Problem Chosen	2025 MCM/ICM Summary Sheet	Team Control Number
B		2518957

Shaping Tomorrow: Building Sustainable Tourism Economies for Future

Sustainable tourism has become a common concern for tourist destinations around the world, as the global tourism industry is booming. This paper takes Juneau as an example to explore the establishment of a sustainable tourism industry system, and proposes corresponding solutions for the development of tourism in various regions.

For Task 1, based on the theory of **Multi-Objective Planning**, we construct a dynamic optimization system for sustainable tourism industry. We introduce a **dynamics model** into the system and use **Genetic Algorithm (GA)** to get the optimal solution. Based on this, we use **Particle Swarm Optimization (PSO)** to further optimize the whole model. After completing the model construction and optimization, sensitivity analysis was carried out to obtain the key factors affecting the tourism system in Juneau.

In addition, for the problem of difficult to predict the data of tourists' consumption level in the economic model, we introduce the **Long and Short-Term Memory (LSTM)** neural network and combine it with the **Bayesian Propagation** method to provide confidence intervals for the prediction results, so as to enhance the scientificity and rationality of the decision-making. Combining the above steps, we get a complete and scientific sustainable tourism optimization system.

For Task 2, we develope a well-established migration system for tourism model. For the target city, **Dynamic Time Warping (DTW)** was first used to calculate and compare the time series similarity between Juneau and the city. The static characteristics of the two cities are also taken into account to establish the similarity between them. Based on the similarity between the two cities, and taking into account the actual situation of the target city, we reset the weights and constraints in the multi-objective optimization. Finally, we upgraded the Quantum Behaved **Particle Swarm Optimization (QB-PSO)** system by integrating the **Graph Attention Networks (GAT)** in it to improve the efficiency of exploring the optimal solution.

It is worth mentioning that for the high-dimensional feature data of the target city, we introduce **Graph Neural Network (GNN)** to downscale the data and provide support for subsequent modeling. Finally, we introduce the **Network Flow** model to upgrade the system and realize the dynamic balance of tourist flow among different attractions.

Finally, based on this sustainable tourism optimization system for the city of Juneau, we presented a memorandum to the Juneau City Tourism Commission to share tourism industry optimization recommendations and explore their future impacts.

Keywords: Multi-Objective Planning; GA-QB-PSO; GAT; Migration Strategy; GNN; DTW

Contents

1 Introduction

1.1 Problem Background

Tourism occupies a pivotal position in the global economic system, and while it generates significant economic benefits for destinations, it also faces serious challenges in terms of sustainability. The Mendenhall Glacier, is receding at an accelerated rate, having retreated a distance equivalent to the length of eight standard soccer fields since 2007, a change that can be attributed in part to the environmental impacts of excessive tourism activity.

This study is dedicated to constructing a sustainable tourism management model that integrates tourist flow, environmental carrying capacity, economic benefits and social impacts by using mathematical modeling methods.

1.2 Restatement of the Problem

Given the above research context, this paper aims to address the following key questions:

Question 1：Construct a model of sustainable tourism in Juneau, Alaska, specifying optimization conditions and constraints. Develop expenditure planning for additional revenues and analyze how these expenditures contribute to sustainable tourism. In addition, conduct a sensitivity analysis to identify the most influential factors.

Question 2：Demonstrate how the sustainable tourism model can be applied to other destinations affected by over-tourism. Explore how location choices can influence key measures and use the constructed model to promote attractions or areas with fewer tourists to achieve a more balanced development.

Question 3Submit a MEMORANDUM to the City of Juneau Tourism Commission outlining the paper's predictions, the effects of each measure, and recommendations for optimization.

1.3 Our Work

First, based on multi-objective planning, we establish a dynamic optimization system for sustainable tourism industry in Juneau City. Then, we model the system dynamics, simulate the optimal solution by genetic algorithm, and optimize the model as a whole using particle swarm algorithm. Finally, a sensitivity analysis is performed to show how additional expenditures feed back into the model to promote sustainable tourism and the most important factors that influence this tourism system. It is worth mentioning that for the problem of predicting tourist spending level data in the economic model, we introduced LSTM neural networks and combined them with Bayesian propagation to provide prediction confidence intervals, which improves the comprehensiveness of the decision.

In exploring how to migrate the Juneau City tourism model to another location that is also affected by over-tourism, a well-established migration system was developed. Taking Bali as an example, firstly, Dynamic Time Warping (DTW) is used to calculate and compare the time-series similarity between Juneau City and Bali in terms of dynamic characteristics, such as tourist flow, inflation rate, and so on. At the same time, the similarity between the two cities is obtained by considering the static characteristics of the two cities, such as industrial structure and tourism resources. Based on the similarity between the two cities, we targeted the existing

Juno City tourism industry model and reset the weights and constraints in the multi-objective optimization according to the specific conditions of Bali. Finally, we upgraded the Quantum Behavioral Particle Swarm Optimization (QB-PSO) system by integrating the Graph Attention Mechanism (GAT) in it to reduce the number of unnecessary iterations and find the optimal solution satisfying all constraints faster. It is worth mentioning that for the complexity and high-dimensional feature data of the Bali tourism system, we introduced graph neural network (GNN) to use its powerful representation capability to downscale the data and extract the most critical information features for subsequent modeling.

Finally, based on the established City of Juneau Sustainable Tourism Optimization System, we presented a memorandum to the City of Juneau Tourism Commission sharing tourism industry optimization measures and their future impacts.

2 Assumptions and Justifications

Assumption 1：We assume that the data available on the web are accurate.

Justification: We believe that the data within both the webpage and the literature are accurate, and based on this data, we can construct a more comprehensive and effective evaluation system.

Assumption 2：We assume that local tourism revenue consists of both tourist spending revenue and tax revenue.

Justification: In practical terms, consumption revenue and tax revenue are clearly the main sources of income. Tourist consumption behavior generates direct income for the local area. Meanwhile, tax revenue is a key part of the local tourism economy. The government controls the flow of tourists by levying taxes and fees and supports local infrastructure construction, environmental protection, and community development to provide for the sustainable development of the tourism industry.

