Research on Sustainable Tourism Forecasting Model for Juneau based on AHP-PSO and Dynamic Strategy

Weizhi Zhang[#, *], Haoran Ma[#], Zihan Ni[#]

College of Information Science and Engineering, Northeastern University, Shenyang, China, 314001

*Corresponding author: 20235225@stu.neu.edu.cn

#These authors are contributed equally.

Abstract. Cruise ship tourists have provided significant revenue for the city of Juneau, Alaska. However, with the surge in visitor numbers and rising temperatures, issues such as overcrowding and glacier melting have emerged. Therefore, the development and implementation of sustainable tourism plans are urgent. In response, this study has developed a sustainable tourism forecasting model for Juneau, using particle swarm optimisation algorithms to simulate changes in various indicators from 2025 to 2046, in order to determine the optimal weight allocation. This study holds important theoretical and practical significance. Theoretically, it enriches the research on sustainable tourism models by incorporating dynamic constraints and long-term environmental changes. Practically, it offers a scientific reference for Juneau to achieve sustainable tourism development. The main innovations of this study include the integration of multi-dimensional factors in the model, the consideration of dynamic constraints and long-term environmental changes, and the exploration of cooperative strategies between tourism revenue distribution and infrastructure investment.

Keywords: Sustainable Tourism Prediction Model, AHP, Dynamic Adjustment Strategy, PSO.

1. Introduction

In recent years, the rapid development of the global tourism industry has made sustainable tourism a key issue. Juneau City faces environmental, social, and economic challenges due to the increase in cruise ship visitors and urgently needs scientific tourism planning and management. Mestanza et al. pointed out that existing sustainable tourism evaluation models mostly focus on a single dimension and lack comprehensive consideration[1]. Zhang et al. proposed a multi-objective optimisation model combining the Analytic Hierarchy Process (AHP) and Particle Swarm Optimisation (PSO) algorithms to integrate economic, environmental, and social benefits[2]. Wang Qiang et al. argued that current tourism planning models neglect long-term sustainability factors[3]. Liu et al. combined environmental footprint assessment with linear programming to optimise tourism's environmental impact, but synergistic effects remain underdeveloped[4]. This paper proposes a new sustainable tourism optimisation model that integrates the Analytic Hierarchy Process (AHP), Particle Swarm Optimisation (PSO) algorithm, and dynamic adjustment strategies[5]. It’s the first to incorporate dynamic constraints, long-term changes in environmental indicators, and the continuous improvement of resident satisfaction into the optimisation design, and explores cooperative strategies between tourism revenue distribution and infrastructure investment.

The main contributions of this paper include: 1) constructing a sustainable tourism forecasting model that integrates the Analytic Hierarchy Process (AHP), particle swarm optimisation (PSO) algorithm, and dynamic adjustment strategy to comprehensively consider multi-dimensional factors; 2) incorporating dynamic constraints and long-term changes in environmental indicators into the model for the first time to ensure the sustainability of tourism planning; and 3) proposing a tourism revenue distribution and infrastructure investment cooperation strategy to improve economic efficiency while taking into account social and environmental benefits.

2. The proposed Method

2.1. Overview of The Model

This paper proposes a sustainable tourism forecasting model, which can be divided into four parts. It analyses the impact of environmental factors, infrastructure development, local resident satisfaction, and local income on sustainable tourism[6]. Specifically, environmental factors include carbon footprint and glacier melting; infrastructure development encompasses drinking water supply and waste management; local resident satisfaction depends on housing supply, overcrowding, and tourist noise issues; and local income primarily stems from hotel taxes and tourist fees. Additionally, we considered various scenarios, such as total expenditure being less than 80% of total income[7], and provided corresponding model solutions for each scenario. This model holds significant reference value for Juneau City in Alaska, United States. Figure 1 shows the model frame work.

