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RESEARCH ARTICLE

Enabling Intelligent Transport in Smart Cities: A 5G Valley in Türkiye

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ABSTRACT
This research examines the integration of smart transportation systems with 5G technologies in a designated pilot area in Ankara as part of the IPA-2 Project. The main objective of this study is to identify the critical factors influencing the practitioners of smart transportation systems in the pilot region. Using the Analytic Hierarchy Process (AHP) methodology, key considerations for achieving "smart" transportation systems are explored. During the study, communication was established with smart transportation experts from every continent, and an AHP-based questionnaire was sent to 10 experts from each continent, totaling 70 experts. The experts were selected from among electrical engineers, transportation engineers, and planners specializing in ITS (Intelligent Transportation Systems). Experts who have worked or are currently working on smart transportation projects formed the sample for this study. The views of transportation system practitioners were collected, and the parameters deemed most important by the experts were identified. The findings emphasize the centrality of environmental awareness among smart transportation system practitioners and highlight the need for eco-friendly transportation solutions. The results also demonstrate that experts consider the "smart environment" parameter the most important. This finding underscores the significance of a clean and sustainable environment for 5G applications in transportation.

Keywords: Smart transportation, Environmental sustainability, Analytical hierarchy process (AHP), 5G, Informatics and Information Technologies in Architecture

1. Introduction

The rapid urbanization of cities has brought forth several challenges, including overcrowding, resource depletion, environmental degradation, and increased air pollution. In response, the smart city concept has gained prominence as an innovative framework for sustainable urban development. This research focuses on the integration of advanced technologies and data-driven strategies into smart cities, highlighting their potential to enhance residents' quality of life, optimize city operations, and contribute to sustainable growth.

As urban populations grow and technological advancements continue, the shift toward smart cities has gained momentum, as discussed by scholars such as Bibri and Krogstie (2020), Liu and Peng (2021), Kumar and Al-Dubai (2020), Giffinger and Gudrun (2021), and Pan and Zhang (2022). Their work emphasizes the transformative capabilities of smart city initiatives, including benefits such as improved sustainability, enhanced governance through artificial intelligence (AI) and the Internet of Things (IoT), and the implementation of data-driven systems to support urban resilience and operational efficiency (Bibri and Krogstie, 2020; Liu and Peng, 2021; Kumar and Al-Dubai, 2020; Giffinger and Gudrun, 2021; Pan and Zhang, 2022).

A core feature of smart cities is their reliance on modern technologies to address urban challenges. Through the deployment of IoT devices, cutting-edge sensors, and advanced data analytics, these cities collect and process data in real time, enabling informed decision-making. This seamless technological integration helps improve urban services and fosters the development of adaptive and responsive environments.

Central to the smart city framework is an aim to enhance residents' quality of life. By leveraging technology to improve public services, transportation, and energy management, smart cities seek to create more livable, sustainable environments. Intelligent transportation systems (ITS) can reduce traffic congestion, improve air quality, and improve public health. Additionally, energy-efficient infrastructure and smart grids align with global sustainability goals, further promoting climate action initiatives. Efficiency gains across sectors such as healthcare, waste management, and transportation further demonstrate the potential of smart cities. By using data-driven strategies, smart cities can optimize resource allocation, reduce operational costs, and enhance governance.

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Predictive analytics and machine learning tools can even prevent disruptions to critical infrastructure, ensuring the reliability of essential services (Liu and Peng, 2021). A critical element of this technological evolution is the implementation of ITS, which plays a pivotal role in transforming urban mobility. ITS integrates advanced technology, data analytics, and communication systems to enhance the efficiency, safety, and sustainability of transportation networks (Khalid et al., 2018). These systems utilize real-time data, sensor networks, and intelligent algorithms to reduce congestion, shorten travel times, improve safety, and reduce environmental impacts (Khalid et al., 2018; Barba et al., 2013).

As urbanization accelerates and the demand for efficient transportation grows, ITS has become increasingly important for shaping future mobility. Governments, private companies, and researchers worldwide are collaborating to implement ITS technologies and develop smarter, more sustainable transportation ecosystems. Recent advances in IoT and 5G communication have accelerated the adoption of ITS (Khalid et al., 2018).

The foundation of ITS lies in the collection, exchange, and analysis of transportation data, which allows for effective monitoring, measurement, and management of urban-transport systems. These technologies aim to optimize road capacity, improve mobility, decrease travel time, and minimize the environmental impacts associated with transportation (Ministry of Transport and Infrastructure, 2021; Wecka et al., 2022).

With the increasing global demand for efficient transport solutions, intelligent systems are becoming more essential than ever to enhance both safety and efficiency. ITS applications span various domains, including traffic management, vehicle safety, public transit information, and emergency response systems. The development of cooperative intelligent transportation systems (C-ITS) emphasizes the importance of real-time data exchange between vehicles and their environments, with 5G technology being a key enabler of these systems (Bojkovic et al., 2020). The development of 5G networks, which are characterized by ultra-low latency and the ability to transmit real-time data, is expected to revolutionize autonomous vehicles and artificial intelligence (AI) applications in transportation (Ministry of Transport and Infrastructure, 2020). As the demand for Connected, Cooperative, and Autonomous Mobility (CCAM) continues to rise, the role of 5G and next-generation communications will become even more critical. Although 5G technologies are still emerging, they hold great promise in terms of enhancing existing services and introducing new innovations in IoT, smart cities, and ITS (Guevara and Cheein, 2020).

