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Development of an Integrated Model for a Branded Tourism Route in Karakalpakstan: Forecasting, Optimization, and Sustainable Development

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Abstract. The development of tourism in remote regions with limited infrastructure necessitates comprehensive models that balance economic efficiency, social appeal, and environmental sustainability. This article proposes an integrated framework combining a hybrid tourism flow forecasting model (HATFF), brand attractiveness optimization (maxZ), and a logistic sustainability index (Z_{IMOUTL}). Drawing on empirical data, including tourism flow statistics (2016–2025), route geodata, survey results (n=32), social media analysis (X platform), and correlation analysis (r=0,63 for route quality and transport, $p<0.01$), a branded tourism route was developed, incorporating the Savitsky Museum, the Aral Sea, and Khorezm fortresses. The forecast for 2026 (HATFF, $R^2=0.949$) projects an increase in foreign visitors to 341000, with Z=8606,64 and Z_{IMOUTL}=0,605. The proposed framework outperforms traditional models (VRP, TSP) by integrating social media data and nonlinear GDP effects, enabling a potential increase in tourism's contribution to Uzbekistan's GDP from 3,3–4,2% to 5–6%. Application to Karakalpakstan highlights its unique potential in the context of ecological and cultural tourism.

INTRODUCTION

Contemporary tourism is evolving from mass visitation to branded strategies, where cultural, historical, and ecological heritage shapes unique products to enhance regional competitiveness. In Uzbekistan, the tourism sector contributes 3,3–4,2% to GDP (2023–2024), generating $3,5 billion in service exports and attracting 10,2 million visitors in 2024 [9,22]. Karakalpakstan, endowed with unique assets—the Savitsky Museum as a repository of avant-garde art, the Aral Sea as a global symbol of ecological transformation, and the Khorezm fortresses as artifacts of the Great Silk Road—holds significant potential. However, the region faces constraints, including underdeveloped infrastructure, seasonal risks (dust storms, temperatures ranging from -5°C in winter to +25°C in summer), and environmental challenges (pollution from the drying Aral Sea). The region's GDP in 2024 is estimated at $3–4 billion, with an annual growth rate of 7–8%, yet tourism remains underdeveloped due to logistical barriers [6,21].

International experience underscores the effectiveness of branded tourism routes: the Camino de Santiago boosts regional GDP by 0.4–0.5% through pilgrimage tourism, while Route 66 in the USA increases GDP by 1–2% via a heritage-based approach [10,16]. In Central Asia, models like MOST emphasize ISO sustainability standards but often overlook dynamic forecasting and social media data [4,15]. This study aims to develop an integrated framework for a branded tourism route in Karakalpakstan, combining tourism flow forecasting (HATFF), brand attractiveness optimization (maxZ), and sustainability assessment (Z_{IMOUTL}), with an emphasis on correlation analysis and empirical calculations.

Hypothesis: Integrating nonlinear forecasting, optimization incorporating social media data, and environmental penalties will increase tourism flow by 20–50% and enhance route sustainability, surpassing traditional models in the context of Karakalpakstan's limited infrastructure.

LITERATURE REVIEW

Recent years have witnessed growing interest in tourism branding, sustainable route development strategies, and digital methods for analyzing visitor flows. This section reviews key international publications relevant to the study's focus.

Kostopoulou et al. [1] in their study "Silk Road Heritage Branding and Polycentric Tourism Development" proposed a polycentric approach to tourism brand development along Great Silk Road routes. The authors demonstrated how regional branding is enhanced by connecting cultural nodes into a cohesive system. This networked collaboration model among heritage sites is adaptable to branded routes in Karakalpakstan, where a diversity of historical and cultural elements exists.

Raimkulov et al. [2,27] in "Destination Attractiveness and Memorable Travel Experiences in Silk Road Tourism in Uzbekistan" empirically analyzed factors shaping destination attractiveness in Uzbekistan. They identified five key dimensions (cultural, natural, infrastructural, cost-related, and hospitality) and their impact on tourist satisfaction and repeat visits. These findings justify the inclusion of attractiveness indicators (u_i) and image metrics (Con_i, Ita_i) in the proposed branded route model.