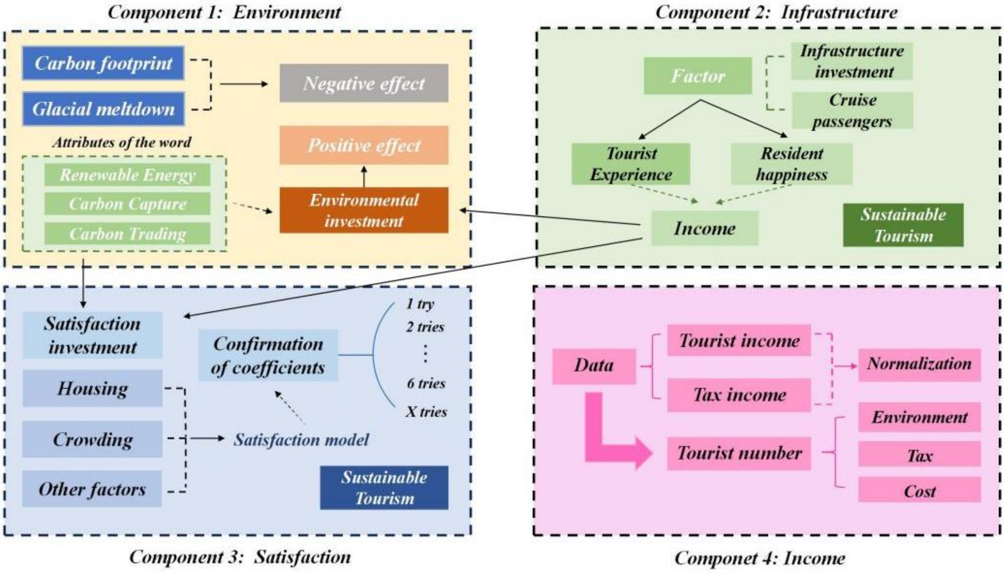


Figure 1. Model framework

2.2. Sustainable Tourism Prediction Model for Juneau

In order to construct the Sustainable Tourism Prediction Model for Juneau, considering the relationship between the four indicators *E*, the infrastructure indicator *B*, the resident satisfaction indicator *R*, the tourism income indicator *nI* and the evaluation of the sustainability indicator *P*, we established the following formula based on the hierarchical analysis method:

$$P=I_{pE}*E+I_{pB}*B+I_{PR}*R+I_{PI}*Ni \quad (1)$$

where *E* denotes an environmental indicator, *B* denotes an infrastructure indicator, *R* denotes a resident satisfaction indicator, and *nI* denotes a tourism income indicator. I_{pE}, I_{pB}, I_{pR}, and I_{PI} represent their weights respectively.

Compare the variables in pairs, subjectively set all elements, and obtain the complete judgment matrix, as shown in the table 1 below:

Table 1. Judgment Matrix

Evaluation	E	B	R	nI
E	1	2	6/5	1
B	1/2	1	3/5	1/2
R	5/6	5/3	1	5/6
nI	1	2	6/5	1

After conducting a consistency test, the CR value was found to be 0.042, which is less than 0.1, indicating that the consistency test was passed. Using the arithmetic mean method to calculate the weights, the weights of the four indicators were determined to be 0.33, 0.12, 0.22 and 0.33, respectively. Comparing with other literature, such as the study on ecological tourism in Malaysia, it was found that their indicator systems and weights are almost the same as our results. Combining the actual situation of Juneau City, Alaska, the core formula for the solution model was determined[8].

$$P=0.33E+0.12B+0.22R+0.33nI \tag{2}$$

2.3. Decision Model for Evaluation of Relevant Indicators

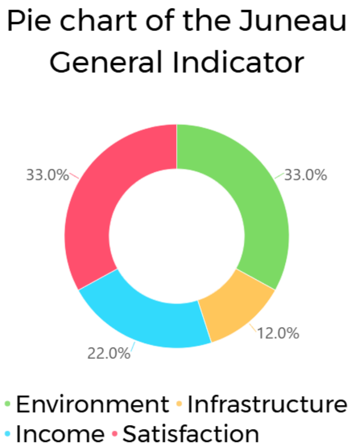
In order to construct an environmental indicator evaluation model for Juneau, we established the following formula based on the hierarchical analysis method, taking into account the relationship between the environmental indicator *E* and the environmental investment I_E, the indicator of the remaining area of the glacier *ni*, and the indicator of the carbon footprint *f:*

$$\mathbf{E = w_I * I_E + w_i * ni + w_f * f} \tag{3}$$

where w_I, w_i, w_f indicate the weight of each respectively.

