.022876	0.022876	0.049383	0.043573	0.075163	0.033406	0.027233	0.023239
	0.049383	0.055556	0.04321	0.055556	0.049383	0.055556	0.049383	0.049383	0.049383	0.049383	0.043573	0.058097	0.058097	0.04902	0.011619
	0.043573	0.058097	0.058097	0.043573	0.043573	0.058097	0.043573	0.043573	0.043573	0.043573	0.043573	0.058097	0.058097	0.04902	0.011619
	0.075163	0.041757	0.075163	0.033406	0.075163	0.033406	0.075163	0.075163	0.075163	0.075163	0.043573	0.058097	0.058097	0.04902	0.011619
	0.033406	0.008351	0.050109	0.041757	0.033406	0.041757	0.033406	0.033406	0.033406	0.033406	0.043573	0.058097	0.058097	0.04902	0.011619
	0.027233	0.03268	0.04902	0.010893	0.027233	0.010893	0.027233	0.027233	0.027233	0.027233	0.043573	0.058097	0.058097	0.04902	0.011619
	0.023239	0.046478	0.029049	0.011619	0.023239	0.011619	0.023239	0.023239	0.023239	0.023239	0.043573	0.058097	0.058097	0.04902	0.011619

Step 5. Compute the multiplicative relative importance by Eqs. (5) and see Table 3.

Table 3: The multiplicative relative importance.

	ISA ₄	ISA ₃	ISA ₂	ISA ₁	ISC ₁	ISC ₂	ISC ₃	ISC ₄	ISC ₅	ISC ₆	ISC ₇	ISC ₈	ISC ₉	ISC ₁₀	ISC ₁₁	ISC ₁₂	ISC ₁₃	ISC ₁₄	ISC ₁₅	ISC ₁₆	ISC ₁₇	ISC ₁₈	
	0.851753	0.845826	0.821435	0.831076	ISC ₁	ISC ₂	ISC ₃	ISC ₄	ISC ₅	ISC ₆	ISC ₇	ISC ₈	ISC ₉	ISC ₁₀	ISC ₁₁	ISC ₁₂	ISC ₁₃	ISC ₁₄	ISC ₁₅	ISC ₁₆	ISC ₁₇	ISC ₁₈	
	0.832055	0.809221	0.832055	0.809221	0.831076	0.809221	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.830283	0.805165	0.814817	0.836699	0.831076	0.805165	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.836699	0.793507	0.830283	0.830283	0.831076	0.793507	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.807057	0.826537	0.81772	0.834066	0.831076	0.826537	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.851653	0.851653	0.814136	0.814136	0.831076	0.851653	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.836699	0.836699	0.829428	0.811387	0.831076	0.836699	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.851653	0.839845	0.824292	0.824292	0.831076	0.839845	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.85949	0.874424	0.820297	0.820297	0.831076	0.874424	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.809172	0.831076	0.831076	0.839036	0.831076	0.831076	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.900976	0.900976	0.888813	0.908167	0.831076	0.900976	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.861021	0.88611	0.88611	0.876766	0.831076	0.88611	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.814136	0.832683	0.832683	0.824292	0.831076	0.832683	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.805165	0.793507	0.836699	0.823068	0.831076	0.793507	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.815966	0.807817	0.815966	0.815966	0.831076	0.807817	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.823222	0.823222	0.787643	0.823222	0.831076	0.823222	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.838087	0.838087	0.82897	0.845611	0.831076	0.838087	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076
	0.857014	0.839036	0.831076	0.831076	0.831076	0.839036	0.836699	0.830283	0.834066	0.814136	0.811387	0.824292	0.820297	0.839036	0.908167	0.876766	0.824292	0.823068	0.815966	0.823222	0.845611	0.831076	0.831076

