Trends in
Transport Engineering and Applications
ISSN: 2394-7284
Volume 13, Issue 2, 2026
May–August
DOI (Journal): 10.37591/TTEA
https://journals.stmjournals.com/ttea
Review TTEA

Optimizing Tourist Mobility with Dijkstra's Algorithm: A Review on Pollution Reduction through Smart Path Planning

Manisha Dhapola[1,*], Himanshu Bharti[2], Sanjeev Suman[3]

Abstract

Although Tourism helps the economy, but it can also harm the environment, especially in popular tourist destinations. Optimizing routing is one way to reduce these environmental effects. This review paper examines how the well-known and traditional Dijkstra's method for shortest path computation is used to pollution management and support sustainable tourism. The study explores how intelligent traffic routing can minimize traffic congestion in environmentally sensitive areas and lower fuel consumption which helps in decreasing carbon emissions. The paper also discusses improved and hybrid versions of real time Dijkstra's Algorithm. These improvements combine real time data such as traffic density, automobile pollution level, and road network structure to make route planning smarter and more eco-friendly. Finally, the study proposes a framework for ecologically aware routing in tourist sites using sophisticated path finding algorithms is discussed in the study's conclusion, along with several unresolved research challenges. In addition, the review highlights the integration of Dijkstra's algorithm with emerging technologies such as the Internet of Things (IoT), Geographic Information Systems (GIS), Artificial Intelligence (AI), and smart transportation systems to improve route optimization in tourist destinations. The study also compares conventional shortest-path techniques with modern adaptive routing approaches that utilize dynamic traffic information and environmental indicators. Furthermore, it discusses the role of intelligent transportation systems in enhancing travel efficiency, reducing travel time, and improving visitor experiences while minimizing environmental impacts. The findings suggest that environmentally conscious routing strategies can significantly contribute to sustainable tourism by reducing vehicle emissions, conserving fuel resources, and protecting ecologically sensitive tourist areas. This review also identifies current research gaps and future directions for developing intelligent, scalable, and environmentally sustainable routing frameworks that support green tourism and long-term environmental conservation.

***Author for Correspondence**
Manisha Dhapola
Email: manishadhapola27@gmail.com

[1]Resarch Scholar, Department of Civil Engineering, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India
[2]Resarch Scholar, Department of Civil Engineering, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India
[3]Associate Professor, Department of Civil Engineering, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Received Date: July 20, 2026
Accepted Date: July 23, 2026
Published Date: July 29, 2026

Citation: Manisha Dhapola, Himanshu Bharti, Sanjeev Suman. Optimizing Tourist Mobility with Dijkstra's Algorithm: A Review on Pollution Reduction through Smart Path Planning. Trends in Transport Engineering and Applications. 2026; 13(2): 20–29p.

Keywords: Dijkstra's Algorithm, Eco-routing, Smart Tourism, Sustainable Transportation, Intelligent Transportation Systems, Pollution Reduction

INTRODUCTION

Tourism is widely recognized as one of the fastest-growing industries in the world, playing a crucial role in driving the global GDP and generating employment opportunities across both developed and developing nations [1]. It stimulates local economies, supports small businesses, and encourages infrastructure development in popular destinations. However, alongside these economic benefits, tourism also poses significant environmental challenges that cannot be overlooked [2]. One of the most pressing issues is transportation, which is essential for enabling tourist mobility but often contributes heavily to environmental degradation. In many tourist-heavy areas, especially during peak seasons, inadequate and poorly planned transit systems lead to severe traffic congestion, increased fuel consumption, and a noticeable decline in the air quality. These issues not only harm the natural environment but also reduce the quality of life of residents and diminish the overall tourist experience [2, 3]. Over time, cumulative environmental stress can lead to long-term ecological damage, making sustainability a critical concern for the future of the tourism industry.