Assumption 3：We assume that the impacts of rare events such as major natural disasters on the tourism system are not taken into account, and that the capacity of the environment to self-regulate is assumed to remain stable over the planning cycle.

Justification: Rare events such as major natural disasters have a low probability, and the assumption that the environmental self-regulation capacity remains stable over the planning cycle allows the model to focus on the main research factors, reveals the intrinsic links between the core factors more clearly, and makes the model structure clearer and easier to handle.

3 Notations

The key mathematical notations used in this paper are listed in Table 1.

Table 1: Notations used in this paper

Symbol	Description	Unit
R	Income	Dollar
p	Tourist Consumption Income	Dollar
tax	Tourist Tax Rate	/
T	Local Temperature	℃

E	Glacier Height	m
N	Tourist Numbers	1
A	Tourist Satisfaction	/
S	Environment Carrying Pressure	/

4 Sustainable Tourism Industry System

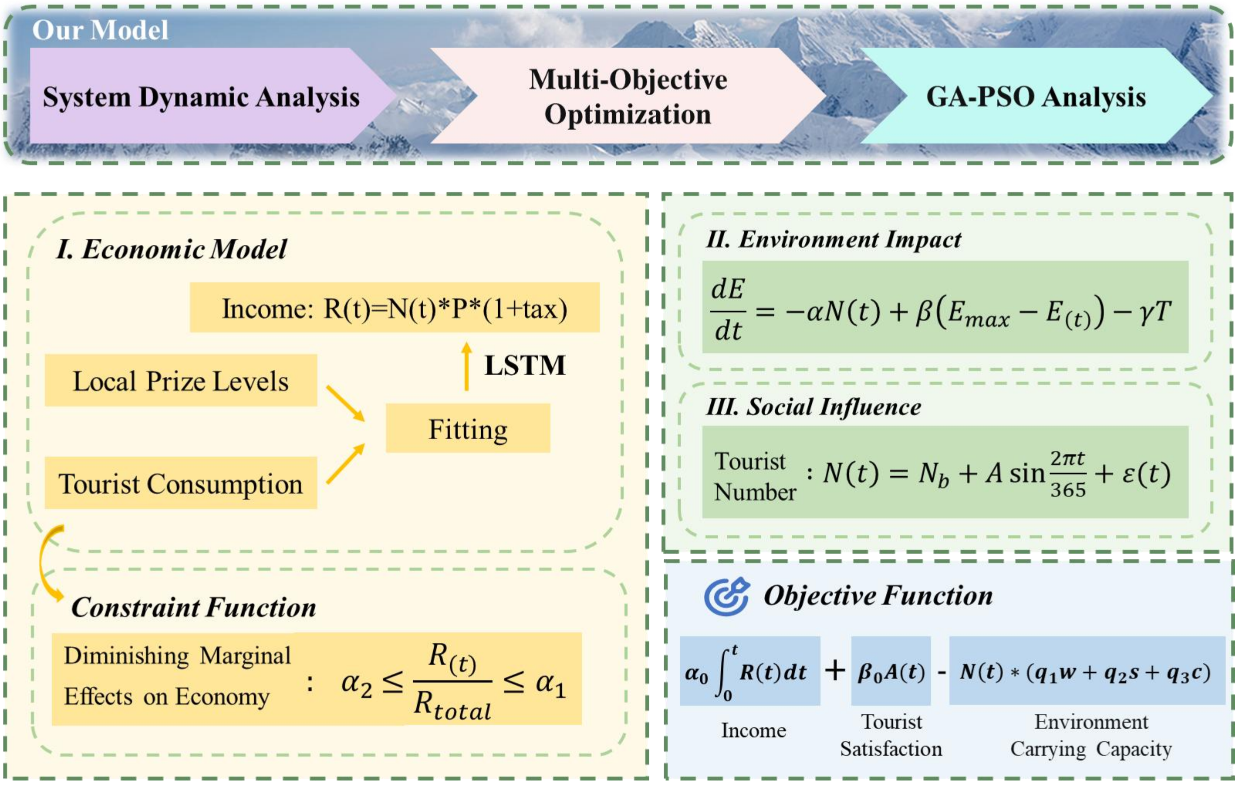

Figure 1 Our System

4.1 The Establishment of Sustainable Tourism System

The core of system dynamics is Causal Relationship, the interaction and influence between the elements (variables) in the system. The causal analysis method starts from the internal structure of the system, truly reflects the essential properties of the system, and is the basis for constructing the system dynamics model. [1] In this problem, we introduce a system dynamics model for simulating the dynamic process of tourism in Juneau, including the trends of tourist numbers, revenues, environmental impacts, and investments, in order to understand the potential impacts of different factors (e.g., the rate of growth of tourist numbers, the rate of increase of environmental impacts, etc.) on the long-term development of tourism.

The simulation analysis allows for the portrayal of feedback relationships between the main variables:

Positive feedback: growth of tourists→increase in tourism revenue→increase in environmental protection investment→reduced environmental pressure→improvement of landscape attractiveness→growth of tourists