Effective communication networks are fundamental to the planning, management, and monitoring of complex transportation infrastructures. Integration and interoperability across different modes of transportation—including highways, urban traffic zones, tunnels, parking facilities, and other systems—are essential for achieving cohesive and efficient transportation strategies.

Technologies such as connected, cooperative, and autonomous mobility (CCAM), IoT, mixed reality (AR/VR), cloud computing, big data, open data, AI, digital twins, blockchain, drones, air taxis, mobility-as-a-service (MaaS), and smart roads are reshaping the future of transportation. The role of communication advancements, particularly 5G, is critical in realizing this transformation (Bertin and Crespi, 2017).

The advent of 5G technology has introduced transformative solutions to transportation, emphasizing both human and environmental considerations. This new paradigm focuses on equitable access while reducing negative impacts such as energy consumption, traffic congestion, and accidents, all of which contribute to broader sustainability conversations (Guevara and Cheein, 2020).

However, there are considerable challenges in the implementation of 5G in transportation. Establishing 5G networks requires substantial investment in infrastructure such as small cell towers, fiber optics and edge computing systems. This investment is not only a one-time expense but also requires continuous maintenance and future upgrades. Case studies from cities such as Vienna and Tianjin illustrate how public-private partnerships have successfully navigated these financial challenges (Bertin and Crespi, 2017).

Concerns about privacy, data security, and the implications of automation for jobs can slow the adoption of such technologies. Addressing these issues through clear policies, public outreach, and education can help build trust and foster acceptance. Pilot programs that gradually introduce these technologies help ease public concerns (Mas and Schuster, 2019).

Costs can be reduced by implementing these systems in phases and encouraging government support through subsidies and tax breaks for private sector partners and telecom providers. Discussing funding options, such as public-private partnerships and government grants, will highlight effective economic strategies (Zhu and Liu, 2021). Expanding pilot programs, especially in varied urban and rural settings, alongside enhanced government support and the development of balanced regulatory frameworks can support sustainable innovation. Collaborations with academic institutions can further drive technological advancements and promote social engagement (Sharma and Li, 2020).

In Türkiye, the Ministry of Transport and Infrastructure (MoTI) is at the forefront of developing smart transportation policies. This includes selecting test sites and trialing 5G technologies for transportation as part of the Instrument for Pre-Accession Assistance (IPA 2) Project. A Presidential Decree issued in 2018 tasked MoTI with creating national strategies, action plans, and technical criteria for intelligent transportation systems (ITS), in addition to establishing a data management center to handle data generated by public and private entities (Presidential Decree, 2018).

The first tests of 5G technologies in Türkiye's transportation sector occurred within the IPA-2 Project, with Hacettepe University serving as the pilot location. This research examines how 5G technologies can be applied to smart transportation in this pilot area.

Hacettepe University, founded in 1967, is one of Türkiye's leading academic institutions, featuring 16 faculties, 15 institutes, vocational schools, and nearly 100 research centers. The 1604 Street designated on its campus is a test site for 5G transportation innovations.

This study examines smart transportation in the context of 5G technology in Türkiye, focusing on its environmental impacts. The key research questions guiding the study are as follows: "What smart transportation strategy is suitable for Türkiye?" and "Is the current transportation system contributing to environmental pollution?" The proposed hypothesis argues that transforming transportation to prioritize smart transportation principles is necessary to reduce pollution while maintaining operational efficiency.

2. Literarute Review

The rapid growth of urbanization, combined with technological progress, has given rise to smart cities, designed to tackle modern urban issues like congestion, resource scarcity, and environmental damage. Smart cities use cutting-edge technologies to improve quality of life, drive sustainability, and boost operational efficiency. Intelligent Transportation Systems (ITS) play a crucial role in achieving these goals by improving mobility through innovative solutions. When integrated with 5G technology, ITS provides a revolutionary approach to managing transportation, greatly improving efficiency, safety, and environmental sustainability.

2.1. Smart Cities and Environmental Sustainability

Smart cities use IoT and data-driven technologies to manage urban services such as transportation, energy, and waste. According to Albino, Berardi, and Dangelico (2015), smart city projects place a strong emphasis on environmental sustainability, acknowledging that urban areas are significant contributors to pollution and energy consumption. Recent developments in 5G technology have facilitated real-time data gathering and analysis, greatly reducing energy consumption and carbon emissions by streamlining the management of urban services, including transportation networks. More recent research (Bibri and Krogstie, 2020; Liu and Peng, 2021) underscores the pivotal role of smart city technologies in crafting sustainable urban futures, particularly in terms of improving efficiency and supporting eco-friendly initiatives.