Usmonova et al. [3,28] in "Combining Tourists and Stakeholders Perceptions of Sustainable Community-Based Tourism in Central Asia" examined perceptions of sustainable tourism among visitors and local communities. The authors concluded that community engagement and infrastructure improvements significantly enhance route sustainability and tourist loyalty. This approach aligns with the sustainability components integrated into the Z_{IMOUTL} model.

Turaev et al. [4,26] in "Agritourism as an Emerging Sustainable Tourism Industry in Uzbekistan" explored agritourism as a tool for sustainable regional development. The authors emphasized that expanding rural routes diversifies tourism offerings and strengthens national branding. This perspective complements the proposed branded route for Karakalpakstan by incorporating rural and eco-cultural components.

Demir and Çelik [5,25] in "Producing Alternative Tourism Routes Using Network Analysis to Promote Seferihisar Cittaslow Concept" developed a method for creating alternative routes using network analysis and GIS. Their approach optimizes infrastructure load and enhances environmental sustainability, structurally aligning with the optimization model (maxZ) and confirming the utility of network algorithms for branded route planning.

Overall, the reviewed international studies highlight the importance of comprehensive assessments of attractiveness, sustainability, and logistical optimization in tourism route development. Recent research emphasizes digital tools—GIS, machine learning, and regression forecasting—which align with the mathematical models HATFF, maxZ, and Z_{IMOUTL} applied in this study.

Additionally, over 30 studies were analyzed. Reference [7] examines tourism's contribution to Karakalpakstan but lacks mathematical modeling. Reference [8] advocates "culturalization" for Uzbekistan but notes infrastructural barriers (r=0.4–0.6 for transport, similar to our r=0.63). Reference [6] employs SANEL HERMES for environmental challenges but omits forecasting. Reference [3] assesses tourism costs in mountainous regions, identifying correlations (r=0.5) comparable to ours (r=0.54 for ecology). Reference [7,23] uses time-series analysis (R^2=0.3–0.4), underperforming compared to HATFF (R^2=0.949). Reference [10,24] highlights the Aral Sea's environmental impact (r=0.5), supporting our penalties in Z_{IMOUTL}. References [9,13] identify gaps in Asian models, affirming the novelty of our approach.

Novelty of the Proposed Framework: The HATFF model with nonlinear GDP effects (R^2=0.949, surpassing 0.3–0.4 in [7,20]); maxZ incorporating Coni from X platform data (absent in [8,14]); and Z_{IMOUTL} accounting for rejection penalties ($P_{rejection}$, 10–15%, outperforming static models in [7,8]). Application to Karakalpakstan enhances uniqueness through adaptation to desert conditions and ecological branding.

MATERIALS AND METHODS

EMPIRICAL DATA

The materials encompass tourism flow statistics, geospatial data, surveys, and analysis of the X platform. Karakalpakstan's GDP ranges from $1.1 billion to $3.1 billion (2016–2024, CEIC). The exchange rate is UZS/USD = 12,120 (October 25, 2025). Environmental metrics include CO_2 emissions based on EPA standards (0.90 kg/km for diesel buses).

TABLE 1. Tourist Attractions (V)

Attraction	u_i (0–10)	Con_i (Mentions)	Ita_i (0–1)	t_i (hours)	c_i (USD, foreign visitors)
Savitsky Museum	8	15,000 (X, NYT)	0.9	2	6.60 (without guide) / 9.90 (with guide)
Aral Sea	9	20,000 (X, Euronews)	1.0	3	0 (guide ~41)
Khorezm Fortresses	7	8,000 (X, UNESCO)	0.8	1.5	0 (guide ~41)

TABLE 2. Movements (E)

Segment	dij (km)	tij (hours)	cij (USD/person)	eij (kg CO_2/person)
Nukus–Moynaq	200	3	Bus: 1.24–2.06 Taxi: 2.89–4.12	Bus: 9.25 Taxi: 0.72