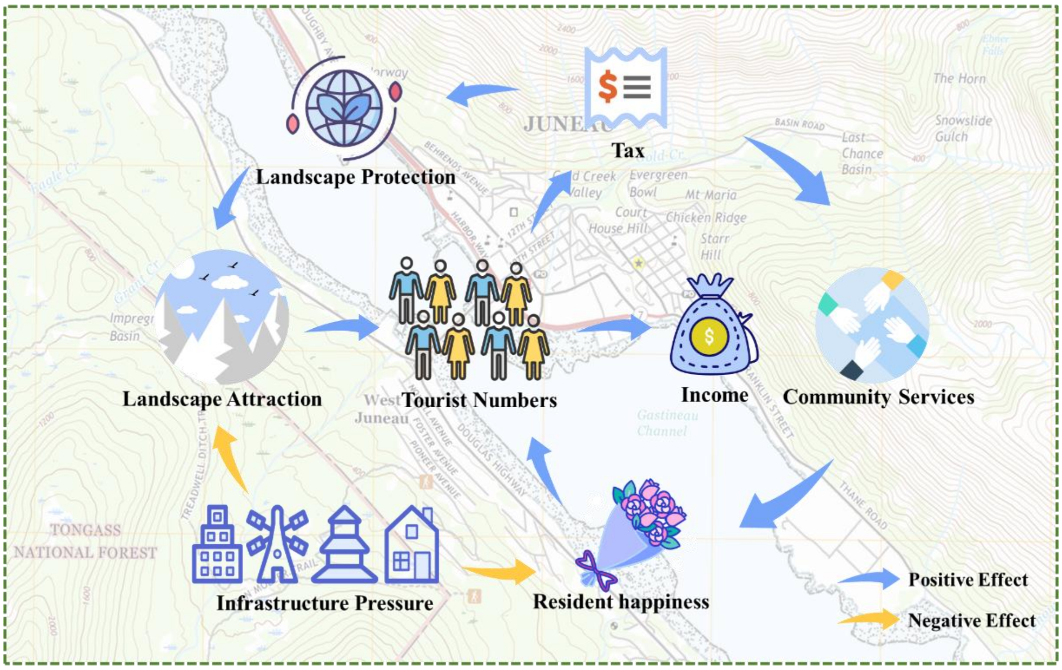

Figure 2 Feedback Networks

Negative feedback: excessive tourists→increased environmental pressure→accelerated melting of glaciers→decreased landscape attractiveness→fewer tourists

After clarifying the interaction relationship between variables through system dynamics simulation, we come to establish tourism economic model, tourism ecological model and social impact model in turn.

➢ Tourism economic models：

1、We define local tourism revenue as consisting of both tourist spending revenue and tax revenue.

$$R(t) = N(t) * p * (1 + tax) \tag{1}$$

where tax denotes the tax rate, which is known data, and **p** denotes per capita tourist spending, which is unknown data.

2、Aiming at the lack of historical data on the per capita consumption level of tourists(**p**) in the tourism economic model, LSTM was used to predict the consumption level of tourists in 2025:

The per capita spending level of tourists is determined by a combination of features such as the local Consumer Price Index for the City of Juneau, the origin of tourists, the level of consumption of residents in the source area, the U.S. inflation rate, and the Consumer Price Index for the City of Juneau. Based on the existing historical data of the features, LSTM is utilized to predict the future features considering the complexity of time series forecasting. Then, still using LSTM to capture the complex nonlinear relationship between the features and the target variables, the future visitor consumption level is predicted. [2]

In this problem, LSTM is able to effectively capture long-term dependencies in time-series data, which improves the accuracy of predicting the per capita spending of tourists in the city of Juneau in the future.

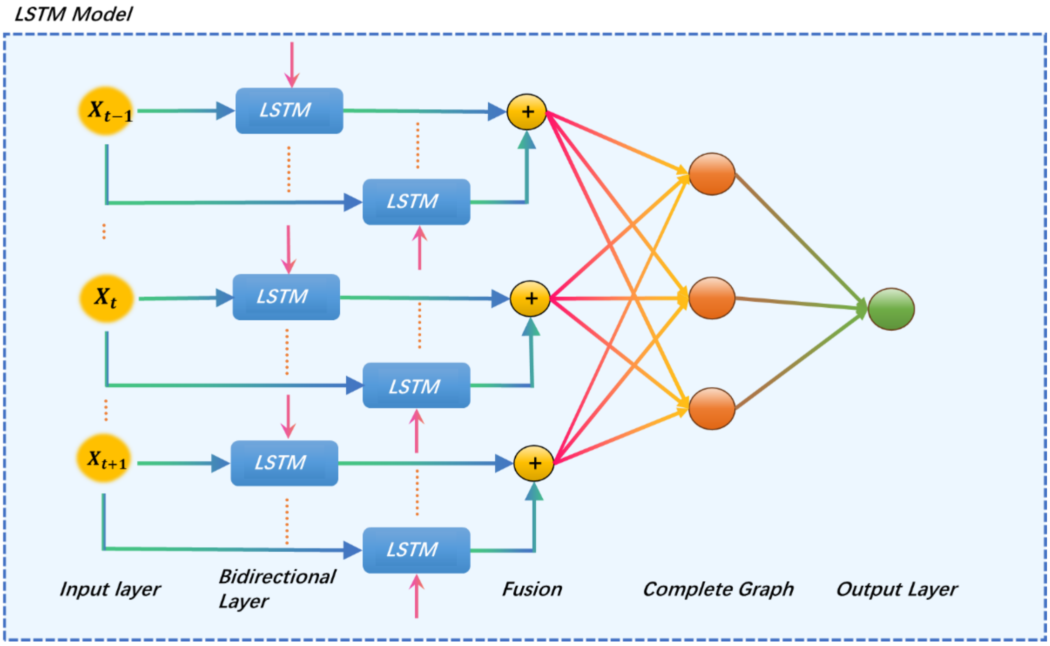

Figure 3 LSTM Networks

Bayesian method is a statistical inference method that updates the probability distribution over unknown parameters based on Bayes' theorem. The Bayesian approach treats the unknown parameters as random variables and calculates the Posterior Distribution (PD) by combining the observations with the Prior Distribution (PD) [3].

In the pre-existing LSTM network, we use MC Dropout and run the model multiple times during the testing phase. Each run keeps the Dropout layer active. This gives a series of predicted values, which in turn calculates the predicted mean and standard deviation. This approach provides not only the prediction value itself, but also the confidence interval for that prediction, which is important for assessing the reliability of the prediction.

Ultimately, we solved for the predicted per capita tourist spending in 2025: p = 267 dollars per person.