2.2. 5G Technologies and ITS

The incorporation of 5G technologies into smart transportation systems promises to significantly improve urban mobility. With faster data transfer rates, lower latency, and improved connectivity, 5G enables real-time monitoring and management of transportation infrastructures. This innovation supports vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, enhancing traffic management and alleviating congestion. Abbas et al. (2015) and Bae and Lee (2016) examined the effects of 5G on transportation, highlighting its capacity to revolutionize urban mobility by improving safety and efficiency and reducing environmental impacts. More recent research by Kumar and Al-Dubai (2020) and Zhang et al. (2021) has also emphasized that 5G could enable autonomous driving, a crucial step toward future urban transportation, by enhancing real-time communication and decision-making systems (Kumar and Dubai, 2020; Zhang et al., 2021).

2.3. ITS and environmental impacts

Intelligent Transportation Systems (ITS) have the potential to minimize the environmental impact of transportation networks. As noted by Sánchez-González et al. (2019), implementing eco-conscious transportation solutions is essential for mitigating urban pollution (Sánchez-González et al., 2019). Borge-Holthoefer et al. (2017) demonstrated that integrating ITS with 5G technology can streamline traffic, decrease fuel usage, and reduce emissions, thus fostering a cleaner environment. In this context, the present study adds to the existing body of research by examining how professionals prioritize environmental sustainability when deploying ITS.

2.4. Application of AHP in Similar Studies

The analytical hierarchy process (AHP) methodology has been extensively applied to assess and rank decision-making factors in smart cities and Intelligent Transportation Systems (ITS). Caragliu and Nijkamp (2011) used the AHP to evaluate the criteria that influence smart city development, underscoring the importance of sustainability in urban planning (Caragliu and Nijkamp, 2011). Similarly, Sánchez-González et al. (2019) employed AHP to examine key factors in smart transportation, with environmental considerations being a top priority for experts (Sánchez-González et al., 2019). This study expands on previous research by applying AHP to assess expert insights on the most significant factors for implementing 5G-enabled ITS, with a particular focus on environmental impact.

In conclusion, incorporating 5G technology into ITS within smart cities represents a pivotal move toward sustainable urban transportation. By analyzing existing literature on 5G, ITS, and sustainability, this research addresses a gap by considering the specific concerns of professionals engaged in the deployment of these technologies (Abbas et al., 2015; Albino et al., 2015; Bae and Lee, 2016; Borge-Holthoefer et al., 2017; Caragliu et al., 2009; Mousa and Shoaib, 2018; Ratti and Townsend, 2011; Sánchez-González, 2019).

AHPs are frequently used in decision-making frameworks across sectors like ITS, urban development, and sustainability evaluations. It is particularly effective for evaluating multi-criteria decisions in which multiple variables must be considered, making it an ideal method for assessing the integration of 5G into smart transportation systems.

Jing et al. (2020) used AHP to evaluate factors influencing the adoption of autonomous vehicles in smart cities. They identified essential criteria, including safety, infrastructure expenses, public acceptance, and environmental impact, illustrating how the AHP can be used to prioritize these factors according to expert opinion. This research parallels the current study, which identifies key factors impacting smart transportation system practitioners (Jing et al., 2020).

Similarly, Wang et al. (2018) applied AHP to analyze sustainable urban mobility strategies, examining metrics such as air quality, energy usage, and congestion reduction. The study emphasized eco-friendly transport, which is consistent with the results of this research, which underscores the role of environmental consciousness in smart transportation systems (Wang et al., 2018).

Tsamboulas et al. (2007) also used the AHP to evaluate transportation infrastructure investments, ranking various options based on cost, safety, and environmental impact. Their research supports the application of AHP in planning smart transportation systems and demonstrates its value in balancing economic, environmental, and social considerations (Tsamboulas et al., 2007).

These examples demonstrate how AHP can systematically assess stakeholder priorities in smart transportation initiatives. By integrating expert feedback, the AHP provides a structured framework for determining which factors should be prioritized in technological advancements like 5G.

There are key initiatives that play a critical role in Türkiye's transportation infrastructure, including Ulak, Aselsan, and Havelsan:

Ulak: A leading company in Türkiye, Ulak is responsible for developing Turkey's first locally produced 5G base station. It is instrumental in advancing telecommunications infrastructures by offering secure and scalable solutions that support both national and global 5G networks (Ulak Haberleşme A.Ş., 2022).

Aselsan: Renowned for its expertise in defense and electronics, Aselsan has expanded its research into telecommunications, focusing on the development of 5G infrastructure, specifically designing essential hardware components and integrating systems for secure communication (Aselsan, 2022).

Havelsan: A specialist in software-driven solutions, Havelsan plays a vital role in Türkiye's digital transformation by contributing to 5G development, particularly in cybersecurity and network management systems, to ensure the resilience and security of 5G networks (Havelsan, 2023).

3. Research method

The selection of the AHP methodology in this study was based on its ability to determine the significance weights of various parameters. This decision-making approach not only addresses problem-solving but also aids in problem definition, solution modeling, comparison phases, and hierarchical structuring of identified concepts. Given the challenge of establishing significance levels among numerous overlapping concepts, decision support systems are essential. These systems assist decision makers by simplifying the evaluation process, generating effective decision options, presenting and analyzing alternatives, and enhancing the likelihood of making informed decisions across multiple concepts (Oğuztimur, 2008). In this study, expert opinions were consulted, and ethics approval was obtained from the Scientific Research Ethics Committee in Social and Human Sciences at Necmettin Erbakan University (dated 23.04.2023, approval number 196.)