Similarly, using the hierarchical analysis method, the weights of three indicators are 0.4, 0.4 and 0.2, and the formula for the environmental indicators is as shown in figure 2 and figure 3:

$$\mathbf{E = 0.4I_E + 0.4ni + 0.2f} \tag{4}$$



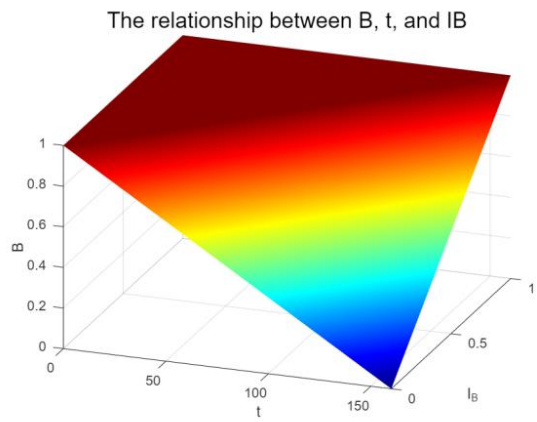


Figure 2. Weights of each indicator in Juneau **Figure 3.** Relationship between B,t and I_B

What's more, in the infrastructure indicator evaluation model, the main consideration is drinking water supply and waste management[9], both of which will be under pressure due to the increase in the number of tourists, while investment in infrastructure will alleviate the pressure. Based on this relationship, we approximate that the infrastructure indicator is linearly related to the number of tourists and infrastructure investment, and that a decrease in tourists and an increase in investment will improve the infrastructure indicator, as shown in the following formula:

$$B=1-t/(t_{max}+I_B) \tag{5}$$

where B denotes the infrastructure indicator, t denotes the number of tourists, I_B denotes infrastructure investment, and t_{max} is the upper limit of tourist arrivals.

The resident satisfaction evaluation model needs to consider the relationship between the resident satisfaction indicator *R* and the housing indicator *h*[8], the crowding level indicator *d*, and the community project investment I_R, also based on the hierarchical analysis method, the following formula was established[10]:

$$R=w_{Rh}*h+w_{Rd}*d+w_{RI}*nI_R \tag{6}$$

where w_{Rh}, w_{Rd}, and w_{RI} denote the weights, respectively.

Similarly, using the hierarchical analysis method to find the weight of the three indicators is 0.25, 0.25, 0.5, and the formula for the environmental indicators is as follows:

$$R=0.25h+0.25d+0.5nI_R \tag{7}$$

With Juneau's tourism revenue reaching a maximum value of $375 million in 2023, we approximate that the city of Juneau will not exceed $400 million in the short term, given the limitations on the number of people in order to achieve sustainable development. Subsequent normalization of tourism revenue *I* ensures that the revenue indicator nI in (0,1) and the *nI* formula is as follows.

$$\mathbf{nI_R = I/4} \tag{8}$$

2.4. Glacier Melting Model

Between 2006 and 2023, there were 10,000 tourists in Juneau, and the glacier ablated a total area of square.If we exclude the glacier's ablation in the absence of tourism, and assuming that the ablation is linear over a short period of time, we can derive a coefficient of the effect of tourists on glacier ablation as in the following equation:

$$\mathbf{k = \frac{\Delta S}{\Delta t} = \frac{0.05712}{1708.5} = 0.0000335} \tag{9}$$

The relationship between the glacier area i_{y+1} and the glacier area of the previous year i_y is approximately as follows:

$$\mathbf{i_y = i_{y-1} - kt = i_y - 0.0000335t} \tag{10}$$

This model reflects the relationship between glacier retreat area and tourist numbers. As tourism continues to grow, the glacier will continue to melt, and such a melting trend is inevitable. However, we can slow down the glacier's melting rate by restricting the number of tourists. Figure 4 shows the relationship between tourist number and congestion indicator.