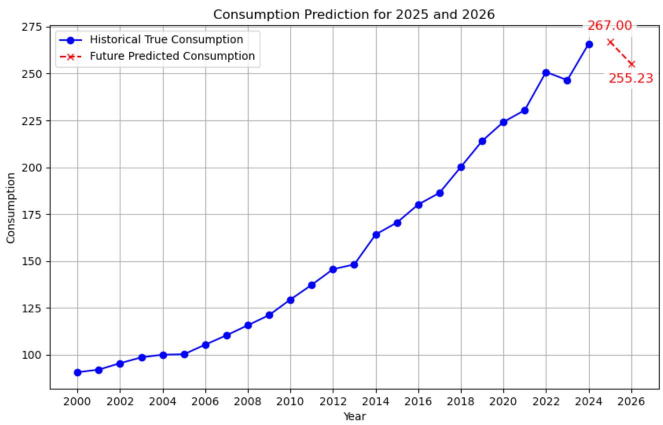

Figure 4 Consumption Prediction

By showing the standard deviation of the forecasts, we can visualize the uncertainty of the model's predictions under possible future economic fluctuations. For the City of Juneau's tourism department or policy makers, knowing the uncertainty of the forecast can help them develop more resilient plans. For example, in cases where the forecast shows a high degree of uncertainty, backup plans can be prepared to address different scenarios that may arise.

3、Establishing constraints based on diminishing marginal benefits

Considering the sustainability of the local economy in Juneau, combined with the marginal diminishing benefit in economics, we believe that when the share of tourism revenues in total local revenues is too large in Juneau, it will lead to an imbalance in the development of the economic sector and inhibit the positive development of other industries, which is not conducive to the long-term enhancement of the economic level of the city of Juneau. Therefore we introduce constraints:

$$\alpha_2 \leq \frac{R(t)}{R_{total}} \leq \alpha_1 \tag{2}$$

Where α_1 is the maximum share of tourism revenue in the SLES, α_2 is the share of tourism development in the City of Juneau at the beginning of the development process, and R_{total} is the total revenue of the City of Juneau's economy. All three are known data.

➢ Ecological&Social impact model of tourism

1、Glacier melting model

Mendenhall Glacier, as a key environmental variable in the tourism ecological modeling of the city of Juneau, not only affects tourists' tourism satisfaction, but also influences the attitudes of local residents toward the development of tourism. Therefore, it is crucial to model glacier melt. [4] We argue that the melting rate of the Mendenhall Glacier is not only related to the local temperature, but also to the pressure on the environmental carrying capacity due to the excessive number of tourists. At the same time, we assume that the ecosystem has a certain self-repairing ability, so we establish a glacier melting model:

$$\frac{dE}{dt} = -\alpha * N(t) + \beta\big(E_{max} - E(t)\big) - \gamma * T + \lambda * \omega_1 * N(t) * p * tax \tag{3}$$

Where $\alpha$is the influence coefficient of the pressure of the number of tourists on the glacier ablation,β is the influence coefficient of the temperature on the glacier ablation,γ is the influence coefficient of the ecosystem self-repairing ability on the glacier ablation,λ is the influence coefficient of the financial investment for environmental protection on the glacier ablation, and E_max is the maximum height of the glacier. All the above are known data.

2、Environmental Carrying Pressure Modeling:

$$S(t) = N(t) * (q_1 * w' + q_2 * s' + q_3 * c') \tag{4}$$

where w'、s'、$c'$are the normalized per capita waste generation (w), drinking water consumption (s), and carbon emissions (c) of tourists, respectively, andq_1、q_2、q_3 are the corresponding weights of each. All of the above are known data.

3、Modeling Changes in Visitor Numbers: given the quarterly variation in tourist ardor in Juneau, we attach a sine function to the visitor base to represent fluctuations in the number of local visitors.

$$N(t) = N * b + a * sin\left(\frac{2 * \Pi * t}{365}\right) + \varepsilon(t) \tag{5}$$

where N denotes the base number of tourists, b denotes the multiplicative factor of the base number of tourists, and a denotes the maximum deviation from the base number of tourists. All of the above are known data. $\varepsilon(t)$ denotes a random error term to capture uncertainty in the model.

4、Tourist arrivals constraint model: A constraint function is introduced, taking into account an upper limit on the number of local tourists and the fact that local tourism revenues should cover the government's investment expenditures into the tourism industry.

$$\begin{gathered} 0 \leq N(t) \leq N_{max} \\ C + I + M \leq N(t) * p * (1 + tax) \end{gathered} \tag{6}$$

included among these, N_{max} represents the maximum number of tourists restricted locally, and C, I, and M represent local operating costs, infrastructure investment, and environmental maintenance costs, respectively. All of the above are known data.

5、Tourist Satisfaction Model: We believe that the attractiveness of the classic tourist landscape and the number of local tourists are the two most important indicators affecting tourist experience and satisfaction. According to the analysis, the closer the glacier height is to the maximum value, the better the tourists' viewing experience is; the more the number of local tourists is, the worse the tourists' viewing experience is.

Therefore, we introduce the **Sigmoid** function to fit the relationship between tourist satisfaction, glacier view and the number of tourists.The **Sigmoid function** is continuous and derivable, and its smoothness makes it very suitable for gradient descent optimization in neural networks; at the same time, the **Sigmoid function** is nonlinear, which can help the model to capture the complex patterns in the data.

$$\mathrm{A(t)} = \frac{\mathrm{A_0}}{1 + \mathrm{e}^{-\mathrm{k}*(\mathrm{E_{max}} - \mathrm{E(t)})}} * (1 - \frac{N(t)}{N_{max}})^{\theta} \tag{7}$$

Where $\mathrm{A_0}$ represents the highest satisfaction of tourists and θ is the influence factor of the number of tourists on the satisfaction of tourists. All the above are known data.