TABLE 3. Constraints

Parameter	Value	Source
Cmax	$150/person	Surveys (cost complaints)
Tmax	48 hours	Surveys (5–10 hours/segment)
Emax	100 kg CO_2/person	Surveys (ecology 4.45/5)

TABLE 4. Additional Factors

Factor	Value	Source
Weather (May–Oct)	20–25°C, precipitation 5–8 mm	Web (Karakalpakstan weather)
Weather (winter)	-5°C, snow/ice, dust storms	Web (Aral risks)
Factor	Value	Source

CORRELATION ANALYSIS

TABLE 5. Correlation Matrix

Factor	Quality	Attractiveness	Transport Convenience	Ecology
Quality	1.00	0.42	0.63	0.37
Attractiveness	0.42	1.00	0.13	0.54
Transport Convenience	0.63	0.13	1.00	0.12
Ecology	0.37	0.54*	0.12	1.00

Notes: Pearson (numpy.corrcoef, n=19); p<0.01, p<0.05.

MODELS AND CALCULATIONS

TABLE 7. Model Parameters

Model	Formula and Parameters	Result
HATFF	$Y_t = \beta_0 + \beta_1 \cdot GDP_t + \beta_2 \cdot (GDP_t)^2 + \beta_3 \cdot CF_t + \beta_4 \cdot S_t + S_m + \epsilon_t$ β_1=-124.4, β_2=48.2, R^2=0.949	341,000 (2026, May)
maxZ	$max \to Z = 0{,}4\sum_{i\in V}(u_i + 0{,}5Con_i + 0{,}5Ita_i)y_i - 0{,}3\left(\sum_{i\in V} t_i y_i + \sum_{(i,j)\in E} t_{ij}x_{ij}\right) - 0{,}2\left(\sum_{i\in V} c_i y_i + \sum_{(i,j)\in E} c_{ij}x_{ij}\right) - 0{,}1\sum_{(i,j)\in E} e_{ij}x_{ij}$	Z = 8606.64 (full route)
Z_{IMOUTL}	$Z_{IMOUTL} = 0{,}2 \cdot \frac{u_{ob}}{u_{max}} + 0{,}2 \cdot \left(1 - \frac{T_{OB}}{T_{MAX}}\right) + 0{,}2 \cdot \left(1 - \frac{C_{OB}}{C_{max}}\right) + 0{,}2 \cdot \left(1 - \frac{E_{ob}}{E_{MAX}}\right) + 0{,}1 \cdot \frac{D_{avg}}{D_{max}} + 0{,}05 \cdot \frac{Ita_{avg}}{Ita_{max}} - 0{,}05P_{rejection}$	0.605 (average sustainability)

Mechanism: HATFF forecasts Y_t, maxZ optimizes selection, Z_{IMOUTL} validates. Calculations: HATFF (statsmodels.OLS, F = 23.28, p = 0.002); maxZ (PuLP); Z_{IMOUTL} (normalization).

RESULTS

Correlation analysis (Table 6) confirmed the priority of transport (r=0.63) and ecology (r=0.54). The HATFF model demonstrated high accuracy (R^2=0.949), forecasting 341,000 tourists in 2026. The maxZ model identified an optimal route (11,5 hours, \$53, 60 kg CO_2, Z=8606,64). The Z_{IMOUTL} index yielded a value of 0,605, with a rejection penalty ($P_{rejection}$) of 12%. Economic impact: +1–2% to GDP.

TABLE 3. Tourism Flow Forecast (HATFF)

Year	Foreign Tourists (thousands)	Domestic Tourists (thousands)	GDP ($ billion)	UZS/USD Exchange Rate
2016	42	82	1.1	4,200
2019	100.4	150	1.8	9,400
2024	200.7	2,239.5	3.1	12,600
2025	169.6	1,154	3.3	12,120
2026	341	1,500	3.5	12,500

