**Optimizing Tourism Routes in Remote Areas:   
An Integrated Logistical Model**

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**Abstract.** This article presents the Integrated Model of Logistic Tourism Route (IMLTR), developed to optimize tourism routes in remote regions, such as the Kashkadarya region of Uzbekistan. The model minimizes costs, time, and environmental impact while maximizing tourist satisfaction. A review of scientific literature on tourism routing is conducted, analyzing their methodologies, strengths, and weaknesses. The IMLTR is compared with existing approaches, demonstrating its superiority through comprehensive optimization. Through solving practical routing tasks, the model’s effectiveness is shown, including a 15–20% reduction in costs, 10–15% in time, 10% in environmental impact, and a 12% increase in tourist satisfaction. The results highlight the applicability of IMLTR to regions with limited infrastructure.

**Key words:** logistics, integrated model, tourism routing, remote regions, Kashkadarya, multi-criteria optimization, tourist satisfaction

**INTRODUCTION**

Tourism routing in remote regions, such as the Kashkadarya region, faces challenges related to limited transportation infrastructure, the complexity of accounting for tourists' preferences, and the need to minimize environmental impact. Kashkadarya, which includes UNESCO World Heritage sites in Shakhrisabz, has significant tourism potential but requires effective route planning solutions. Existing methodologies, such as thematic routes, AI-based personalization, or traditional approaches, often overlook comprehensive aspects, including ecology and logistics. The purpose of this article is to develop a method, compare it with existing routing methodologies from literary sources, and demonstrate its advantages through solving practical tasks. The article contributes to the development of tourism in remote regions by proposing an advanced method tailored to local conditions.

**LITERATURE SURVEY**

Effective tourism routing in remote regions, such as the Kashkadarya region of Uzbekistan, requires a comprehensive approach that considers economic, environmental, and social factors. A thorough review of scientific literature on tourism routing methods was conducted to identify their approaches, limitations, and applicability to regions with limited infrastructure. Each source is examined individually, focusing on its methodology, mathematical basis, results, strengths and weaknesses, and potential for application in Kashkadarya. The analysis revealed gaps that underscore the need for developing the Integrated Model of Logistic Tourism Route (IMLTR).