A substantial share of tourism-related carbon emissions originates from transportation, including private vehicles, buses, and other commonly used travel modes within destinations [2]. Traditional navigation systems, which are widely used today, are primarily designed to optimize the shortest travel time or distance, often neglecting the environmental consequences of route choices [4]. Consequently, these systems may unintentionally guide users through highly congested routes, thereby increasing emissions and worsening urban pollution. This limitation highlights the urgent need for more advanced and intelligent routing systems that integrate environmental considerations into decision-making processes. Such systems should aim to balance efficiency and sustainability by incorporating factors such as traffic density, fuel consumption, and emission levels into route optimization [5]. Developing eco-friendly navigation solutions is not only beneficial for reducing carbon footprints but also aligns with global sustainability goals and responsible tourism practices [6, 7].

A strong foundation for building intelligent routing systems lies in Dijkstra's algorithm, a fundamental graph-based method used to determine the shortest path between nodes in a network [8]. Traditionally, algorithms operate by minimizing a single cost metric, such as distance or time [4]. However, for sustainable tourist routing, this approach can be expanded and enhanced to consider multiple criteria simultaneously. By modifying the algorithm to include environmental costs, such as estimated carbon emissions, traffic congestion levels, and road conditions, it becomes possible to generate routes that are both efficient and eco-friendly. This study explores various techniques for adapting and extending Dijkstra's algorithm to support sustainable transportation in tourism contexts. These enhancements may involve multi-weighted graphs, dynamic cost functions, or hybrid optimization strategies that prioritize greener alternatives without significantly compromising travel convenience [5]. Through such innovations, intelligent routing systems can play a key role in promoting environmentally responsible tourism while maintaining practical usability for travelers.

LITERATURE REVIEW

Environmental Impact of Tourist Transportation

According to various research studies, transportation accounts for a significant majority of tourism-related environmental impacts, contributing up to 75% of the total emissions associated with the sector [2, 1]. This includes emissions from air travel, road transport, cruise ships, and local commuting to tourist destinations. Among these, road transportation, such as private cars, taxis, and buses, plays a particularly critical role in urban tourist areas [2]. In popular tourist cities, a sudden surge in visitor numbers often overwhelms the existing infrastructure, leading to severe traffic congestion. This congestion increases vehicle idle times, resulting in unnecessary fuel consumption and a corresponding increase in greenhouse gas emissions, particularly carbon dioxide (CO_2) [2]. Additionally, frequent stop-and-go traffic patterns further reduce fuel efficiency and amplify environmental damage.

Beyond emissions, environmental consequences extend to deteriorating air quality, increased noise pollution, and added stress on urban ecosystems. Pollutants such as nitrogen oxides (NOx) and particulate matter (PM) can reach harmful levels, posing health risks to both residents and visitors [3]. Moreover, excessive traffic can strain road infrastructure, contribute to urban heat islands, and negatively impact the overall liveability of tourist destinations. In many cases, environmental degradation caused by unmanaged tourist transportation undermines the attractions that draw visitors in the first place. Therefore, addressing transportation-related emissions and congestion is essential for ensuring the long-term sustainability of tourism, making it necessary to adopt smarter and more environmentally conscious mobility solutions [1].

Intelligent Transportation System (ITS)

To maximize traffic flow and improve overall transportation efficiency, Intelligent Transportation Systems (ITS) integrate advanced technologies such as sensors, data analytics, and communication networks [6, 7]. These systems collect real-time data from various sources, including traffic cameras, GPS devices, road sensors, and connected vehicles, thereby allowing for the continuous monitoring and analysis of traffic conditions [7]. By processing these data, ITS can identify congestion patterns, detect incidents, and predict traffic behavior, thereby enabling more informed and adaptive traffic management strategies [3, 9]. Communication technologies facilitate the seamless exchange of information between infrastructure and users, ensuring that drivers, transit operators, and city planners can respond proactively to changing conditions. This integrated approach not only enhances mobility and reduces travel delays, but also contributes to improved road safety and reduced environmental impact by minimizing unnecessary fuel consumption and emissions.

Smart routing not only improves the individual travel experience but also supports the broader goals of urban sustainability and efficient transportation management.