➢ Additional Revenue Expenditure Plan (AREP)

We believe that the allocation of the increased revenue from the City of Juneau's tax levy to support investment in environmental protection, infrastructure improvement, and community development programs should be based on real-time changes in environmental stress, resident well-being, and infrastructure stress to increase policy flexibility and adaptability. We set up three levels of crisis for environmental stress, three levels for infrastructure stress, and two levels for resident well-being, with investment ratios dynamically adjusted according to the hierarchy. We believe that the allocation of the increased revenue from the City of Juneau's tax levy to support investment in environmental protection, infrastructure improvement, and community development programs should be based on real-time changes in environmental stress, resident well-being, and infrastructure stress to increase policy flexibility and adaptability. We set up three levels of crisis for environmental stress, three levels for infrastructure stress, and two levels for resident well-being, with investment ratios dynamically adjusted according to the hierarchy.

$$\begin{gathered} \omega_1 + \omega_2 + \omega_3 = 1 \\ \omega_1 = \begin{cases} 0.6\,, & if\ E(t) < E_{irr} * 1.25 \\ 0.3\,, & if\ E_{irr} * 1.25 < E(t) < E_{irr} * 1.5 \\ \mathrm{g}\,, & otherwise \end{cases} \\ \omega_2 = \begin{cases} 0.5\,, & if\ H(t) < H_{ini} * 0.7 \\ \mathrm{g}\,, & otherwise \end{cases} \end{gathered} \tag{8}$$

$$\omega_3 = \begin{cases} 0.5\text{，} \ if\ S(t) < S_{max} * 0.9 \\ 0.3\text{，} \ if\ S_{max} * 0.6 < S(t) < S_{max} * 0.9 \\ g\text{，} \ otherwise \end{cases}$$

ω_1、ω_2、$\omega_3$are the ratios of the weight of tax revenues for the protection of the environment, the maintenance of infrastructure, and the development of community projects, respectively. E_{irr} is the glacier height threshold below which glacier melt is irreversible.Once below this threshold, glacier melting will be irreversible；$S_{max}$is the maximum environmental carrying capacity for the City of Juneau. Both of these data are known. In case of$\omega_1 + \omega_2 + \omega_3 > 1$，the emergency plan for tourism management is activated.

➢ Multi-objective planning modeling

Integrating economic, ecological, and social impacts, we establish a multi-objective planning model: we want local tourism revenue to increase and tourist satisfaction to increase, while environmental carrying pressure is reduced as much as possible.

1、objective function：

$$Max\_Evaluate(t) = \alpha_0 * \int_0^t R(t)dt + \beta_0 * A(t) - \gamma_0 * (N(t) * (q_1 * w' + q_2 * s' + q_3 * c')) \tag{9}$$

Where α_0 represents the weight of economic factors, β_0 represents the weight of social impacts, and γ_0 represents the weight of environmental carrying pressures, the above is based on the decision of the experts' comprehensive judgment of the tourism system of the city of Juneau, and is known data.

2、constraint function：

$$\begin{cases} \boldsymbol{\alpha_2 \le \dfrac{R(t)}{R_{total}} \le \alpha_1} \ \textbf{（Tourism revenue constraints）} \\ \boldsymbol{0 \le N(t) \le N_{max}} \ \textbf{（Tourism constraints）} \\ \boldsymbol{C + I + M \le N(t) * p * (1 + tax)} \ \textbf{（Income balance constraints）} \end{cases} \tag{10}$$

3、intermediate function：

$$\begin{cases} \dfrac{dE}{dt} = -\alpha * N(t) + \beta * \left(E_{max} - E(t)\right) - * T + \lambda * \omega_1 * N(t) * tax \\ N(t) = N * b + a * sin\left(\dfrac{2 * \Pi * t}{365}\right) + \varepsilon(t) \\ A(t) = \dfrac{A_0}{1 + e^{-k*(E_{max} - E(t))}} * (1 - \dfrac{N(t)}{N_{max}})^{\theta} \end{cases} \tag{11}$$

➢ Particle Swarm-Genetic Algorithm Modeling

1、Genetic Algorithm Model Analysis: We built a basic genetic algorithm model and optimized the model. In order to optimize the model, we counted the number of tourists, temperature, and consumption level in Juneau for each year by limiting the impacts on the ecosystem, environment, and infrastructure of the area, and analyzed the reduction of glacier area, setting appropriate thresholds for each parameter. We set up a dynamical model to simulate the changes in the tourism system of the region, and combined with the well-being index of the residents of the region, the environmental assessment index, and the satisfaction evaluation of tourists to score the individual adaptability of each generation, and iterated step by step, so as to make the city's tourism industry develop in a sustainable way.

2、Genetic algorithm model parameter settings: genetic inheritance relationship was fitted by linear interpolation, Gaussian normal function was set as the parameter of variation, elimination rate was set as 2/3, and fitness value of individuals in each generation was assessed by income. The algorithm fits to the optimal solution faster, so we set the population size to 50 and the number of iterations to 75. the interaction relationship between the important factors in the area is simulated by the established system dynamics model, and the established objective function model is used as the fitness value of each individual of the genetic algorithm.

3、Particle swarm algorithms (optimization of genetic algorithms)

After building the genetic model and analyzing its convergence curve, we found that the genetic algorithm varies based on a small range and within a certain range each time. We realized that the model may fall into the local optimum situation, so we introduced the particle swarm algorithm to optimize it, in order to accurately find and control the analysis, we set the population size to 75, in order to increase the efficiency of the algorithm, the maximum speed is set according to the linearly decreasing mode, and the inertia weight is also set to decrease. In order to prevent falling into local optimum and ignore the effect of convergence speed, we use local PSO algorithm and the results obtained are as follows:

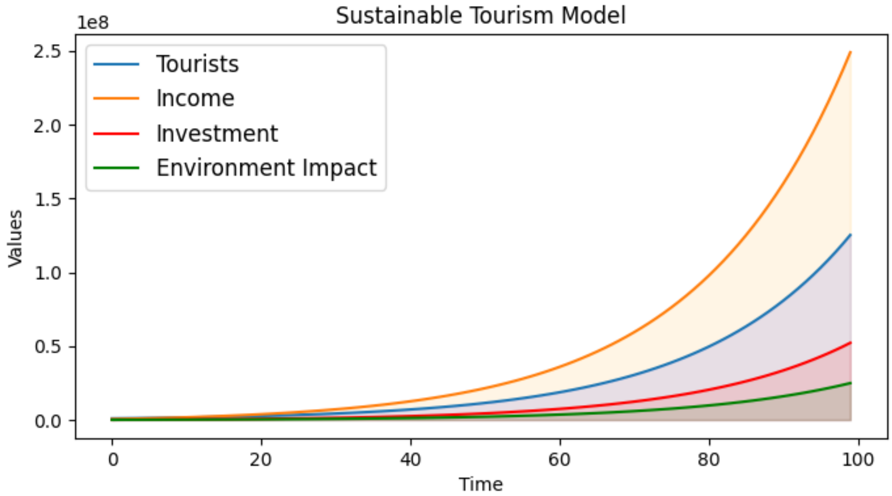

Figure 5 Sustainable Tourism Model

4.2 Sensitivity Analysis

Through the cross-optimization exploration of particle swarm algorithm and genetic algorithm, we get the optimization conditions in the sustainable tourism system of Juneau city under ideal state:

1、 the optimal number of tourists interval: [1856,2985] (unit: people / day); by the current number of tourists in Juneau City, it can be seen that too many tourists in the peak season significantly exacerbated the environmental carrying pressure, as well as the resistance of the local residents; therefore, we recommend the implementation of tourists to limit the flow of tourists, the landscape of the mandatory booking and other management measures, to ensure the ecological sustainability of the development of the development of tourism and the gradual increase in the residents of the development of the tourism industry support. We therefore recommend the implementation of management measures such as tourist flow restrictions and mandatory landscape reservations to ensure ecological sustainability and the gradual increase of resident support for tourism development.

2. Optimal Tax Revenue: [259,462] (unit: USD/person); The length of the optimal tax revenue range is large, so it is clear that different tax rates should be set for the low and high seasons of tourism. Therefore, we suggest that the off-season increase the attractiveness of tourists by lowering the tax, to ensure that the tourism revenue can cover the economic investment of the city government of Juneau in the tourism industry; and the peak season by appropriately increasing the tax, to rationally regulate the number of tourists, and at the same time to provide financial support for the operation and maintenance of infrastructure and the protection of the environment, and the improvement of the negative sentiment of the residents.

Combined with the actual situation of the tourism system in Juneau City, and compared with the sustainable ecosystem, it can be seen that the current economic sustainable development is good; however, there is a big gap between the environmental carrying pressure and the ideal state, and the residents' satisfaction also needs to be improved. This suggests ecological sustainability and social impacts are key concerns for the City of Juneau.

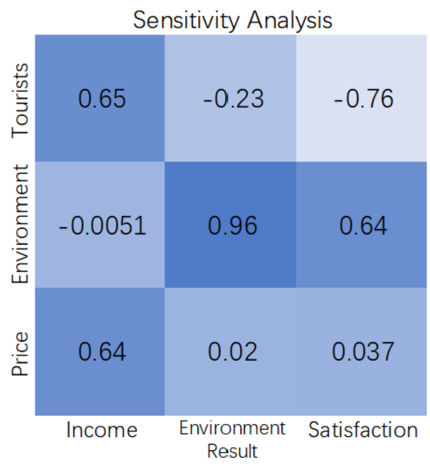

Figure 6 Sensitivity Analysis

The sensitivity analysis heat map in the figure above demonstrates the strength of correlation between key input variables and output indicators in the tourism system. The analysis shows that there is almost no correlation between environmental quality and income, which suggests that changes in environmental conditions have a small direct impact on income. However, environmental quality shows a strong positive correlation of 0.63 with tourist satisfaction, which suggests that good environmental conditions help to enhance the tourist experience.

The number of tourists exhibits a significant positive correlation of 0.65 with income, but a significant negative correlation of -0.76 with tourist satisfaction.This strongly suggests that too many tourists in the scenic area, although it can bring in lucrative tourism income, will significantly reduce tourist satisfaction. This suggests that limiting the upper limit of the number of occupied people can help to enhance the tourist experience.

The presentation of heat map and sensitivity analysis provides a quantitative basis for sustainable development management in Juneau City, which helps the Juneau Tourism Commission to understand the interactions between various factors, so as to formulate a more scientific and reasonable development strategy. The results of the study emphasize the need to fully consider the balance between environmental carrying capacity and quality of visitor experience while pursuing economic benefits.