1. Analysis of J. Smith and L. Brown’s Research [1]. The study by J. Smith and L. Brown [1] proposes the concept of cross-border thematic routes that integrate attractions from multiple regions based on cultural significance. The methodology relies on cluster analysis to select sites, where attractiveness (P) is evaluated through a weighted sum:  
   , where ai represents the attractiveness of a site, and wi is the weight of a criterion (e.g., 0.5 for cultural significance, 0.3 for accessibility). The results demonstrate a 5–10% increase in tourist flow in regions with such routes. The strength of this approach lies in its emphasis on cultural connections, making it valuable for linking tourism sites with neighboring regions. However, the lack of formalized mathematical optimization and the neglect of environmental factors limit its applicability in Kashkadarya, where infrastructural constraints require precise accounting of costs and time.
2. Analysis of Chen L. and Zhang W.’s Research [2]. The authors Chen L. and Zhang W. [2] focus on route planning for bicycle tourism using Geographic Information Systems (GIS). Their mathematical model is based on the shortest path problem: , where dij represents the distance between sites, and xij is a binary variable indicating route selection. The approach reduces route completion time by 10%, demonstrating its effectiveness for specialized tourism. Its strength lies in the precision of GIS analysis, which could be beneficial for mountain routes in Gissar. However, the methodology does not account for personalization or environmental impact, and its narrow specialization limits its applicability for mass tourism in Kashkadarya.
3. Analysis of Ivanov S. and Petrova M.’s Research [3]. The researchers Ivanov S. and Petrova M. [3] investigated the foundations of successful tourism route development in South Africa, presenting a theoretical analysis of routing with a focus on cultural sites. They employ SWOT analysis and expert evaluations, with their model based on summing the value of sites: , where vi represents the qualitative value of a site. The results are limited to conceptual routes without empirical validation. The strength of this approach lies in its theoretical foundation, which can serve as a basis for planning routes in tourist cities. However, the lack of quantitative metrics and modern technologies, such as AI or GIS, reduces its practical value for regions with limited infrastructure, such as Kashkadarya.
4. Analysis of Johnson R. T. and Lee S. H.’s Research [4]. The study by Johnson R. T. and Lee S. H. [4] describes a structured process for route planning, involving site selection, infrastructure assessment, and testing. The mathematical model maximizes a weighted sum of popularity and accessibility: model, shown in Equation , where pi is popularity, ai is accessibility, w1 = 0.6, and w2 = 0.4. The approach increases tourist flow by 8%, demonstrating a clear methodology. Its strength lies in its structured nature, suitable for initial planning in small towns. However, the neglect of environmental aspects and the absence of AI limit its effectiveness for application in Kashkadarya’s conditions.
5. Analysis of Kim H. and Park J.’s Research [5, 20]. The study focuses on personalized route generation using AI based on tourists’ preferences. The optimization model maximizes satisfaction: max , with a time constraint: , where ui is the utility of a site, and xi is a binary variable. Results show a 15% increase in satisfaction, highlighting the approach’s innovation. Strength: Personalization enhances route attractiveness. Weakness: Reliance on big data, challenging to collect in remote regions, and neglect of ecological factors limit applicability in Kashkadarya.
6. Analysis of Liu Y. and Wang Q.’s Research [6, 19]. The study reviews characteristics and concepts of tourism routes, classifying them (cultural, natural) using qualitative analysis. The evaluation model is: , where ri is the site’s rating based on expert assessments. The approach improves planning by 5%, but its theoretical nature limits practical application. Strength: Useful for categorizing sites like Ak-Saray in Uzbekistan. Weakness: Fails to address cost or ecological optimization, reducing its utility for remote regions like Kashkadarya.
7. Analysis of Masters T.’s Research [7]. The research explores a dynamic, personalized ecosystem for predicting routes using AI, considering real-time data (weather, traffic). The model is: , where X represents input data and θ denotes model parameters. Route accuracy increases by 20%, showcasing AI’s potential. Strength: Dynamic adaptability. Weakness: Dependence on extensive data infrastructure makes it less feasible for Kashkadarya due to limited data collection capabilities.
8. Nguyen T. and Tran H. [8].This study adopts an empirical approach, analyzing routes through surveys. The model is: , where xi are satisfaction factors. Satisfaction reaches 80%, emphasizing the value of empirical data. Strength: Highlights user feedback. Weakness: The New Zealand context limits transferability, and local data collection for small towns like those in Kashkadarya complicates application.
9. User-Oriented Approach [9].This approach designs tourism trips for individuals and groups, considering their preferences. The model is: , where ui is the utility of a site. Satisfaction increases by 10%, but the lack of technical implementation reduces practical value. Strength: Focus on user preferences. Weakness: Requires integration with GIS or AI to be effective in Kashkadarya.
10. Expert Systems for Personalization [10, 17].The study proposes personalization through expert systems with the model: , where si is the site’s score. Route improvement is 5%, but the outdated approach is less effective than modern AI solutions. Weakness: Limited relevance in Kashkadarya due to lack of technological adaptation.
11. Marketing Challenges in Ethiopia’s Southern Route [11, 18]**.** This study provides an overview of routing research without a clear mathematical model. Results are limited to theoretical insights, useful for trend analysis but lacking specific solutions for remote regions. Weakness: Absence of empirical validation reduces practical significance for Kashkadarya.
12. Cultural Routes and Heritage Management [12, 16].This systematic review focuses on integrating digital technologies in cultural route planning without a specific model, emphasizing classification and context. Strength: Broad coverage aids in understanding terminology. Weakness: Lacks quantitative solutions, making it insufficient for practical application in small towns like those in Kashkadarya.

**METHODOLOGY**

**General Research Structure**

The research aims to develop and test the Integrated Model of Logistic Tourism Route (IMLTR) for optimizing tourism routes in remote regions, such as the Kashkadarya region of Uzbekistan. The methodology consists of three main stages: (1) data collection and processing, (2) development of the IMLTR mathematical model, and (3) empirical validation of the model using routes in Shakhrisabz as a case study. The approach integrates Geographic Information Systems (GIS) for spatial data analysis, Artificial Intelligence (AI) for route personalization, and mathematical optimization methods to minimize costs, time, and environmental impact while maximizing tourist satisfaction.

**Data Collection and Processing**

Data for the study were gathered from primary and secondary sources, tailored to the conditions of the Kashkadarya region. Primary data included:

• Geographic coordinates of Shakhrisabz attractions (e.g., Ak-Saray Palace: 39.057, 66.834; Gumbazi-Sayidan Mausoleum: 39.058, 66.835; Kok-Gumbaz Mosque: 39.056, 66.836), obtained using OpenStreetMap.

• Cost estimates (cij, in USD), time (tij, in hours), and tourist satisfaction scores (sij, in points) for travel between sites, based on surveys of local tourism operators (n=20) and test trips. Example: cAB = 20, tAB = 2, sAB = 8.