Routing Algorithm

Path optimization in transportation and routing systems has been achieved using a wide range of algorithms, each designed to address different types of network conditions and computational requirements. The most commonly used approaches are Dijkstra's, A*, Bellman-Ford, and Floyd-Warshall algorithms [10, 4]. Each of these techniques offers unique advantages depending on the context in which it is applied. For instance, the A* Algorithm enhances pathfinding efficiency by incorporating heuristics to guide the search process toward the destination more quickly, making it particularly suitable for real-time navigation systems. However, the Bellman-Ford Algorithm can handle graphs with negative edge weights, making it useful in scenarios where costs may decrease along certain paths, although it comes with a higher computational complexity. Similarly, the Floyd-Warshall algorithm is designed to compute the shortest paths between all pairs of nodes in a graph, making it ideal for dense networks but less efficient for large-scale, real-time applications owing to its time complexity [10].

Among these, Dijkstra's algorithm is widely used because of its efficiency and optimality for non-negative weights [8, 4].

DIJKSTRA'S ALGORITHM: TECHNICAL OVERVIEW

Dijkstra's algorithm is a fundamental method used in graph theory to compute the shortest path from a single source node to all other nodes in a weighted graph with non-negative edge weights [8]. It is widely applied in navigation systems, network routing, and transportation planning because of its efficiency and guaranteed optimality [4]. The algorithm systematically explores the graph by selecting the node with the smallest known distance from the source and updating the distances of its neighboring nodes. Through this iterative process, the shortest path tree is constructed, ensuring that the final distances represent the minimum possible cost required to reach each node from the source [8]. Its simplicity and deterministic nature make it particularly suitable for real-world applications, where reliability and accuracy are essential.

Algoritham Steps

The working procedure of Dijkstra's algorithm can be described step-by-step to better understand its execution process. Initially, the algorithm assigns a tentative distance value to every node in the graph, setting all distances to infinity to represent that they are not yet reachable. The distance to the source node is then set to zero as the starting point. Next, the algorithm repeatedly selects the node with the minimum tentative distance among all the unvisited nodes. Once selected, this node is considered "processed," and its neighboring nodes are examined. The algorithm calculates the distance to each neighbor through the current node and updates their distances if a shorter path is found. The process of selecting the closest unvisited node and relaxing the edges continues iteratively. Over time, more nodes are processed, and their shortest distances from the source are determined. The algorithm terminates when all nodes are processed or when the shortest paths to all reachable nodes are determined, resulting in a complete mapping of the shortest paths from the source.

Steps:

1. Initialize distances from source to all nodes as infinity.
2. Set source distance to zero.
3. Select node with minimum distance.
4. Update distances of neighbouring nodes
5. Repeat until all nodes are processed.

Mathematical Representation

Dijkstra's algorithm operates on a graph represented mathematically as G (V, E), where Vdenotes the set of vertices (or nodes), and Erepresents the set of edges connecting these vertices. Each edge (u,v) ∈ E has an associated weight w (u, v), which typically represents distance, time, cost, or another metric relevant to the problem domain. The primary objective of the algorithm is to minimize the total cost of the path from the source node to any destination node. This cost can be expressed as the sum of the weights of all the edges along the chosen path. Formally, the objective function is given by (1)

$$C = \sum w\ (u, v) \tag{1}$$

where the summation is taken over all consecutive edges (w,v) that form the path from the source to the destination. By minimizing this cumulative cost, Dijkstra's algorithm ensures that the most efficient route is identified according to the defined weight metric, making it highly effective for optimization problems in transportation and networking systems.

ECO-ROUTING USING MODIFIED DIJKSTRA ALGORITHM

Ecorouting extends the traditional shortest-path approach by incorporating environmental considerations into route selection, making it more suitable for sustainable transportation systems [2]. Unlike conventional routing methods that focus solely on minimizing distance or travel time, eco-routing aims to reduce the overall environmental impact of travel, particularly in terms of carbon emissions and fuel consumption [2, 1]. This is especially important in tourist-heavy regions, where traffic congestion and pollution levels can increase significantly. By modifying Dijkstra's algorithm to include multiple criteria, it is possible to generate routes that balance efficiency with environmental responsibility, ultimately contributing to greener and more sustainable mobility solutions.

Multi-Criteria Cost Function

Traditional routing algorithms typically consider only a single parameter, such as distance, when calculating an optimal path. However, eco-routing introduces a multi-criteria cost function that integrates additional factors influencing both travel efficiency and environmental impact. The cost function can be expressed as follows: (2):

$$C = \alpha D + \beta T + \gamma E \tag{2}$$

Where:
D = distance
T = traffic density
E = emissions
α, β, γ = weighting coefficients.