The Analytic Hierarchy Process (AHP) has consistently been a reliable tool for both researchers and decision-makers and is one of the most frequently used multi-criteria decision-making frameworks. A bibliographic review by Steuer (2003) emphasizes AHP's significance among decision-making methodologies. One of AHP's notable strengths is its versatility, which enables its combination with methods such as Linear Programing, Quality Function Deployment, and Fuzzy Logic (Saaty and Ozdemir, 2003).

The key steps of this methodology are as follows:

1. Defining the decision issue.
2. Identifying the criteria that affect decision-making.
3. Structuring a problem in a hierarchical model that includes objectives, criteria, sub-criteria, and alternatives.
4. Pairwise comparisons of the different elements.
5. Calculate the maximum Eigenvalue, Consistency Index (CI), Consistency Ratio (CR), and normalize the values for each criterion and alternative.
6. Assess the CI and CR values. If these fall within acceptable limits, decisions are made based on the normalized results; otherwise, the process is repeated until acceptable values are reached (Saaty, 1987).

Problem Identification: Determining the ideal condition for Türkiye's smart transportation system is of paramount importance. Accordingly, it is essential that policymakers' viewpoints are captured. This study focuses on gathering these insights by using the AHP method as the primary framework for analysis (Haller et al., 1996). The structural outline of this approach is presented in Figure 1.

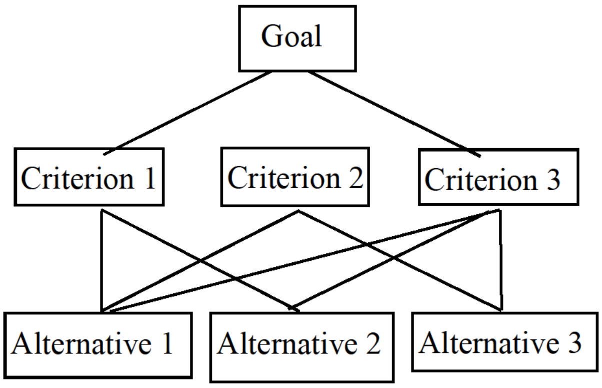

Figure 1. Simple AHP scheme

3.1. Determination of Smart Transportation Criteria

The selection of criteria for smart transportation plays a critical role in decision-making. Presently, the established criteria include "local accessibility, international connectivity, access to ICT infrastructure, sustainable practices, innovation, transportation safety, clean and non-motorized transportation, and a mixed modal approach" (Giffinger, 2007; Cohen, 2010).

3.1.1. Development of a Hierarchical Structure for Decision-Making

This phase involves defining parameters necessary for analyzing the decision problem (Saaty, 2008). It is important to select parameters that enhance the ability of the identified issue within the hierarchical framework. The relationships between the entire system and its components must be thoroughly examined to obtain meaningful insights. Furthermore, the decision hierarchy should encompass all key concerns of the stakeholders (Haller et al., 1996).

3.1.2. Comparison Matrices and Parameter Weight Assignment

The next crucial step in the AHP process is making comparisons, where two options or criteria are evaluated based on the decision-makers' judgments. The relative importance of each criterion is revealed by performing pairwise comparisons. The comparison data is arranged in an "nxn" matrix format (Chandran et al., 2005). At each level of the hierarchy, pairwise comparisons are conducted between elements, and decision-makers indicate their preferences using the Saaty scale for relative importance (Saaty and Vargas, 2006; Saaty, 1980).

The Saaty scale is a key tool for accurate assessment in the AHP methodology, where a score of nine is assigned to the most important concept (Saaty, 2004). When this process is repeated for other evaluation criteria, a corresponding vector for B column (1) is generated for each criterion (Saaty et al., 2003).

$$B_i = \begin{bmatrix} \mathrm{b}_{11} \\ \mathrm{b}_{21} \\ . \\ . \\ . \\ \mathrm{b}_{n1} \end{bmatrix} \tag{1}$$

3.1.3. Creation of parameter comparison matrices and concept weight determination

The pairwise comparison phase constitutes the second fundamental step in the Analytic Hierarchy Process (AHP). This phase entails evaluating and contrasting two options or criteria based on the decision-maker's judgment. The values derived from these pairwise comparisons are organized in an "nxn" matrix, which we refer to as the pairwise comparison matrix. This matrix has a dimensional format of non, corresponding to the number of factors (n) assessed (Table 1) (Chandran et al., 2005).