	ISA ₅	ISA ₆	ISA ₇	ISA ₈
	0.857014	0.851753	0.831076	0.845826
	0.817827	0.825356	0.817827	0.825356
	0.814817	0.823068	0.830283	0.836699
	0.836699	0.830283	0.836699	0.830283
	0.840643	0.846488	0.840643	0.81772
	0.839845	0.783381	0.851653	0.801228
	0.799639	0.811387	0.764221	0.764221
	0.824292	0.832683	0.832683	0.824292
	0.85949	0.834549	0.844812	0.85949
	0.792197	0.831076	0.831076	0.857014
	0.917309	0.913305	0.923381	0.925802
	0.902314	0.898023	0.909126	0.905958
	0.851653	0.839845	0.851653	0.846098
	0.830283	0.830283	0.814817	0.814817
	0.787643	0.823222	0.774543	0.823222
	0.697899	0.798512	0.787643	0.774543
	0.845611	0.862586	0.801276	0.838087
	0.851753	0.831076	0.792197	0.821435

Step 6. Compute the value of joint generalize factor by Eq. (6) as shown in Figure 3.

Step 7. Order the alternatives as shown in Figure 3. The alternative 4 is the best and alternative 2 is the worst.

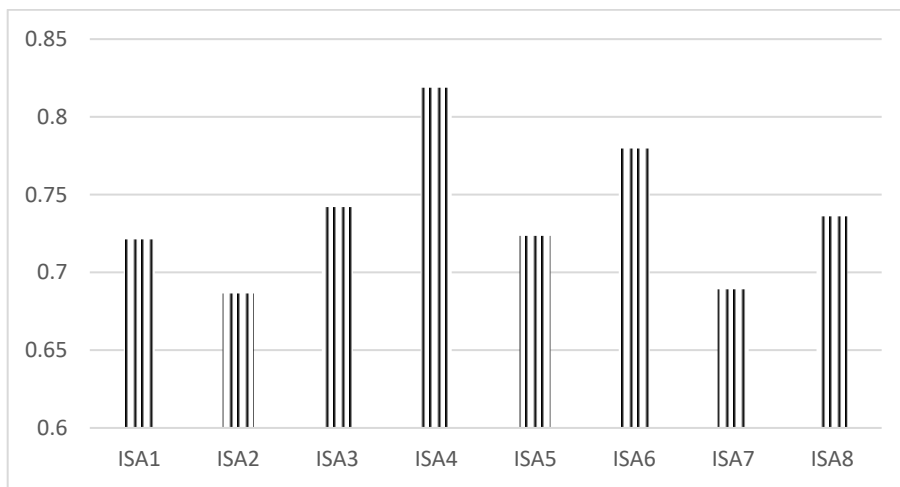


Figure 3: The value of joint generalize factor.

5. Analysis

Any modification to the criterion's weight amount must be taken into account since it greatly influences the final order of WASPAS design choices. This research used sensitivity analysis to demonstrate how the weights of the requirements affect the order of options. We change the weights of criteria to show the different rank of alternatives. We put one criterion with 0.07 and other criteria are equal weight as shown in Figure 4. Then put all 18 cases as input of WASPAS method. Then we compute the rank of alternatives as shown in Figure 5. We show the results are stable.

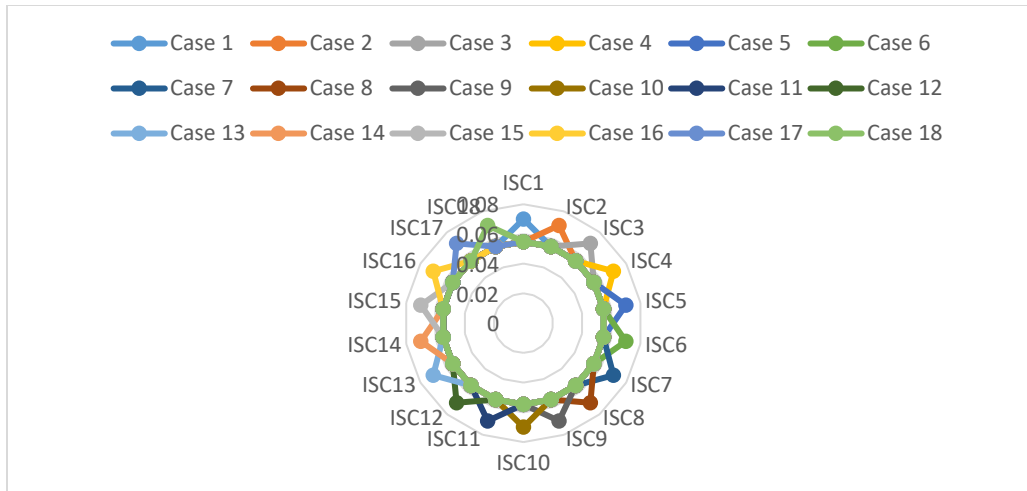


Figure 4: The 18 cases of weights of criteria.