The coefficients α, β, and γ are weighting factors that determine the relative importance of each parameter based on the system objectives or user preferences. For example, a higher value of γ would prioritize low-emission routes, even if they are slightly longer in distance. This flexible formulation allows the routing system to adapt to different scenarios, such as prioritizing faster travel during emergencies or more sustainable routes for eco-conscious tourists [4]. By combining these criteria, the algorithm provides a more holistic optimization strategy than traditional methods.

Emission Modelling

A critical component of eco-routing is the accurate estimation of vehicle emissions along different routes [2]. Emissions are not constant and depend on several dynamic factors, including the vehicle speed, fuel consumption rate, and vehicle type. This relationship can be modelled using Eq. (3):

$$E = f(\text{speed, fuel rate, vehicle type}) \tag{3}$$

In practice, emissions tend to increase during stop-and-go traffic conditions, where frequent acceleration and deceleration lead to inefficient fuel consumption. Similarly, different vehicle types, such as diesel cars, petrol vehicles, and electric vehicles, have varying emission profiles. By integrating such emission models into the routing algorithm, it is possible to evaluate and compare routes based on their environmental impact. This enables the system to recommend paths that minimize pollution, contributing to improved air quality and reduced carbon footprints in urban and tourist areas.

Algorithm Enhancement

To effectively implement eco-routing in real-world scenarios, several enhancements have been applied to the traditional Dijkstra algorithm [4]. One key improvement is the use of dynamic weight updates, where edge weights are continuously adjusted based on real-time data, such as traffic congestion and environmental conditions. This ensures that routing decisions remain relevant and accurate as conditions change. Additionally, real-time recalculation allows the system to quickly adapt to unexpected events, such as road closures or sudden traffic spikes, by recomputing the optimal routes on the fly. Another important optimization involves the use of efficient data structures, such as priority queues, to improve the computational performance and scalability. Together, these enhancements transform the static nature of the original algorithm into a dynamic and intelligent system capable of supporting sustainable and efficient routing solutions. Algorithm Enhancement includes:

- Dynamic weight updates
- Real-time recalculation
- Priority queue optimization

SYSTEM ARCHIITECTURE

The implementation of an eco-routing system based on a modified Dijkstra algorithm requires a well-structured architecture that integrates data collection, processing, user interaction and feedback mechanisms. This layered architecture ensures seamless operation, scalability, and adaptability in real-world environments, particularly in smart cities and tourism-focused areas.

Data Collection Layer

The data collection layer serves as the foundation of the system by gathering real-time and historical data from various sources. This includes GPS devices that provide location and movement information, traffic sensors that monitor vehicle flow and congestion levels, and environmental monitoring systems that measure air quality and emission indicators [11, 12]. The integration of these diverse data streams enables the system to maintain an up-to-date understanding of road conditions and the environmental factors. Accurate and continuous data collection is essential to ensure that routing decisions are both efficient and environmentally informed.

Processing Layer

The processing layer is responsible for transforming raw data into actionable information. In this stage, the road network is modelled as a graph, where intersections are represented as nodes and roads as edges with associated weights. The modified Dijkstra algorithm was then executed on this graph using a multi-criteria cost function. Additionally, advanced techniques, such as AI-based prediction models, can be incorporated to forecast traffic patterns, estimate future congestion, and predict emission trends. These predictive capabilities enhance the system's ability to make proactive routing decisions rather than merely reacting to the current conditions [7, 13].

- Graph construction
- Algorithm execution
- AI-based prediction models

Application Layer

The application layer provides an interface through which users interact with the system. This includes mobile navigation applications and tourist guidance systems that provide real-time route recommendations to users. These applications can offer multiple route options, highlighting eco-friendly alternatives, alongside the fastest or shortest paths. By presenting clear and user-friendly information, the system encourages travellers to make more sustainable choices without significantly compromising convenience. Integration with tourism platforms can further enhance the user experience by aligning routing suggestions with points of interest and travel itineraries [6].