Table 1. Pairwise comparison matrix for criteria

	Criterion 1	**Criterion 2**	**Criterion n**
Criterion 1	w1/w1	w1/w2	w1/wn
Criterion 2	w2/w1	w2/w2	w2/wn
Criterion n	wn/w1	wn/w2	wn/wn

$$A = \begin{bmatrix} \mathrm{a}_{11} & \mathrm{a}_{12} & \cdots & \mathrm{a}_{1n} \\ \mathrm{a}_{21} & \mathrm{a}_{22} & \cdots & \mathrm{a}_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ \mathrm{a}_{n1} & \mathrm{a}_{n2} & \cdots & \mathrm{a}_{nn} \end{bmatrix} \tag{2}$$

A column vector (2), B is generated with the "n" number and "n" components. The B-column vectors are calculated using the following formula: (3)

$$b_i j = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{3}$$

Once the relative importance of the concepts has been established, the next stage is to calculate the consistency ratio (CR) of the comparison matrix. (Hafeez et al., 2007).

If the constructed hierarchy consists of n criteria, a total of n(n-1)/2 pairwise comparisons are necessary, excluding self-comparisons. As a result, when each step of the construction process is repeated with other evaluation factors, a column vector B equals the number of vailable factors. Expressing unit B column vector in matrix format yields the following formation of matrix C (4).

$$C = \begin{bmatrix} \mathrm{C}_{11} & \mathrm{C}_{12} & \cdots & \mathrm{C}_{1n} \\ \mathrm{C}_{21} & \mathrm{C}_{22} & \cdots & \mathrm{C}_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ \mathrm{C}_{n1} & \mathrm{C}_{n2} & \cdots & \mathrm{C}_{nn} \end{bmatrix} \tag{4}$$

3.1.4. Assessment of comparison consistency

The consistency evaluation stage is a crucial part of the Analytic Hierarchy Process (AHP). The term "quality of the outcome" refers to how well the decision-maker's judgments align with the consistency criterion, which directly impacts the entire decision-making process (Russo and Camanho, 2015).

For a comparison matrix to be considered consistent, the largest eigenvalue (λmax) must equal the matrix size (n). The consistency index and consistency ratio were calculated using this relationship (Saaty and Ozdemir, 2003).

To determine the consistency index (CI), the following formula was applied (Zhou and Shi, 2009; Ömrüberk and Şimşek, 2014).

$$CI = \frac{\lambda - n}{n - 1} \tag{5}$$

When the ratio is equal to "0," it indicates that the decision-maker has complete consistency in her/his judgments. As the ratio approaches "1," it signifies an inconsistency in the decision-maker's judgments.

3.1.5. Conclusion-Decision

The final step of the AHP process involves determining the hierarchy (Saaty, 2004). This is achieved by multiplying decision matrix K (6) by column vector W, also referred to as the priority vector. The result is a column vector L composed of m elements. This vector L reflects the percentage distribution of decision points and helps establish the relative significance of each decision point (Saaty and Vargas, 2006).

$$K = \begin{bmatrix} \mathrm{S}_{11} & \mathrm{S}_{12} & \cdots & \mathrm{S}_{1n} \\ \mathrm{S}_{21} & \mathrm{S}_{22} & \cdots & \mathrm{S}_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ \mathrm{S}_{m1} & \mathrm{S}_{m2} & \cdots & \mathrm{S}_{mn} \end{bmatrix} L = \begin{bmatrix} \mathrm{S}_{11} & \mathrm{S}_{12} & \cdots & \mathrm{S}_{1n} \\ \mathrm{S}_{21} & \mathrm{S}_{22} & \cdots & \mathrm{S}_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ \mathrm{S}_{m1} & \mathrm{S}_{m2} & \cdots & \mathrm{S}_{mn} \end{bmatrix} x \begin{bmatrix} \mathrm{w}_1 \\ \mathrm{w}_2 \\ . \\ . \\ . \\ \mathrm{w}_n \end{bmatrix} = \begin{bmatrix} \mathrm{l}_{11} \\ \mathrm{l}_{21} \\ . \\ . \\ . \\ \mathrm{l}_{m1} \end{bmatrix} \tag{6}$$

3.2. Determination of Expert Group

The experts were selected from among electrical engineers, transportation engineers, and planners specializing in ITS. Experts who have worked or are currently working on smart transportation projects formed the sample for this study. The experts were contacted via email. The purpose of the article was explained to them, and they were invited to contribute. A total of 70 experts (10 from each continent) who accepted the invitation participated in the study.

3.3. Purpose of the Stage Activities

- **Literature Review:** This study comprehensively examines existing literature related to smart transportation and the environmental effects of current transportation systems in Türkiye. This will provide a comprehensive understanding of smart transportation strategies and their potential environmental consequences.
- **Data Collection:** We acquired data on this condition of transportation in Türkiye, covering various modes of transportation, infrastructure, and their environmental repercussions. These empirical data will aid in evaluating current transportation systems and their impacts on the environment.
- **Analysis:** The gathered data were evaluated to identify patterns, trends, and correlations between transportation behaviors and environmental pollution. This analysis provides insights into the current state of transportation in Türkiye and its environmental implications.
- **Comparative study:** Smart transportation strategies in other countries and current practices in Türkiye. Identify successful models and best practices to guide the creation of a customized smart transportation strategy for Türkiye.
- **Formulation of Recommendations:** Develop specific recommendations for a smart transportation strategy that addresses the unique needs and challenges facing Türkiye. Provide actionable insights for policymakers and stakeholders to improve transportation and reduce environmental pollution.
- **Hypothesis Testing:** The collected data are tested against the developed hypothesis to determine its validity. Validate or refute the hypothesis based on the findings of the literature review, data analysis, and comparative study.