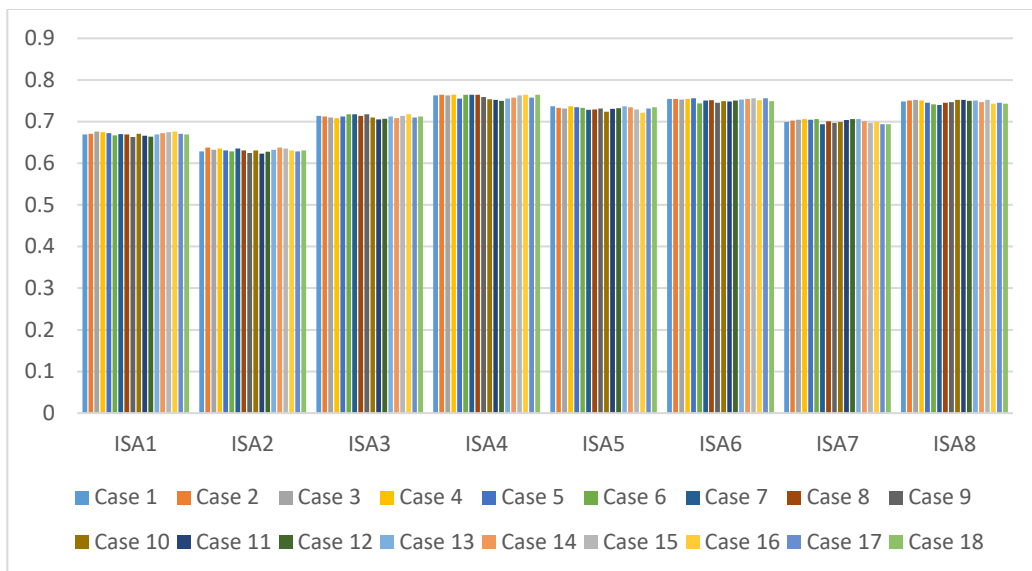


Figure 5: The different ranks under 18 cases.

6. Conclusions

Assessing Intelligent Transportation Systems (ITS) is crucial for understanding their impact and ensuring their effectiveness in modern transportation networks. Through a comprehensive evaluation using diverse criteria, stakeholders can make informed decisions and improve the overall performance of ITS. The assessment criteria discussed in this paper highlight the multidimensional nature of evaluating ITS, considering aspects such as safety, efficiency, mobility, environmental impact, user satisfaction, cost-effectiveness, scalability and interoperability, data security and privacy, technological reliability and resilience, regulatory and policy compliance, equity and accessibility, system integration, innovation and future-readiness, stakeholder engagement, performance monitoring and evaluation, resilience and disaster preparedness, social and economic impact, and continuous improvement and adaptation. By assessing safety, stakeholders can gauge the effectiveness of ITS in reducing accidents and minimizing their severity. Efficiency assessment helps determine whether ITS optimizes traffic flow, reduces congestion, and

enhances transportation operations. Mobility evaluation focuses on the accessibility and availability of transportation options, ensuring that ITS benefits all population segments. Environmental impact assessment considers the contribution of ITS to reducing emissions, improving air quality, and promoting sustainable transportation practices.

Assessing Intelligent Transportation Systems is a complex endeavour requiring a comprehensive and multidimensional approach. By considering the diverse criteria discussed, stakeholders can gain a holistic understanding of the effectiveness, efficiency, and impact of ITS. The findings from these assessments are valuable in shaping future planning, decision-making, and implementation strategies, ultimately leading to improved transportation systems that meet the evolving needs of society. We used the MCDM methodology to deal with various criteria and rank the alternatives. The WASPAS method was used to rank the alternatives. The results show the alternative 4 is the best and alternative 1 is the worst. The sensitivity analysis show the rank is stable.