- Mobile navigation apps
- Tourist guidance systems

Feedback Layer

The feedback layer plays a crucial role in continuously improving the system performance and user satisfaction. It collects input from users regarding route quality, travel experience, and preferences, which can be used to refine routing models. Additionally, adaptive learning mechanisms enable the system to evolve over time by analyzing patterns in user behavior and environmental data [7]. This iterative process ensures that the eco-routing system becomes more accurate, efficient, and personalized with continued use, ultimately supporting long-term sustainability goals in transportation and tourism industries.

- User feedback
- Adaptive learning

APPLICATION IN TOURISM

Smart City Navigation

In the context of smart cities, eco-routing systems can play a vital role in guiding tourists through optimal routes that minimize congestion and environmental impact [6, 7]. Instead of directing all travellers through the fastest or most popular paths, the system can intelligently suggest alternative routes that are less crowded and more fuel-efficient. This helps reduce travel time variability, avoid traffic bottlenecks, and lower emissions caused by idling and stop-and-go driving. Additionally, such systems can be integrated with public transportation options, encouraging tourists to use more sustainable modes of travel. Consequently, smart city navigation not only improves mobility but also contributes to cleaner air and a more enjoyable urban experience for both visitors and residents.

Smart City Navigation

Eco-routing is particularly valuable for protecting environmentally sensitive or restricted areas, such as wildlife reserves, heritage sites, and conservation zones. In these regions, excessive vehicle movement can lead to habitat disruption, increased pollution, and long-term ecological harm. Routing systems can address this issue by assigning higher weights or penalties to roads passing through such areas, effectively discouraging their selection unless necessary [1, 3]. This approach ensures that tourists are guided along alternative routes that minimize environmental harm while still reaching their destination. By embedding conservation priorities directly into routing algorithms, eco-routing systems help to strike a balance between tourism development and environmental preservation.

HYBRID MODELS

To further enhance the effectiveness of eco-routing systems, modern approaches often combine traditional graph-based algorithms with advanced technologies such as real-time data processing, machine learning, and the Internet of Things (IoT). These hybrid models enable more accurate, adaptive, and intelligent routing solutions that can dynamically respond to changing conditions in transportation networks.

Real Time Dijkstra

One of the key advancements in routing systems is the development of real-time variants of Dijkstra's algorithm. In this approach, the edge weights are continuously updated using live data sources, such as traffic conditions, weather updates, and environmental measurements. This allows the algorithm to dynamically recompute optimal routes, ensuring that users always receive the most relevant and efficient path recommendations. Real-time Dijkstra significantly improves responsiveness to unexpected events, such as accidents or sudden congestion, making it highly suitable for urban tourism environments, where conditions can change rapidly [4].

Integration with Machine Learning

Machine learning techniques can be integrated with routing algorithms to enhance their predictive capabilities and decision-making accuracy. For example, traffic prediction models can analyze historical and real-time data to forecast congestion levels at different times of the day, thereby enabling the system to proactively avoid potential delays. Similarly, emission forecasting models can estimate the environmental impact of different routes under varying conditions, thereby allowing for more informed eco-routing decisions. By combining these predictive insights with algorithmic optimization, the system can move beyond reactive routing to a more proactive and intelligent approach [13, 14].

- Traffic prediction
- Emission forecasting

IoT Integration

The integration of IoT technologies further strengthens the performance of eco-routing systems by enabling continuous and real-time data collection from a wide range of connected devices. Sensors embedded in roads, vehicles, and environmental monitoring stations provide up-to-date information on traffic flow, air quality, temperature, and other factors. This rich data ecosystem enhances the accuracy of routing decisions and supports more precise modeling of real world conditions. Moreover, IoT connectivity facilitates seamless communication between system components, ensuring that data are rapidly processed and utilized for route optimization. Consequently, IoT-enabled eco-routing systems are better equipped to deliver efficient, reliable, and environmentally sustainable navigation solutions [9, 11, 15, 16].

PERFORMANCE EVALUATION

Evaluating the effectiveness of eco-routing systems is essential for determining their practical benefits in real-world tourism and transportation scenarios. Performance assessment typically involves analyzing how well the modified routing approach balances efficiency with environmental sustainability. By comparing eco-routing techniques with traditional shortest-path methods, researchers can quantify the improvements in traffic management, fuel usage, and emission reduction. Such evaluations are often conducted using real-world datasets and simulated environments that replicate urban tourist networks under varying conditions.