The proposed framework outlines a systematic approach to the study, encompassing a literature review, data collection, analysis, comparative study, recommendation formulation, and hypothesis testing. Each phase is designed to effectively address the research questions and evaluate the hypothesis.

4. Findings

According to the results, the importance rankings were as follows:
- Clean and engine-free transportation with a weight degree of 0.354,
- Sustainable, innovative, and safe transportation system with a weight degree of 0.238,
- Mixed model of transportation system with weight degree of 0.109,
- Local accessibility with weight degree of 0.103,
- Access to ICT Infrastructures with a weight degree of 0.101,
- International accessibility was ranked 6th with a weight degree of 0.095.

The results of this study suggest that stakeholders and decision-makers prioritize clean and engine-free transportation as the most important criterion, followed by a sustainable, innovative, and safe transportation system. Additionally, the mixed model of transportation systems, local accessibility, access to ICT infrastructures, and international accessibility are recognized as important factors, although with decreasing levels of significance (Table 2).

Table 2. Article Findings

SUB-CRITERIA	The people, who works in In the Ministry and take part in the smart transportation 5G Valley project.	Ranking
Local accesibility	0,103	4
International accesibility	0,095	6
Access to ICT Infrastructures	0,101	5
Clean and engine-free transportation	**0,354**	**1**
Sustainable, innovative and safe transportation system	0,238	2
Mixed model in transportation system	0,109	3
TOTAL	1	

The results of the study support the hypothesis, demonstrating a shared agreement among participants that the transportation system needs to be redefined according to smart transportation principles, with a key focus on reducing pollution. The emphasis on clean and engine-free transportation is the most vital sub-criterion for smart transportation. This highlights the strong priority that decision makers place on promoting non-motorized and non-fossil fuel vehicles to address environmental challenges.

The significance attributed to sustainable and innovative transportation systems, which are ranked second, underscores the urgent need for research and development in this area. Sustainable transportation is essential for reducing the carbon footprint linked to mobility, particularly as the transportation sector is a major contributor to global carbon emissions. This study emphasizes the critical role of sustainable transportation planning in alleviating the negative impacts of climate change, especially in urban settings that contribute to the climate crisis.

Local accessibility is the third most important factor, underscoring its role in fostering livable urban environments. This study reveals that accessibility, which extends beyond conventional transportation policies, is considered a fundamental aspect of human-centered transportation applications. The idea of "accessibility" is positioned as a cornerstone for sustainable transportation planning, in line with the goal of creating an inclusive transportation system (MoTI, 2021).

Although there are challenges in attaining the desired level of local accessibility, the study acknowledges ongoing initiatives, affirming its critical place on the policy agenda. This suggests that achieving an accessible transportation system requires specific objectives that align with the vision of fostering sustainable and livable cities.

In summary, the findings provide important insights into the priorities and views of decision makers regarding smart transportation in Türkiye. The emphasis on clean and engine-free transportation, sustainable and innovative systems, and local accessibility reflects a collective acknowledgment of the need for transformative changes in the transportation sector. These findings have broader implications for policy development, stressing the importance of harmonizing transportation strategies with environmental sustainability and human-centered approaches to improve urban livability.

Based on the results of this study, we prioritize the essential components of smart transportation systems in urban areas as follows:

Clean and Engine-Free Transportation: The highest priority, reflecting a commitment to minimizing pollution.

Sustainable, Innovative, and Safe Transportation Systems: Recognizing the need for research and development.

Mixed Model for Transportation Systems: Integrating various transportation modes for greater efficiency.

Local Accessibility: Essential for creating livable urban environments.

Access to ICT Infrastructures: Promoting technological integration.

International Accessibility: Enhancing connectivity with broader networks.

The recommended steps for advancing smart transportation in cities are as follows:

Raising Awareness:

- Objective: To increase public awareness of the importance of smart and sustainable transportation.
- Rationale: Fostering awareness is fundamental for gaining public support and engaging in adopting environmentally friendly and accessible transportation practices.

Enhancing the Structure of Governance:

- Objective: To strengthen the governance framework overseeing transportation policies and initiatives.
- Rationale: An effective governance structure is vital for coordinating and implementing strategic measures and ensuring alignment with broader developmental goals (Smith, 2017).

Enhancing Regulations and Supervision:

- Objective: To improve regulatory frameworks and supervisory mechanisms in the transportation sector.
- Rationale: Robust regulation and supervision are crucial for ensuring compliance, safety, and the overall effectiveness of transportation systems (Forkenbrock, 2016).

Developing Institutional Capacity:

- Objective: To build institutional capacity within relevant organizations to manage and implement smart transportation initiatives.
- Rationale: Institutional capacity development is integral for sustaining long-term planning and effective execution of transportation strategies (Litman, 2014).