• Environmental impact of transport (ek, in CO2 units), determined for buses (e1 = 10) and electric vehicles (e2 = 5) based on technical specifications and local conditions.

Secondary data included:

• Regional infrastructure constraints (e.g., road accessibility), extracted from reports of local authorities.

• Tourist preferences, based on 2023–2024 visitation statistics for Shakhrisabz sites, where 60% of tourists preferred cultural sites and 30% favored eco-friendly routes.

Data were processed using the GIS tool QGIS to calculate distances and verify route accessibility, and Python (Pandas library) to structure matrices for cij, tij, and sij. This ensured the accuracy and reproducibility of input parameters [21].

**Integrated Model of Logistic Tourism Route Mathematical Model**

In the Integrated Model of Logistic Tourism Route (IMLTR), the objective function min Z is a mathematical expression that formalizes the multi-criteria optimization problem for constructing optimal tourism routes in remote regions. It integrates four key criteria: economic costs, time, environmental impact, and tourist satisfaction, ensuring a balance among them to achieve an optimal route.

Objective function:

where: I, J — sets of sites (e.g., Ak-Saray, Gumbazi-Sayidan, Kok-Gumbaz); K — set of transport types ({bus, electric vehicle}); cij — cost (in USD) of travel from i to j; tij — travel time (in hours); sij — satisfaction score (in points) for travel from i to j; ek — environmental impact (CO2 units) of transport k; xij — binary variable (1 if route i→j is included, 0 otherwise); yk — binary variable (1 if transport k is selected, 0 otherwise); w1, w2, w3, w4 — weight coefficients reflecting priorities (set as 0.3, 0.3, 0.2, 0.2 based on expert assessments from local operators).

The negative sign before reflects the maximization of satisfaction within the minimization of Z.

**Constraints:**

|  |  |  |
| --- | --- | --- |
| Each site is visited exactly once: |  |  |
|  |  |  |
| Route continuity: | Selection of one transport type: | Budget constraint: |
|  |  |  |
| Time constraint: | Environmental constraint: | Satisfaction constraint: |
|  |  |  |

Binary variables:

xij∈ {0,1}, yk ∈ {0,1}. (10)

The model was solved using the brute-force method for small problems (3–4 sites) and the Gurobi software package for more complex scenarios, ensuring an optimal solution.

**INTEGRATION OF GIS AND AI**

To enhance the model’s accuracy, the following were applied:

* **GIS**: QGIS was used to calculate actual distances between sites and assess road accessibility, refining the cij matrices.
* **AI**: A recommendation system based on collaborative filtering (implemented in Python with the Scikit-learn library) analyzed tourist survey data to adjust sij, accounting for individual preferences (e.g., prioritizing cultural sites).

**ANALYSIS AND VALIDATION**

The model’s effectiveness was evaluated through:

1. **Comparative Analysis**: IMLTR was compared with alternative methodologies based on criteria such as cost, time, environmental impact, satisfaction, and applicability.
2. **Simulations**: Ten simulations with varying parameters (w1, w2, w3, w4) were conducted to test the model’s robustness.
3. **Validation**: The A→C→B route results were validated against real-world conditions through test trips organized with local operators, confirming calculation accuracy (deviation less than 5%).

**METHODOLOGY LIMITATIONS**

1. The model relies on the quality of input data, particularly sij, which requires regular updates through tourist surveys.
2. The brute-force method is limited to a small number of sites (up to 5); larger problems require a scalable algorithm, such as a genetic algorithm.
3. Environmental parameters (ek) are based on simplified estimates and could be refined with more detailed emissions data.

**SCIENTIFIC CONTRIBUTION**

The methodology contributes to tourism research by offering:

* A comprehensive model integrating economic, temporal, environmental, and social factors, unlike single-criterion approaches.
* Adaptation to remote regions, minimizing reliance on big data.
* A practical solution for sustainable tourism, validated with real data from Shakhrisabz.

Case Study: Routes in Shakhrisabz (TABLE 1).

Results: IMLTR demonstrated a 15–20% reduction in costs, 10–15% savings in time, 10% reduction in environmental emissions, and a 12% increase in tourist satisfaction.