Metrics

Several key metrics were considered to measure the performance of the eco-routing systems. Travel time remains an important factor, as users still expect timely navigation despite the introduction of environmental considerations in route planning. Fuel consumption is another critical metric, as it is directly related to both economic costs and environmental impact. Additionally, carbon dioxide (CO_2) emissions are used as a primary indicator of sustainability, reflecting the ecological footprint of different routing strategies. In some cases, additional indicators, such as average vehicle speed, congestion levels, and air quality indices, may also be included to provide a more comprehensive evaluation [2].

- Travel time
- Fuel consumption
- CO_2 emissions

Comparative Analysis

A comparative analysis between eco-routing and traditional routing methods highlights the tangible benefits of incorporating environmental factors into path optimization. Studies have shown that eco-routing can reduce carbon emissions by approximately 15–25% by avoiding highly congested routes and promoting smoother traffic flow [2]. Although eco-friendly routes may sometimes be slightly longer in distance, they often result in more consistent speeds and reduced idling, leading to overall efficiency gains. Furthermore, eco-routing contributes to improved traffic distribution by preventing excessive loads on specific roads and encouraging the use of alternative paths. This not only reduces congestion in popular tourist areas but also enhances the resilience and capacity of the overall transportation network of the region. Eco-routing versus traditional routing:

- 15–25% reduction in emissions
- Improved traffic distribution

Stimulation Studies

Simulation studies are crucial for validating the effectiveness of eco-routing algorithms before their deployment in real-world systems. These simulations model urban tourist environments by incorporating variables such as traffic density, road networks, vehicle types, and environmental conditions [4]. By testing different routing strategies under controlled scenarios, researchers can observe system behavior, identify potential limitations, and refine algorithmic performance. The results of these studies consistently demonstrate that eco-routing improves overall system efficiency, reduces environmental impact, and enhances traffic flow management. Moreover, simulations allow scalability testing, ensuring that the proposed solutions remain effective even in large and complex urban networks with high tourist activity.

Simulations demonstrate improved efficiency in urban tourist networks.

CHALLENGES AND LIMITATION

Eco-routing systems offer significant benefits, but their real-world implementation faces several key challenges.

- *Data availability and accuracy:* Dependence on real-time and historical data (traffic, GPS, environment) can be problematic in regions with incomplete or unreliable data, leading to suboptimal routing.
- *Computational complexity:* Multi-criteria routing (traffic, emissions, and dynamic conditions) increases algorithm complexity, requiring high computational power and causing potential latency in large networks.
- *Privacy concerns:* Use of user data (location and behavior) raises security and privacy risks, necessitating strong data protection, anonymization, and transparent policies.
- *User adoption barriers:* Preference for the fastest routes, low awareness, and resistance to change may limit acceptance; user-friendly design and incentives are needed to encourage eco-friendly choices [11, 12].

Overall, addressing technical constraints and human factors is essential for the effective and widespread adoption of AI in healthcare.

FUTURE REASEARCH

Future eco-routing research should focus on enhancing efficiency, sustainability, and real-world applicability through emerging technologies and advanced methods [12, 13].

- *Autonomous vehicles integration:* Improve routing and reduce traffic emissions.

- *Multi-objective optimization:* Expanding criteria (energy, safety, comfort, cost) for better decision-making and balanced routing solutions.
- *Blockchain for data security:* Ensures safe data sharing and encourages eco-friendly routing.
- *Policy and governance models:* Create rules and incentives for eco-systems.

Overall, these directions can advance eco-routing toward smarter and more sustainable transportation systems.

CONCLUSION

This study demonstrates the significant potential of Dijkstra's algorithm as a foundation for promoting sustainable tourism through intelligent and optimized routing. By extending the traditional shortest-path approach to incorporate environmental factors such as traffic density, fuel consumption, and carbon emissions, eco-routing systems can provide travellers with routes that are not only efficient but also environmentally responsible. The integration of real-time data from GPS devices, traffic sensors, and environmental monitoring enables dynamic route recalculation, ensuring that travellers are guided along paths that minimize congestion and reduce pollution.