References

- [1] J. N. Njoku, C. I. Nwakanma, G. C. Amaizu, and D. Kim, "Prospects and challenges of Metaverse application in data-driven intelligent transportation systems," *IET Intelligent Transport Systems*, vol. 17, no. 1, pp. 1–21, 2023.
- [2] Z. Lv and W. Shang, "Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: A comprehensive review," *Green Technologies and Sustainability*, vol. 1, no. 1, p. 100002, 2023.
- [3] R. Jabbar *et al.*, "Blockchain technology for intelligent transportation systems: A systematic literature review," *IEEE Access*, vol. 10, pp. 20995–21031, 2022.
- [4] B. B. Gupta, A. Gaurav, E. C. Marín, and W. Alhalabi, "Novel graph-based machine learning technique to secure smart vehicles in intelligent transportation systems," *IEEE transactions on intelligent transportation systems*, 2022.
- [5] C. Zhao, Y. Lv, J. Jin, Y. Tian, J. Wang, and F.-Y. Wang, "DeCAST in TransVerse for parallel intelligent transportation systems and smart cities: Three decades and beyond," *IEEE Intelligent Transportation Systems Magazine*, vol. 14, no. 6, pp. 6–17, 2022.
- [6] S. Yang, H. Lu, and J. Li, "Multifeature fusion-based object detection for intelligent transportation systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 24, no. 1, pp. 1126–1133, 2022.
- [7] T. R. Ramesh, M. Vijayaragavan, M. Poongodi, M. Hamdi, H. Wang, and S. Bourouis, "Peer-to-peer trust management in intelligent transportation system: An Aumann's agreement theorem based approach," *ICT Express*, vol. 8, no. 3, pp. 340–346, 2022.
- [8] R. W. Liu, Y. Guo, Y. Lu, K. T. Chui, and B. B. Gupta, "Deep network-enabled haze visibility enhancement for visual IoT-driven intelligent transportation systems," *IEEE Transactions on Industrial Informatics*, vol. 19, no. 2, pp. 1581–1591, 2022.
- [9] N. Yuvaraj, K. Pragmaash, R. A. Raja, and T. Karthikeyan, "An investigation of garbage disposal electric vehicles (GDEVs) integrated with deep neural networking (DNN) and intelligent transportation system (ITS) in smart city management system (SCMS)," *Wireless personal communications*, vol. 123, no. 2, pp. 1733–1752, 2022.
- [10] J. Liu, L. Zhang, C. Li, J. Bai, H. Lv, and Z. Lv, "Blockchain-based secure communication of intelligent transportation digital twins system," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 11, pp. 22630–22640, 2022.
- [11] C. Liu and L. Ke, "Cloud assisted Internet of things intelligent transportation system and the traffic control system in the smart city," *Journal of Control and Decision*, vol. 10, no. 2, pp. 174–187, 2023.
- [12] T. Yuan, W. Da Rocha Neto, C. E. Rothenberg, K. Obraczka, C. Barakat, and T. Turlletti, "Machine learning for next-generation intelligent transportation systems: A survey," *Transactions on emerging telecommunications technologies*, vol. 33, no. 4, p. e4427, 2022.
- [13] R. Rajamoorthy *et al.*, "A novel intelligent transport system charging scheduling for electric vehicles using Grey Wolf Optimizer and Sail Fish Optimization algorithms," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 44, no. 2, pp. 3555–3575, 2022.
- [14] K. Rudnik, G. Bocewicz, A. Kucińska-Landwójtowicz, and I. D. Czabak-Górska, "Ordered fuzzy WASPAS method for selection of improvement projects," *Expert Systems with Applications*, vol. 169, p. 114471, 2021.