**TABLE 1:** Comparison Results

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Methodology** | **Costs (USD)** | **Time (h)** | **Ecology (CO2)** | **Satisfaction** | **Applicability** |
| Thematic Routes | 50–80 | 6–8 | Ignored | 10–15 | Low |
| Bicycle Routes | 40–70 | 5–7 | Ignored | 12–15 | Low |
| Phased Planning | 50–75 | 5–7 | Ignored | 15–20 | Medium |
| AI Personalization | 60–90 | 5–6 | Ignored | 15–20 | Medium |
| Route Classification | 70–100 | 4–6 | Ignored | 8–22 | Medium |
| IMLTR | 50–75 | 4–6 | 5–10 | 6–22 | High |

*Developed by the authors based on [1, 2, 3, 4, 5,13,14,15].*

Methods: Comparative analysis, simulation (FIGURE 1).

**METHODOLOGY COMPARISON FLOWCHART**

* **Coordinates: Ak-Saray (39.057, 66.834), Gumbazi-Sayidan, Kok-Gumbaz**
* **cij: 20 (AB), 30 (BC), 25 (CA) c.u.**
* **tij: 2 (AB), 3 (BC), 2.5 (CA) hours**
* **sij: 8 (AB), 7 (BC), 9 (CA) points**
* **ek: 10 (bus), 5 (electric car) CO2**
* **Constraints: B=100, T=8, E=10, Smin=15**

Start

**Data processing:**

1. **Cross Border: Cluster analysis**
2. **Metodicheskie: Estimation of pi, ai**
3. **Personalized: AI,**
4. **IMITLR: GIS, AI, minZ**

**"Personalized:**

**A→C→B: 75 u, 7.5 h, 24 points, no ecology"**

**"Cross Border:**

**A→B→C: 75 c.u., 7.5 h, 24 points, no ecology"**

**"metodicheskie:**

**A→B→C: 75 c.u., 7.5 h, 24 points, no ecology"**

**"IMITLR:**

**A→C→B: 75 c.u., 7.5 h, 5 CO2, 24 points"**

* **Criteria: cost, time, ecology, satisfaction, applicability**
* **Cross Border: 75, 7.5, -, 24, low**
* **metodicheskie: 75, 7.5, -, 24, medium**
* **Personalised: 75, 7.5, -, 24, medium**
* **IMITLR: 75, 7.5, 5, 24, high"**

**Result:**

* **Route: A→C→B**
* **75 c.u., 7.5 h, 5 CO2, 24 points**
* **Electric car**
* **Recommendations: implement IMITLR, integrate with GIS."**

**Assessment:**

* **Ecology (0.4): IMITLR = 1, others = 0, Applicability (0.3): IMITLR = 1, others ≤ 0.5**
* **Cost, time, satisfaction (0.1): all = 1, IMITLR = 1.0, select IMITLR"**

Stop

**FIGURE 1.** Comparison of Methodologies Algorithm

**CONCLUSIONS**

This study developed and tested an integrated model of a tourist logistics route for optimizing routes in remote regions, using the Kashkadarya region of Uzbekistan as an example. The results confirm that IMITLR effectively solves the problem of multi-criteria optimization by integrating economic, time, environmental, and social factors. Empirical testing on the routes of Shakhrisabz (Ak-Saray, Gumbazi-Sayidan, Kok-Gumbaz) showed a reduction in costs by 15–20% (from 80–100 u.e. to 50–75 u.e.), time by 10–15% (from 6–8 hours to 4–6 hours), environmental impact by 10% (from 15 to 5–10 units of CO2), and tourist satisfaction by 12% (from 15 to 16–22 points on a scale of 1–25).

IMITLR's scientific contribution lies in the creation of a comprehensive model that surpasses existing approaches (e.g., [1], [9]) by: (1) integrating costs, time, ecology, and satisfaction into a single objective function; (2) adapting to regions with limited infrastructure; (3) using GIS and AI for accurate analysis and personalization of routes. The mathematical model, expressed as Equation , with constraints on budget, time, ecology, and satisfaction, provides reproducible and sustainable results.

The practical significance of the study is manifested in the possibility of implementing IMITLR in the tourist infrastructure of Kashkadarya, which contributes to increasing the attractiveness of the region and the sustainable development of tourism. It is recommended to integrate the model with GIS applications for tourists and to cooperate with local operators to regularly update data on preferences.

The limitations of the study include dependence on the quality of input data (e.g., satisfaction ratings) and the limited scalability of the exhaustive search method for tasks with a large number of objects. For further research, we propose: (1) developing heuristic algorithms (e.g., genetic) to optimize large routes; (2) expanding environmental parameters to include detailed emissions data; (3) testing the model in other remote regions to confirm its universality.

IMITLR is an innovative solution that makes a significant contribution to the theory and practice of tourism routing, ensuring a balance between economic efficiency, environmental sustainability, and tourist satisfaction.

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