5 A Migration System Based on Similarity Analysis

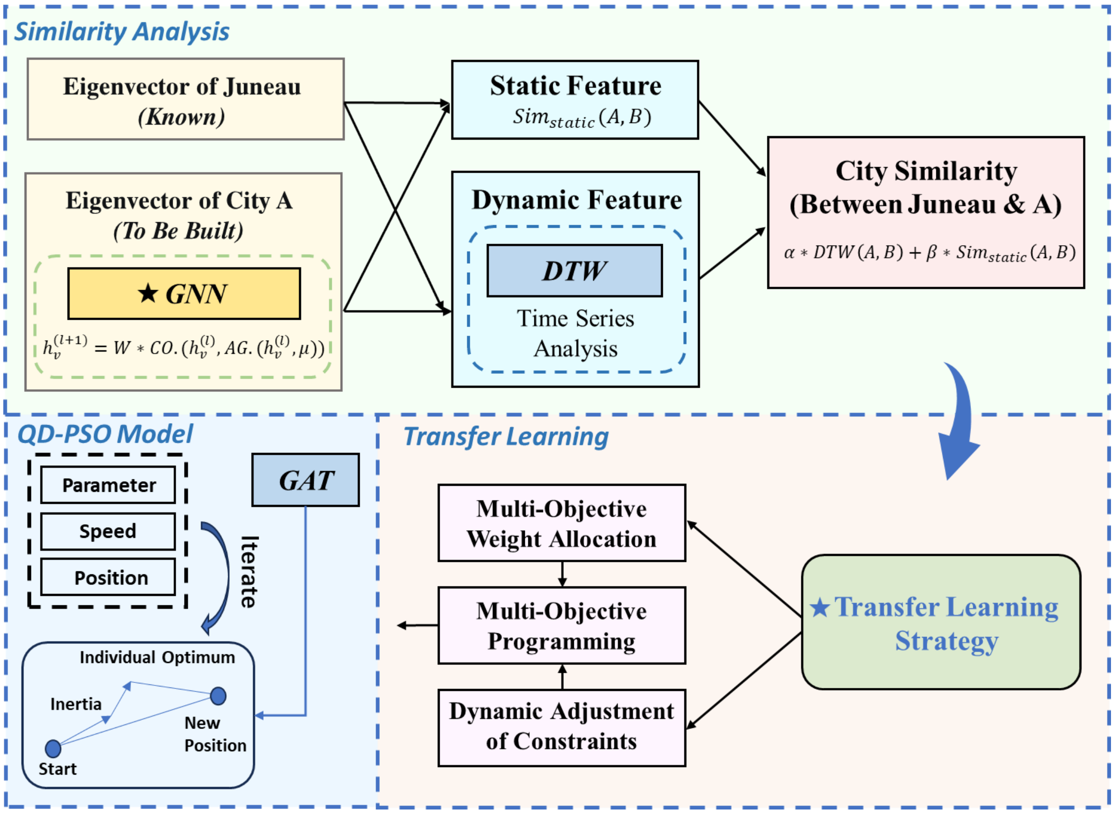

Figure 7 Our Migration System

5.1 The Establishment of Our System

This question is intended to migrate the model established in question one to another destination, and we might use the Indonesian island of Bali as an example. This place full of beautiful temples and smiles has become synonymous with global tourism problems. [5]

In order to effectively migrate the successful tourism management model of the city of Juneau to Bali, a strategy migration system has been established. The main elements of the system are as follows:

5.1.1 Feature extraction

Aiming at the complexity and high dimension characteristics of Bali tourism data, we adopt graph neural network (GNN) technology for data dimension reduction processing. The powerful representation learning capability of GNN is utilized to extract the most representative feature information from the high-dimensional data, providing high-quality data support for subsequent modeling.

$$h_v^{(l+1)} = \sigma * (W * CONCAT\left(h_v^l, AGGREGATE\left(\left\{h_u^{(l)}, \forall \mathcal{N}(v)\right\}\right)\right)) \tag{12}$$

Sketch of the GNN schematic description:

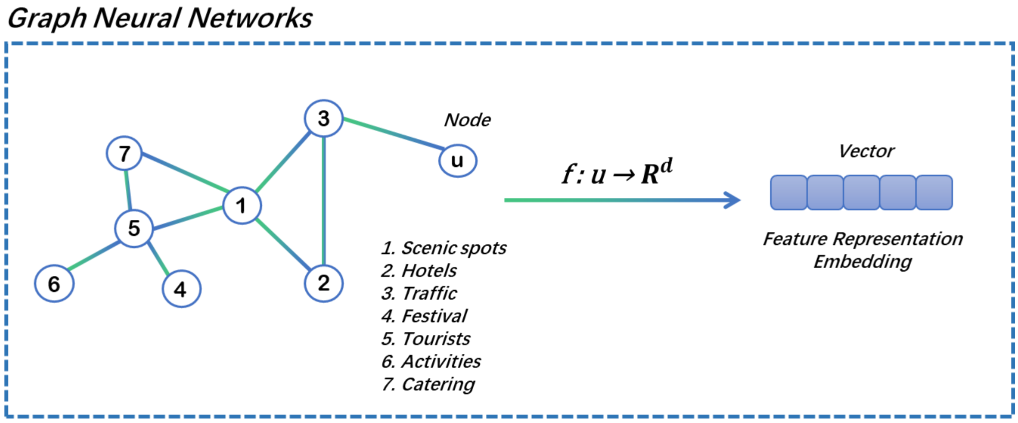

Figure 8 Graph Neural Networks

5.1.2 Urban similarity determination

Calculating city similarity usually involves a combination of time series similarity (dynamic features) and static features.

1、Time series similarity analysis (dynamic characterization):

In this problem, we collect the monthly tourist flow, monthly tourism economic revenue, and monthly environmental index of Bali and Juneau City in 2024, and use the *Fastdtw* function to calculate the DTW distance between the two time series and find the optimal alignment path. The monthly tourist flow of the two places in 2024 is used as an example:：

$$\begin{aligned} N_{Juneau} &= \{n_1, n_2, \dots \dots n_{12}\} \\ N_{Bali} &= \{m_1, m_2, \dots \dots m_{12}\} \end{aligned} \tag{13}$$

（1）Create a 12 × 12 distance matrix D， $D(i,j) = d_{ij} = \sqrt{(n_i - m_j)^2}$

（2）Establish recurrence relationship:Define a cumulative distance matrix C to store the minimum cumulative distance from the starting point to the current point. The recursive relationship is as follows:

$$C(i,j) = d(n_i, m_j) + min(C(i-1,j)C(i,j-1), C(i-1,j-1)) \tag{14}$$

（3）initial conditions：

$$C(0,0) = d(n_1, m_1)$$

（4）boundary condition：

$$\begin{cases} C(i,0) = \infty \\ C(0,j) = \infty \end{cases}$$

（5）optimal path：

$$\mathrm{DTW}_{\mathrm{tourists\_number}}(\mathrm{A}, \mathrm{B}) = C(n,m) \tag{15}$$

The optimal path is the path from the starting point (0,0) to the ending point (n,m) such that the cumulative distance is minimized. This path can be found by backtracking:

1) Start at the end: from $C(n,m)$：

2) Select Next Point: Selects the next point based on a recursive relationship:

If $C(i-1,j)$ is minimized, the next step is $C(i-1,j)$.

If $C(i,j-1)$ is minimized, the next step is $C(i,j-1)$.