Enhancing Vehicle Accessibility through Infrastructure and Superstructures:

- Objective: To improve vehicle accessibility by enhancing both infrastructure and superstructures.
- Rationale: Enhancing accessibility promotes inclusivity and accommodates diverse mobility needs within the population (Dablanc et al., 2019).

Enhancing Integration Across Different Modes of Transportation:

- Objective: To facilitate seamless integration of various transportation modes.
- Rationale: Integrated transportation systems can optimize efficiency and improve overall accessibility for commuters (Hall, 2019).

Accessing Information Technology:

- Objective: To enhance access to information technology and improve transportation services.
- Rationale: Implementing technology ensures real-time information, efficient operations, and improved user experience in transportation systems (Zheng et al., 2018).

International Access:

- Objective: To strengthen international connectivity and accessibility in transportation networks.

- Rationale: International access fosters economic, cultural, and social exchanges and contributes to sustainable development (Cattaneo et al., 2020).

These objectives collectively represent a holistic approach to addressing the developmental needs of the transportation sector, prioritizing sustainability, inclusivity, and effective governance.

To improve the generalizability of the findings from the 5G-enabled smart transportation system study in Türkiye's 5G Valley, it is essential to acknowledge the wider relevance of the insights. Critical elements, such as environmental sustainability and technological infrastructure, are pertinent to urban mobility challenges across the globe. The results of this study can benefit cities worldwide that are grappling with similar issues, including rapid urbanization and the need for sustainable transportation solutions. Conducting comparable research in a variety of urban settings—such as well-established smart cities (e.g., Singapore) and emerging regions (e.g., parts of Africa)—could uncover common trends and unique challenges.

Reproducing the study in different contexts will enhance our understanding of how 5G technologies can be effectively incorporated into transportation systems. Comparative studies across countries can highlight differences in policy frameworks and infrastructure readiness.

The results should be adapted to local circumstances and priorities while focusing on pertinent factors that reflect regional needs. Forming strong collaborations among government entities, the private sector, and research institutions can expedite the advancement of smart transportation systems. The findings should be developed into flexible solutions that can be implemented in both large and small urban areas through pilot projects.

5. Discussion

The outcomes of this study offer essential insights into the elements impacting the implementation of smart transportation systems within the 5G Valley in Ankara, Türkiye. The integration of 5G technology into transportation infrastructure was analyzed using the Analytic Hierarchy Process (AHP), which highlighted environmental sustainability as a key consideration for professionals in the field.

A key finding from the research is the significant emphasis placed on the "smart environment" parameter by experts. This result reflects the growing trend of smart transportation practitioners to prioritize environmentally friendly solutions. The focus on maintaining a clean and sustainable environment aligns with global initiatives aimed at combating climate change and minimizing carbon emissions. This underscores the need for transportation systems that incorporate green technologies and practices, such as electric vehicles, renewable energy sources, and efficient traffic management systems designed to reduce emissions.

Furthermore, the role of 5G technologies in smart transportation systems is another critical component discussed in this study. The rapid connectivity and low latency offered by 5G networks facilitate real-time data exchange and enhanced communication among vehicles, infrastructure, and traffic management systems. This connectivity is vital for the creation and implementation of intelligent transport systems (ITS), which can optimize traffic flow, enhance safety, and alleviate congestion. This study provides a thorough assessment of 5G applications that align with the priorities identified by practitioners, especially those focused on environmental sustainability.

The application of the analytical hierarchy process (AHP) methodology enabled a structured evaluation of the perspectives and priorities of transportation system professionals. By identifying and ranking crucial factors, the AHP enables a deeper understanding of the relative significance of various parameters in the realm of smart transportation. This methodological approach created a solid framework for decision making, ensuring that the most critical considerations were considered in the rollout of 5G-enabled transport solutions.

While the findings are encouraging, they also uncover challenges that need to be addressed for effective implementation. Transitioning to 5G-enabled smart transportation requires significant investments in infrastructure, technology, and training. Policymakers must prioritize funding and incentives to foster the adoption of green technologies, ensuring that environmental sustainability becomes a core element of transportation planning rather than an ancillary consideration.

Ensuring interoperability among different systems and technologies is also a technical challenge. Future research should focus on establishing standards and protocols that enable seamless integration across diverse platforms and technologies. Collaborative efforts among technology providers, urban planners, and policymakers are essential for creating an ecosystem that supports innovation while addressing interoperability issues.

Future studies should also examine the long-term effects of 5G integration on transportation efficiency and environmental outcomes, specifically exploring how these technologies impact traffic patterns, emission reductions, and urban mobility. Moreover, the social implications of these changes—such as public acceptance, equitable access to smart transportation, and potential job displacement—should be studied to provide a comprehensive understanding of the effects of 5G-enabled transportation systems.

In summary, this study enhances the existing knowledge of smart transportation and 5G technology integration, emphasizing environmental sustainability. By underscoring the importance of eco-friendly practices and offering a detailed evaluation of practitioner priorities, this research provides valuable insights for developing intelligent transport systems in smart cities. This highlights the necessity for ongoing research that addresses not only technical challenges but also the social and economic aspects of these transformative technologies.