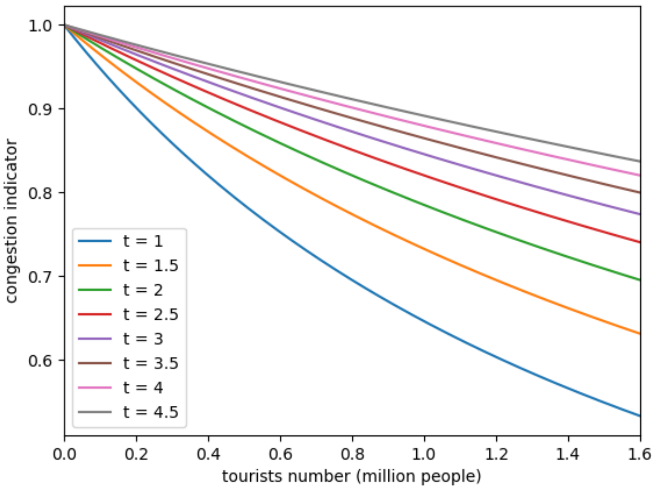


Figure 4. The relationship between tourist number and congestion indicator

Through analysis of economic reports for Juneau, we find that the average number of tourists per day is related to the annual number of tourists in Juneau by:

$$\mathbf{\bar{t} = \frac{t\times 2}{365} = \frac{t}{182.5}} \tag{11}$$

We define the crowding index *d* , where *d* is in the range [0,1]. As the crowding degree increases, *d* becomes larger, and the relationship between *d* and *t* is:

$$\mathbf{d = \frac{\rho_1}{\rho_2} = \frac{3}{3+t} = \frac{3}{3+\frac{t}{182.5}}} \tag{12}$$

2.5. Carbon Footprint Model

Since we will limit the number of tourists to between 0 and 1.6 million, and the hardness is approximately linearly related to the number of tourists, we set the hardness index as 1 when the number of tourists reaches 1.6 million, and set the hardness index as 0 when the number of tourists is 0. The relationship between the hardness index *f* and the number of tourists *t* is as follows:

$$\mathbf{f = 1 - \frac{t}{160}} \tag{13}$$

In this formula, the hardness index *f* decreases as the number of tourists *t* increases. When the number of tourists reaches the upper limit of 1.6 million, the hardness index *f* will decrease to 0.

2.6. Tourist Prediction Models that Take Into Account Stochasticity

With the development of urban tourism, we approximate the total number of tourists per year *t* as follows:

$$\mathbf{t_y = gE \cdot \frac{1}{(1+\frac{T}{100})\cdot(1+\frac{C}{23400})} \cdot t_{y-1} \cdot r} \tag{14}$$

where *g* is the natural growth rate of tourists, *E* is the environmental index of the year, *T* represents the number of tourists for the current year, and *C* represents the tourist number for the previous year. *r* is the fluctuation factor of the system.

This prediction model better reflects the relationship between the number of tourists by the environment, consumption, and last year's development of tourims (the heat of this tourist place), the ice sheet recession, carbon footprint enhancement, environmental damage, insufficient publicity, consumption or tax is too high will cause a decline in the number of tourists. Eq. as a random factor, which fluctuates randomly within [0.9,1.1] every year, reflects the fact that the number of tourists is affected by uncertainties, such as tourism fever, negative news, natural climate, etc., which reflects a better uncertainty.

2.7. Model Constraints and Dynamic Adjustment Strategy for Investment Ratios

Based on an analysis of the U.S. tourism official website and relevant literature, combined with the line chart of total visitor numbers to Juneau from 2006 to 2023, it is evident that visitor numbers to Juneau reached a record high in 2023, resulting in 57% of residents experiencing negative emotions. In light of this, the model sets an upper limit for Juneau City's tourist volume in 2023, namely no more than 1.6 million tourists per year, to ensure the sustainable development of the tourism industry. Additionally, the lower limits for environmental indicator *E*, infrastructure indicator *B*, resident satisfaction indicator *R*, and tourism revenue indicator *nI* are set at 0.75, 0.6, 0.6, and 0.6, respectively.