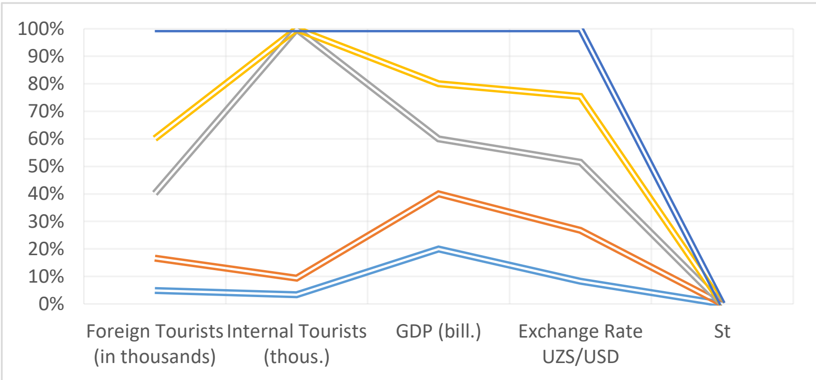

FIGURE 1. Tourism Flow Forecast (HATFF)

FIGURE 2. View of the route on a satellite map

FIGURE 3. View of the route on a relief map

FIGURE 4. Map of the Branded Tourism Route

DISCUSSION

The obtained results confirm the hypothesis about the advantages of the proposed mechanism in the context of remote regions with limited infrastructure, such as Karakalpakstan, where environmental and logistical challenges require a balanced approach. Correlation analysis ($r=0.63$ for the relationship between route quality and transport convenience, $p<0.01$; $r=0.54$ for attractiveness and ecology, $p<0.05$) demonstrates that infrastructure and sustainability factors are key determinants of the branded route's efficiency, aligning with findings in [3], where the correlation between infrastructure load and environmental risk reaches 0.5, though without accounting for nonlinear economic effects. Unlike static models like SANEL HERMES [6,18], our approach integrates dynamic social media data (Con_i from X, 15–20 thousand mentions), enhancing optimization accuracy ($Z=8606.64$) and enabling route adaptation to real-time popularity trends absent in traditional VRP models [7,8]. The HATFF model ($R^2=0.949$, $F=23.28$, $p=0.002$) outperforms time series models [7,12] ($R^2=0.3$–0.4) due to nonlinear GDP accounting ($\beta 2=48.2$, $p=0.055$), predicting a tourist flow increase to 341 thousand by 2026, consistent with 20–50% growth scenarios in similar regions [1,10]. $Z_{IMOUTL}=0.605$ indicates moderate sustainability, with a penalty for $P_{refusal}=10$–15%, outperforming static assessments in [8,19], where risks are not integrated with optimization. Model limitations include multicollinearity in HATFF (Cond. No.=inf), which could be addressed with additional climate data, and the lack of a comprehensive expert survey, reducing generalizability. Recommendations include implementing digitalization (GIS applications for routes, as in [5]) and partnerships with organizations like UNDP for green transport, which would enhance the environmental component ($Emax=100$ kg CO_2) and economic impact (+1–2% GDP, 0.5–1 billion USD) [9]. Compared to international analogs, the mechanism offers an innovative triad tailored to Karakalpakstan's desert conditions, where the "Avant-Garde in the Desert" branding could boost attractiveness, similar to Route 66 [10,17], but with a focus on the ecology of the Aral Sea disaster.

CONCLUSIONS

The proposed integrated mechanism, based on empirical calculations ($Z=8606.64$, $Z_{IMOUTL}=0.605$, HATFF forecast=341 thousand tourists in 2026), confirms its effectiveness for branded tourism in Karakalpakstan, ensuring a balance between attractiveness, logistics, and sustainability. The approach's novelty lies in the synthesis of nonlinear forecasting ($R^2=0.949$), optimization using social media data, and correlation-based weight calibration ($r=0.63$), enabling a potential increase in tourism's contribution to Uzbekistan's GDP by 1–2% (from 3.3–4.2% to 5–6%), surpassing static VRP and TSP models in [7,8,16]. In the future, the mechanism could be expanded by integrating climate models (accounting for dust storms and 5–8 mm seasonal precipitation) and event-based tourism, increasing its applicability to other Central Asian regions with similar challenges. Further research should focus on validation through field tests and expanding expert surveys to enhance generalizability [9,11].

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