6. Conclusion

This article offers a thorough examination of transportation systems in Türkiye, focusing on their intelligent features and environmental implications. This research delves into the intricacies of intelligent transportation systems (ITS) and evaluates their minimal negative impact on the environment. The insights derived from this study aim to guide ITS designers and provide essential recommendations for future research and conceptual approaches during the design phase.

By employing the Analytic Hierarchy Process (AHP) methodology, this paper reveals key insights: experts concur that sustainable transportation is a core component of smart transportation. This finding not only validates the efficiency of intelligent transportation systems (ITS) and emphasizes their compatibility with eco-friendly initiatives.

This research pays special attention to the selection of pilot regions and the integration of 5G technology within the ITS framework. The primary focus is the IPA-2 project, and Hacettepe University's campus has been designated as a significant pilot area. Within this 5G test zone, an advanced transportation system is being developed that leverages 5G technology to enable real-time data exchange among vehicles. The study also underscores the essential role of urban greenery, particularly trees, in reducing the environmental footprint of transportation systems.

Continuous monitoring activities in the 5G test zone—including daily traffic assessments, carbon emissions tracking, and evaluation of the emission-absorbing capacity of trees—offer crucial insights into the environmental impact of transportation systems. Authored by the IPA-2 Project team, this article provides an in-depth analysis of Türkiye's intelligent transportation systems. The importance of the study lies not only in its informative conclusions but also in its potential to shape future research in this dynamic area. With a strong focus on sustainability and the adoption of innovative technologies, this article highlights the importance of forward-thinking transportation planning and design approaches to support urban development and environmental protection.

According to the findings of this study, clean and engine-free options are the foremost parameters in smart transportation, highlighting its critical importance to users. Surveys conducted as part of the research identified sustainable, innovative, and safe transportation systems as the second most vital parameter, suggesting that users prioritize reliability over sustainability. The next significant aspect identified is the mixed model for transportation systems, which indicates that users expect a combination of transportation modes in smart solutions. Although local accessibility, access to ICT infrastructure, and international accessibility are recognized, they are deemed less significant by users than the other parameters.

In summary, this study acts as a driving force for enhancing discussions surrounding intelligent transportation systems, establishing a foundation for informed decision-making, policy development, and further exploration of smart and sustainable urban mobility.

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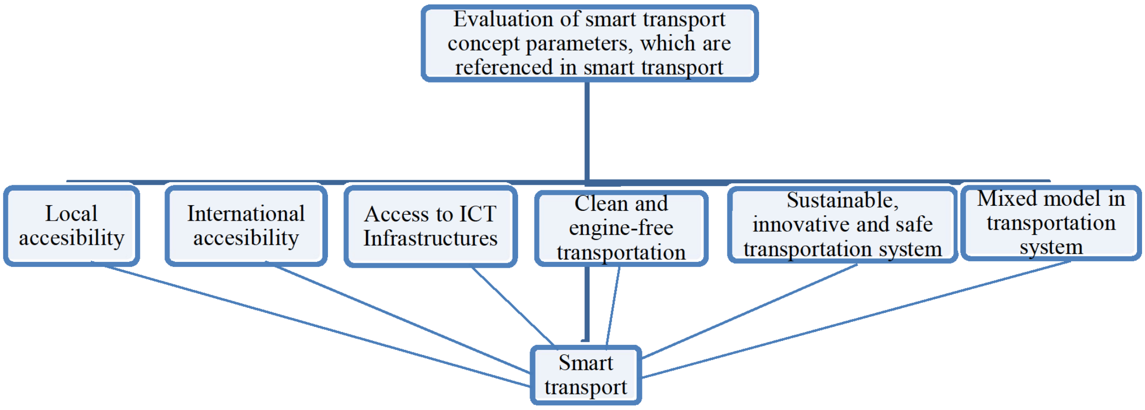
QUESTIONNAIRE ON ENABLING SMART TRANSPORTATION IN SMART CITIES: A CASE STUDY OF THE ANKARA 5G VALLEY



Which parameter is more important for smart transport?

Local accessibility	9	7	5	3	1	3	5	7	9	International accessibility
Local accessibility	9	7	5	3	1	3	5	7	9	Access to ICT Infrastructures
Local accessibility	9	7	5	3	1	3	5	7	9	Clean and engine-free transportation
Local accessibility	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems
Local accessibility	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

International accessibility	9	7	5	3	1	3	5	7	9	Local accessibility
International accessibility	9	7	5	3	1	3	5	7	9	Access to ICT Infrastructures
International accessibility	9	7	5	3	1	3	5	7	9	Clean and engine-free transportation
International accessibility	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems
International accessibility	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	Local accessibility
Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	International accessibility
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Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems
Access to ICT Infrastructures	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	Local accessibility
Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	International accessibility
Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	Access to ICT Infrastructures
Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	Sustainable, innovative, and safe transportation systems
Clean and engine-free transportation	9	7	5	3	1	3	5	7	9	Mixed-model transportation system

Sustainable, innovative, and safe transportation systems	9	7	5	3	1	3	5	7	9	Local accessibility
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