During the sustainable development process, investment ratios should be dynamically adjusted based on annual indicators rather than remaining fixed, as fixed ratios may lead to a vicious cycle. When an indicator falls below the lower limit, it indicates insufficient investment, necessitating an increase in the investment ratio to improve the indicator. If an indicator reaches 1, it signifies excessive investment, requiring a reduction in the investment ratio to conserve funds. The adjustment ranges for *au* and *ad* must be determined based on the characteristics of different cities. Identifying the optimal *au* and *ad* values is a key component of the model's calculations. This dynamic adjustment strategy for investment ratios significantly enhances the model's stability, enabling it to autonomously adjust and ultimately achieve sustainable development with all indicators at high levels.

3. Result

3.1. The solution of model

We optimize the sustainability indicators, environmental indicators, infrastructure indicators, resident satisfaction indicators, and tourism revenue indicators over the 20-year period 2025-2046 by using the particle swarm optimization algorithm to find the optimal investment ratio. We can consider this set of weight allocation as the optimal solution when all five indicators remain stable during 2025-2046, all of them are higher than the preset lower limit value, and the sustainability indicator P is the largest.

It was finally concluded that the tourism industry in the city of Juneau can achieve sustainable development and the sustainability indicator P is the largest when the environmental investment ratio W_{IE} = 0.33, the infrastructure investment weight W_{IB} = 0.2, the resident satisfaction investment weight W_{IR} = 0.27, the change in the investment ratio au = 0.05, ad = 0.02, the average tax revenue T = \$1, and the per capita profit = \$234. The prediction graphs considering tourist fluctuations and ignoring tourist fluctuations are as shown in figure 5:

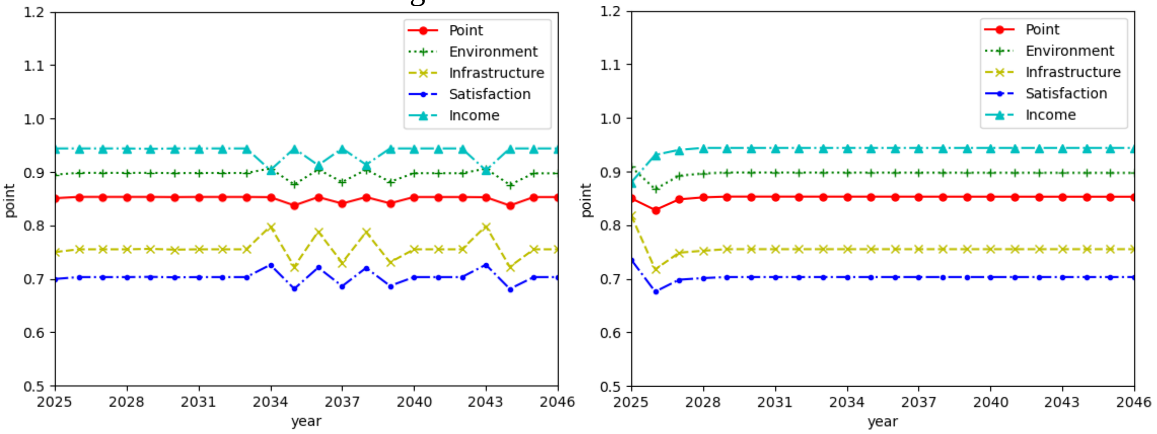


Figure 5. Consider the forecast chart for tourist fluctuations and non-fluctuations

3.2. Analysis of experimental results

Observation of the forecast image reveals that if the impact of tourist fluctuations is ignored, the five indicators remain almost unchanged for 20 years, and under the calculated investment strategy, Juneau can achieve long-term stable and sustainable development, with a sustainability indicator of about 0.85; even if the fluctuations of tourists are added, because of the dynamic adjustment strategy of the investment ratio, the model can detect the problem in time and adjust the investment, and after the fall of an indicator it quickly rebound, and finally stabilize the sustainable development indicator around 0.85.The percentage of Juneau's travel proceeds invested is as shown in figure 6:

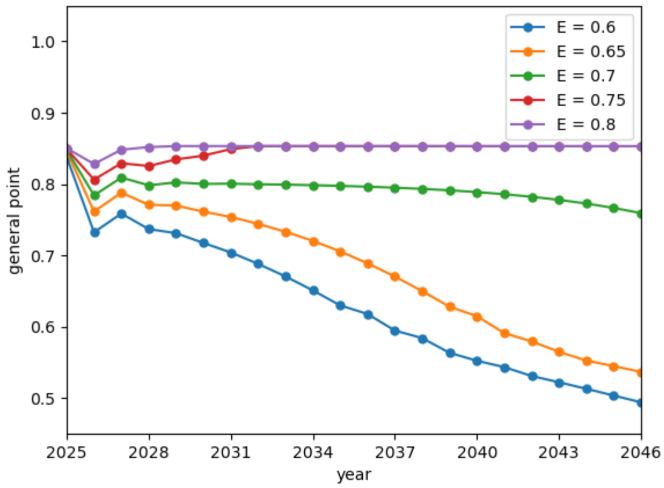


Figure 6. Relationship between sustainability indicators and environmental indicators

Among them, environmental protection investment accounts for the largest proportion. After changing the initial environmental indicators, the results as shown in the figure 5 above are obtained. If the initial environmental indicators are less than 0.7, the sustainable development indicators will decline year by year after a slight increase and sustainable development cannot be realized. Similarly, changing the infrastructure indicator and the resident satisfaction indicator will not result in such a drastic change in the sustainable development indicator, which reflects the paramount importance of the environment in Juneau's sustainable development process.

This investment covers three main areas: environmental protection and promotion, infrastructure, and community projects. Environmental investment focuses on pollution control, clean energy, and facility upgrades. Infrastructure spending targets waste management, pipeline and power maintenance, traffic control, and new transport options like bike-sharing. Community project funding aims to organize local activities, lower housing costs, and boost resident welfare, enhancing the regional environment, infrastructure, and quality of life.

3.3. Sensitivity analysis

A sensitivity analysis was conducted using four variables: ideal tourist natural growth coefficient, per capita tax revenue, per capita consumption, and glacier melting rate. Each of these four variables was varied by 10%, and the resulting P-value errors are shown in the figure 7. As can be seen, when these four variables change, the error ratio is less than 5%, which aligns with our expectations. The model passed the sensitivity analysis, demonstrating strong stability.

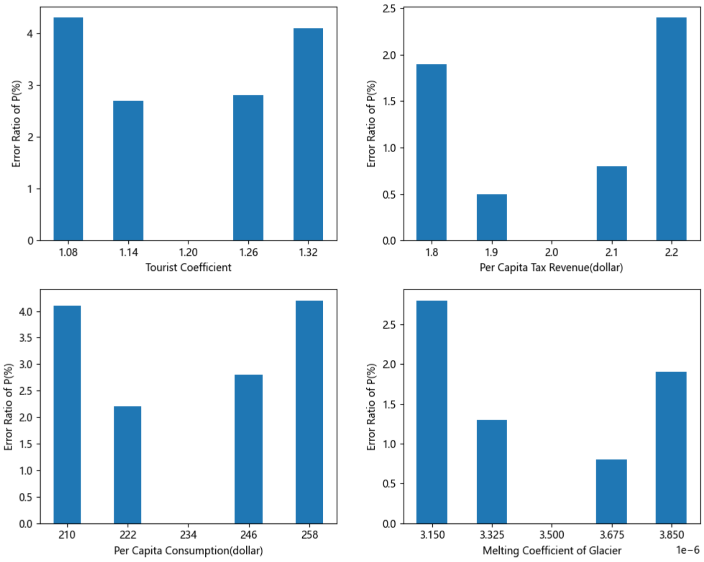


Figure 7. Relationship between sustainability indicators and environmental indicators

3.4. The result of model

The Predictive Model for Sustainable Tourism for the city of Juneau integrates various factors, including tourist limits, sustainable development indicators, environmental and infrastructure indicators, resident satisfaction, tourism revenue, and investment allocation. By adjusting investment ratios, tax rates, and tourist fees, the model optimizes sustainable development indicators while incorporating constraints like tourist caps and indicator minimums. The optimal strategy allocates 33% of additional revenue to environmental protection, 20% to infrastructure, and 27% to community programs. Sensitivity analysis shows the model is stable, with environmental indicators being the most influential factor. This approach helps Juneau achieve sustainable tourism development.