- [15] D. Karabašević, D. Stanujkić, S. Urošević, and M. Maksimović, "An approach to personnel selection based on SWARA and WASPAS methods," *Bizinfo (Blace)*, vol. 7, no. 1, pp. 1–11, 2016.
- [16] M. Badalpur and E. Nurbakhsh, "An application of WASPAS method in risk qualitative analysis: a case study of a road construction project in Iran," *International Journal of Construction Management*, vol. 21, no. 9, pp. 910–918, 2021.
- [17] R. Lukić, D. V. Kljenak, S. Anđelić, and M. Gavrilović, "Application of WASPAS method in the evaluation of efficiency of agricultural enterprises in Serbia," *Економика пољопривреде*, vol. 68, no. 2, pp. 375–388, 2021.
- [18] E. K. Zavadskas, Z. Turskis, and J. Antucheviciene, "Selecting a contractor by using a novel method for multiple attribute analysis: Weighted Aggregated Sum Product Assessment with grey values (WASPAS-G)," *Studies in Informatics and Control*, vol. 24, no. 2, pp. 141–150, 2015.
- [19] S. Chakraborty, O. Bhattacharyya, E. K. Zavadskas, and J. Antucheviciene, "Application of WASPAS method as an optimization tool in non-traditional machining processes," *Information Technology and Control*, vol. 44, no. 1, pp. 77–88, 2015.
- [20] M. K. Ghorabae, E. K. Zavadskas, M. Amiri, and A. Esmaceli, "Multi-criteria evaluation of green suppliers using an extended WASPAS method with interval type-2 fuzzy sets," *Journal of Cleaner Production*, vol. 137, pp. 213–229, 2016.
- [21] S. Chakraborty and E. K. Zavadskas, "Applications of WASPAS method in manufacturing decision making," 2014.
- [22] S. Chakraborty, E. K. Zavadskas, and J. Antuchevičienė, "Applications of WASPAS method as a multi-criteria decision-making tool," 2015.
- [23] A. Mardani *et al.*, "A systematic review and meta-Analysis of SWARA and WASPAS methods: Theory and applications with recent fuzzy developments," *Applied soft computing*, vol. 57, pp. 265–292, 2017.
- [24] A. Alinezhad, J. Khalili, A. Alinezhad, and J. Khalili, "WASPAS method," *New Methods and Applications in Multiple Attribute Decision Making (MADM)*, pp. 93–98, 2019.
- [25] S. Xia, Z. Yao, G. Wu, and Y. Li, "Distributed offloading for cooperative intelligent transportation under heterogeneous networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 9, pp. 16701–16714, 2022.
- [26] V. Shepelev *et al.*, "Forecasting the passage time of the queue of highly automated vehicles based on neural networks in the services of cooperative intelligent transport systems," *Mathematics*, vol. 10, no. 2, p. 282, 2022.
- [27] Y. Lin, Q. Li, D. Lyu, and X. Wang, "A Review of Wi-Fi-Based Traffic Detection Technology in the Field of Intelligent Transportation Systems," *Buildings*, vol. 12, no. 4, p. 428, 2022.
- [28] A. R. Khan *et al.*, "DSRC technology in Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) IoT system for Intelligent Transportation System (ITS): A review," *Recent Trends in Mechatronics Towards Industry 4.0: Selected Articles from iM3F 2020, Malaysia*, pp. 97–106, 2022.
- [29] Q. Ren, O. Abbasi, G. K. Kurt, H. Yanikomeroğlu, and J. Chen, "Caching and computation offloading in high altitude platform station (HAPS) assisted intelligent transportation systems," *IEEE Transactions on Wireless Communications*, vol. 21, no. 11, pp. 9010–9024, 2022.
- [30] F. A. Omonov, "The important role of intellectual transport systems in increasing the economic efficiency of public transport services," *Academic research in educational sciences*, vol. 3, no. 3, pp. 36–40, 2022.
- [31] H. Gao, W. Huang, T. Liu, Y. Yin, and Y. Li, "Ppo2: Location privacy-oriented task offloading to edge computing using reinforcement learning for intelligent autonomous transport systems," *IEEE transactions on intelligent transportation systems*, 2022.