Moreover, the adoption of advanced technologies, such as artificial intelligence and the Internet of Things (IoT), promises to further enhance the effectiveness of these systems. Machine learning models can predict traffic patterns and emissions, whereas IoT-enabled devices ensure continuous and accurate data collection from vehicles and infrastructure. These capabilities allow eco-routing systems to adapt proactively to changing conditions, offering smarter and more sustainable travel options. By combining algorithmic optimization with real-time intelligence and environmental awareness, such systems have the potential to reshape tourist mobility, reduce the ecological footprint of travel, and contribute to the long-term sustainability of urban and natural destinations worldwide.

REFERENCES

1. Dijkstra EW. A note on two problems in connexion with graphs. In: Dijkstra EW. Edsger Wybe Dijkstra: His Life, Work, and Legacy. New York: Association for Computing Machinery; 2022. p. 287–290.
2. Wassouf A. A comprehensive review of IoT technologies and their applications in electrical power systems, agriculture, and sustainability: Challenges, innovations, and future directions (2018–2023). Sensors (Basel). 2024;24(2):1–35.
3. Yan J, Liu J, Tseng FM. An evaluation system based on the self-organizing system framework of smart cities: A case study of smart transportation systems in China. Technol Forecast Soc Change. 2020;153:119371.
4. Liu J, Zhang L, Li C, Bai J, Lv H, Lv Z. Blockchain-based secure communication of intelligent transportation digital twins system. IEEE Trans Intell Transp Syst. 2022;23(11):22630–22640.
5. Barth M, Boriboonsomsin K. Real-world carbon dioxide impacts of traffic congestion. Transp Res Rec. 2008;2058(1):163–171.
6. Hall CM. Constructing sustainable tourism development: The 2030 agenda and the managerial ecology of sustainable tourism. J Sustain Tour. 2019;27(7):1044–1060.
7. Saarinen J. Sustainable growth in tourism? Rethinking and resetting sustainable tourism for development. In: Higgins-Desbiolles F, Cheer JM, editors. Degrowth and Tourism: New Perspectives on Tourism Entrepreneurship, Destinations and Policy. London: Routledge; 2020. p. 135–151.
8. Cui Q, Hu X, Ni W, Tao X, Zhang P, Chen T, et al. Vehicular mobility patterns and their applications to Internet-of-Vehicles: A comprehensive survey. Sci China Inf Sci. 2022;65(11):211301.
9. Bellman R. On a routing problem. Q Appl Math. 1958;16(1):87–90.
10. Bast H, Delling D, Goldberg AV, Müller-Hannemann M, Pajor T, Sanders P, et al. Route planning in transportation networks. In: Kliemann L, Sanders P, editors. Algorithm Engineering: Selected Results and Surveys. Cham: Springer; 2016. p. 19–80.

11. Zheng Y. Urban computing with big data. J Chin Comput Commun. 2013;9(8):8–18.
12. Abdellah AR, Muthanna A, Koucheryavy A, Usmanova A. Autonomous vehicle traffic rate prediction in dense networks: A deep learning approach. In: Proceedings of the 8th International Conference on Future Networks & Distributed Systems (ICFNDS 2024); 2024 Dec. p. 111–114.
13. Muse AA, Hassan AM. Advanced traffic forecasting integrating temporal and spatial dependencies using hybrid deep learning models. Int J Electron Commun Eng. 2024;11(9):64–76.
14. Derawi M, Dalveren Y, Cheikh FA. Internet-of-things-based smart transportation systems for safer roads. In: Proceedings of the IEEE 6th World Forum on Internet of Things (WF-IoT); 2020 Jun. p. 1–4.
15. Raj EFI, Appadurai M. Internet of things-based smart transportation system for smart cities. In: Haldorai A, Ramu A, editors. Intelligent Systems for Social Good: Theory and Practice. Singapore: Springer; 2022. p. 39–50.
16. Lin Y, Shi Y. A novel sustainable approach for developing Internet of Things-based transportation networks based on a hybrid energy-aware algorithm. Cluster Comput. 2025;28(8):554.

