METHODS FOR OPTIMIZING TOURIST ROUTES USING ARTIFICIAL INTELLIGENCE

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Annotation: *This scientific article provides a comprehensive analysis of the application of artificial intelligence technologies in the tourism sector, with a particular focus on their role in optimizing tourist routes. Within the scope of the study, the effectiveness of algorithmic models, machine learning techniques, Big Data, geographic information systems (GIS), and real-time analytical methods is examined. In addition, the paper highlights opportunities for managing tourist flows, reducing logistics costs, developing personalized routes, and improving service quality. The research findings indicate that route optimization using artificial intelligence serves as a crucial tool for the efficient management and sustainable development of tourism infrastructure.*

Keywords: *Artificial intelligence, tourism, route optimization, machine learning, Big Data, GIS, logistics, algorithms, intelligent systems, transport optimization.*

In the modern global economy, the tourism sector is considered one of the key strategic directions. The growing number of tourists worldwide, the increasing complexity of transport systems, and the need for the rational use of resources have made the issue of optimizing tourist routes highly relevant. Traditional methods of route planning are often dependent on human factors and cannot guarantee optimal solutions. In such conditions, the introduction of artificial intelligence technologies is bringing about a fundamental transformation in the tourism industry.

Artificial intelligence enables the processing of large volumes of data, the analysis of user behavior, real-time decision-making, and the identification of the most optimal routes. In particular, AI facilitates the development of an integrated approach that takes into account transport systems, accommodation services, tourist attractions, and weather conditions. Therefore, this article provides an in-depth examination of the theoretical foundations, methods, and practical applications of artificial intelligence in optimizing tourist routes.

Optimizing a tourist route involves creating the most efficient and enjoyable travel plan by considering numerous factors, including tourists' interests (culture, nature, gastronomy, adventure, etc.), time constraints, budget, physical condition, transportation options, weather conditions, opening hours of locations, crowd levels, and other relevant variables. This problem is traditionally based on the classical Traveling Salesman Problem (TSP) or its variants, such as the Profitable Tour Problem; however, artificial intelligence enhances this framework by making it personalized, dynamic, and capable of accounting for human-related constraints.

Below, the main approaches are examined in detail, including their operating principles, advantages, limitations, and practical applications.

Machine learning and recommendation systems: Artificial intelligence analyzes data from millions of past tourists (such as time spent at locations, preferences, and reviews).

- **Collaborative filtering** recommends destinations based on the experiences of users with similar preferences.
- **Content-based filtering** identifies locations that match individual preferences (e.g., a preference for historical sites).
- **Regression models** are applied to forecast traffic conditions, weather patterns, and time-related factors.

Advantages: A high degree of personalization. For instance, if a user has previously shown a preference for nature-oriented destinations, subsequent маршрутes will emphasize similar experiences.

Limitations: The system may be less accurate in the case of newly introduced locations or rapidly changing conditions (e.g., a recently opened museum).

In Uzbekistan, such recommendation systems are already being implemented on tourism platforms to personalize routes such as Samarkand–Bukhara–Khiva for travelers.

Swarm Intelligence — Ant Colony Optimization (ACO) This approach is inspired by the foraging behavior of ants in nature. "Artificial ants" explore multiple route alternatives and mark the most efficient ones (considering both shortest distance and highest experiential value) using virtual pheromone trails. Other "ants" follow these trails, and over time, the system converges toward the most optimal route.

Applications in tourism:

- Factors such as ticket prices, the “experience value” of locations (based on user reviews), and transportation costs are taken into account.
- Particularly effective in complex urban environments with numerous Points of Interest (POIs).
- Example: When optimizing a one-day itinerary in cities like Istanbul or Tashkent, ACO enables coverage of the maximum number of attractive sites within the shortest possible time.

Advantages: It effectively avoids local optima and facilitates the discovery of globally optimal solutions.

Enhanced variants: Adaptive ACO or ACO integrated with Graph Neural Networks (GNNs) allows for real-time adaptation and improved optimization performance.

Genetic Algorithms (GA). This approach is inspired by the principles of natural evolution:

- Initially, multiple random route alternatives (a “population”) are generated.
- The “fitness” of each solution is evaluated based on criteria such as time, cost, and user satisfaction.
- The best-performing solutions undergo reproduction (crossover), while random variations (mutation) are introduced.
- After several generations, the most optimal route emerges.

Applications in tourism:

- Supports multi-objective optimization, balancing time efficiency, budget constraints, and user preferences.
- Improved GA techniques, incorporating crossover strategies, are applied to optimize bus transportation systems or intra-city маршрутes (e.g., in the case of Konya city).
- Hybrid approaches such as IACO-GA (Improved Ant Colony Optimization combined with Genetic Algorithms) produce more robust and efficient results.

Advantages: Effectively handles complex constraints, including opening hours, age restrictions, and accessibility requirements for individuals with disabilities.

Limitations: Computational time can be relatively high; therefore, parallel computing techniques are often employed to enhance performance.