4. Conclusions

This paper presents the Predictive Model for Sustainable Tourism for the city of Juneau, designed to address the challenges posed by increasing tourist numbers and rising temperatures. The model integrates four key components: environmental factors, infrastructure development, local resident satisfaction, and local income. By establishing a sustainability indicator evaluation model that combines environmental, infrastructure, resident satisfaction, and tourism income indicators through a weighted sum, we propose a framework to enhance and stabilize sustainability. Utilizing the

Analytic Hierarchy Process (AHP), the weights of these four indicators are determined, forming the basis of the Sustainable Tourism Prediction Model for Juneau. The model employs Particle Swarm Optimization (PSO) algorithms to simulate indicator changes from 2025 to 2046, seeking optimal weight allocation. It also introduces a dynamic adjustment strategy for investment ratios to improve model stability and achieve sustainable development with high indicators. Experimental results indicate that Juneau can attain long-term stable and sustainable development under the calculated investment strategy. Sensitivity analysis reveals the model's strong stability and highlights the environment as the key factor affecting Juneau's sustainable development. This model offers a valuable reference for Juneau to realize sustainable tourism.

However, this study has some limitations. The model could be further refined by incorporating more real-time data and expanding the range of indicators. Future work will focus on these aspects to enhance the model's accuracy and applicability. Additionally, we plan to explore the integration of other advanced optimization algorithms to improve the model's performance and efficiency.

References

[1] Mestanza G J, Bakhat R. An integrated CRITIC-VIKOR model for overtourism assessment in Spain: post-COVID-19 sustainable actions [J]. International Journal of Multicriteria Decision Making, 2022, 9 (2): 87-107.

[2] Bertocchi D, Camatti N, Giove S, et al. Venice and Overtourism: SimulatingSustainable Development Scenarios through a Tourism Carrying Capacity Model [J]. Sustainability, 2020, 12 (2): 512-512.

[3] Kuščer K, Mihalič T. Residents'Attitudes towards Overtourism from the Perspective of Tourism Impacts and Cooperation-The Case of Ljubljana [J]. Sustainability, 2019, 11(6): 1823.

[4] Li J. Research on Improving the Quality and Efficiency of Tourism Public Services Based on Value Co-creation in the Context of Smart City[C]//ChongQing University of Education,AEIC Academic Exchange Information Center(China).Proceedings of 2nd International Conference on Public Management, Digital Economy and Internet Technology(CPDI 2023). Lyceum of the Philippines University; Chongqing University of Education, 2023:438-447.

[5] Raihan, Asif, et al. Tourism-energy-economy-environment nexus toward sustainable and green development in Malaysia[J]. Innovation and Green Development, 2025, 4(4): 100257-100257.

[6] Sharma, A., Hassan, A. Overtourism as destination risk: impacts and solutions[C]//Tourism security-safety and post conflict destinations. Bingley, UK: Emerald Publishing, 2021: 288.

[7] Seraphin, H., Yallop, A. C. Overtourism and tourism education: a strategy for sustainable tourism futures[M]//Contemporary geographies of leisure, tourism and mobility. Abingdon, Oxon; New York, NY: Routledge, 2021.

[8] Gao Jing, Wu Bihu, Zhao Zhifeng.A sustainalbe path model for tourism based revitalization of traditional villages based on a cultural geography perspective [J]. Areal Research and Development, 2020, 39(04):73-78

[9] Liu Yansui. Research on the urban-rural integration and rural revitalization in the new era in China[J]. Acta Geographica Sinica, 2018, 73(4): 637- 650.

[10] Sun Jiuxia, Xu Xinjian, Wang Ning, et al. Ways and patterns of tourism's role in poverty alleviation and rural revitalization: Expert discussion on tourism for poverty alleviation and rural revitalization[J]. Journal of Natural Resources, 2021, 36(10): 2604-2614.