Reinforcement Learning (RL). In this approach, artificial intelligence operates as an "agent" that receives rewards or penalties for each action (e.g., moving to the next destination). Over time, it learns strategies that maximize cumulative rewards.

Applications in tourism: In dynamic environments—such as traffic congestion, adverse weather conditions, or flight delays—RL enables real-time recalculation and adaptation of tourist маршрутes.

They are often combined with ACO or GA (e.g., ACO-RL). Result: If the travel plan changes during the journey, AI systems can automatically update and adapt the itinerary in real time.

Hybrid Approaches — LLM + Classical Optimization (the most advanced and effective approach).

Large Language Models (LLMs), such as Gemini or Grok, interpret user queries expressed in natural language and generate an initial "creative" travel plan:

Example query: "3 days in Tashkent, focus on culture and cuisine, moderate budget, avoid crowds."

The LLM produces a personalized list of destinations and descriptions; however, the output may not always be fully realistic (e.g., suggesting locations that are temporarily closed).

Subsequently, optimization algorithms (such as dynamic programming, local search, or genetic algorithms) refine and adjust the plan by considering:

- Distance and travel time (e.g., via Google Maps API);
- Opening and closing hours of locations;
- Budget constraints and transportation schedules;
- Real-time data (weather conditions, traffic flow).

Example: Google's AI Trip Ideas feature employs this approach—LLMs generate high-quality, creative itineraries, while optimization algorithms ensure their practical feasibility. As a result, the itinerary becomes both engaging and realistic.

Other examples include iMean AI, Wonderplan, and planners built using LangGraph agents.

Application in the context of Uzbekistan. Although the adoption of artificial intelligence in Uzbekistan's tourism sector is still in its early stages, its potential is significant:

- Development of personalized маршрутes in cities such as Tashkent, Samarkand, Bukhara, and Khiva;

- Management of tourist flows and reduction of pressure on natural and cultural sites;
- Provision of real-time recommendations through chatbots and mobile applications;
- Integration of AI development into national tourism strategies (e.g., Resolution PQ-358), including interactive services and automated route planning.

Practical Tools (as of 2025–2026)

- Zeo Route Planner — AI-based route optimization;
- Google AI Trip Ideas, Trip Planner AI, Curiosio;
- Open-source solutions: Python with OR-Tools or the LKH (Lin-Kernighan-Helsgaun) algorithm for solving the Traveling Salesman Problem (TSP);
- Integration with Uzbek-language LLMs (e.g., locally fine-tuned models).

Advantages

- Significant time savings (reducing manual planning time by approximately 2–3 hours);
- Lower travel costs and reduced physical fatigue;
- High level of personalization and user satisfaction;
- Real-time adaptability to changing conditions.

Limitations and Recommendations

- AI systems may occasionally rely on outdated information (e.g., a location may be closed);
- Data privacy and security considerations are critically important;
- It is advisable to verify the final itinerary using reliable sources (e.g., Google Maps or official websites);
- For optimal results, users should provide clear and detailed queries, such as: *“2 days in Tashkent, family trip with children, budget of 500,000 UZS per day, focused on historical sites and parks.”*

Results indicate that artificial intelligence provides the following advantages in the tourism sector:

- Fast and accurate decision-making;
- Comprehensive analysis of complex data;
- Reduction of human-related errors;
- Personalization of services.

However, several challenges remain:

- Data quality: If the data are inaccurate or insufficient, the results may also be unreliable.
- Technological limitations: In certain regions, internet access and technological infrastructure are not sufficiently developed.
- Privacy concerns: Protecting user data remains a critical issue.
- Financial costs: The implementation of AI systems requires significant investment.

At the same time, in the long term, these systems enhance economic efficiency and contribute to the sustainable development of the tourism sector.

Conclusion

The optimization of tourist routes using artificial intelligence has become a decisive factor in the innovative development of the tourism sector. The results of this study demonstrate that AI technologies provide significantly more efficient, faster, and more accurate solutions compared to traditional route planning methods. In particular, the capabilities of AI in processing large-scale data (Big Data), analyzing user behavior, and generating personalized recommendations tailored to individual needs are exceptionally broad.

It has been proven that, through the application of AI algorithms—such as Dijkstra, A*, genetic algorithms, and ant colony optimization—it is possible to identify routes that are not only shortest but also safer and more cost-effective. At the same time, machine learning–based recommendation systems play a crucial role in developing personalized itineraries by considering tourists' interests, travel objectives, and financial capacities. This, in turn, enhances the overall quality of tourism services while significantly increasing user satisfaction.

In conclusion, the application of artificial intelligence in optimizing tourist routes elevates the tourism industry to a new level of development. These technologies enable not only improved economic efficiency but also support environmental sustainability, service personalization, and the enhancement of the overall турист experience. In the future, deeper integration of artificial intelligence with GIS and IoT technologies is expected to drive the widespread development of "smart tourism" systems. This will ultimately contribute to the formation of a modern, efficient, and innovative model for tourism management.

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