If $C(i-1,j-1)$is minimized, the next step is $C(i-1,j-1)$.

Repeat the above steps: until you return to the starting point (0,0).

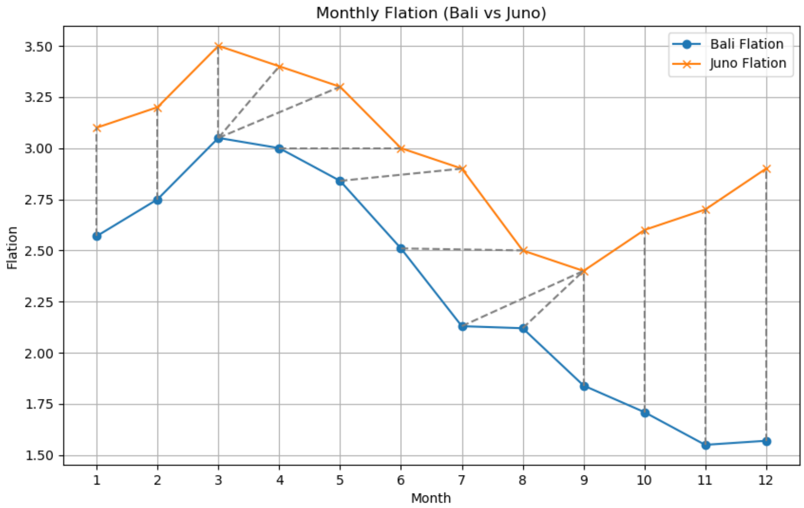

Figure 9 DTW Analysis

（6）Interpretation of results:

The optimal path represents the best alignment of two time series such that the cumulative distance between them is minimized. This helps to understand how different cities are similar or different on certain key indicators.

In the migration of city tourism models, calculating the time series similarity helps to understand the similarity or difference of different cities in certain key indicators (e.g., tourist flow, economic fluctuation, etc.), thus providing a basis for model migration.

2、Static characterization：

In this problem, we collect economic, social, and ecological data such as tourism resources, infrastructure carrying capacity, demographic information, and economic and industrial share structure of the economy in Bali and Juneau City [6], and normalize them so as to build static feature vectors：

$$S_{Juneau} = [E_{Juneau}, S_{Juneau}, Ec_{Juneau}] \\ S_{Bali} = [E_{Bali}, S_{Bali}, Ec_{Bali}] \tag{16}$$

The Euclidean distance is used to compute the similarity of static features:

$$Sim_{static}(\text{Juneau}, \text{Bali}) = \frac{1}{1 + \sqrt{\sum(S_{Juneau\ i} - S_{Bali\ j})\text{^}2}} \tag{17}$$

The static characteristics of the two cities, such as their industrial structure, tourism resources, and economic conditions, were considered to further assess the degree of similarity between them. This step helps to identify which successful experiences in Juneau can be directly applied to Bali.

Finally, the final similarity between Bali and the city of Juneau is calculated by weighted combination:

$$Sim(Juneau, Bali) = \alpha * DTW_{tourism}(Juneau, Bali) + \beta * Sim_{static}(Juneau, Bali)$$

Where the weight ratio occupied by α and β assigns weights according to the importance of time and static features, which are known data.

Through the above modeling and solving, we get the final similarity between Bali and Juneau City is 0.65.

5.1.3 Model adjustments

Make the necessary adjustments to the existing tourism industry model for the City of Juneau based on the identified city similarities:

（1）Multi-objective weighting：

Adjusting and optimizing target weights to reflect differences in city characteristics:

$$w_i^{Bali} = Sim(Juneau, Bali) * w_i^{Juneau} + \big(1 - Sim(Juneau, Bali)\big) * w_i^{base} \tag{18}$$

For ecologically sensitive cities，$w^{base} = [w_1, w_2, w_3] = [0.3, 0.4, 0.3]$

Where w_1, w_2, w_3 represent the weight allocation of economy, society and ecology in multi-objective planning, respectively.

Combining the above, we can get the objective function established for Bali:

$$maxEvaluate(t) = w_1^{Bali} * \int_0^t R(t)dt + w_2^{Bali} * A(t) - w_3^{Bali} * (N(t) * (w + s + c)) \tag{19}$$

（2）Constraint optimization：

1）For critical value data in constraints that are not accessible, a similarity-weighted relaxation of the original constraints can be performed

For example, there is a lack of sources of data on the upper limit of tourist arrivals in Bali:

$$N_{max}^{Bali} = Sim(Juneau, Bali) * N_{max}^{Juneau} + \big(1 - Sim(Juneau, Bali)\big) * N_{max}^{global} \tag{20}$$

Imitate：

$$N^{Bali}(t) \le Sim(Juneau, Bali) * N_{max}^{Juneau} + \big(1 - Sim(Juneau, Bali)\big) * N_{max}^{global} \tag{21}$$

Included among these，N_{max}^{global} is the upper bound on the number of people constrained by the global tourist attraction and is known data.

2）Add new constraints to the geographical characteristics of the new tourist site to ensure that the model meets both the actual local needs and the sustainable development goals.

For example, in response to the special religious environment in Bali, we introduced a cap on tourist visits to specific sites such as religious churches, taking into account the fact that tourist behavior must not interfere with large-scale local religious activities and the protection of religious and cultural heritage sites：

$$N^{Bali\_church}(t) \le N_{max}^{Bali\_church} \tag{22}$$

（3）Finalization of multi-objective planning：

objective function：

$$Max\_Evaluate(t) = \alpha_1 * \int_0^t R(t)dt + \beta_0 * A(t) - \gamma_0 * (N(t) * (q_1 * w' + q_2 * s' + q_3 * c')) \tag{23}$$

constrain function:

$$\begin{cases} \alpha_2^{Bali} \le \dfrac{R(t)}{R_{total}} \le \alpha_1^{Bali} \text{（Tourism revenue constraints）} \\ 0 \le N(t) \le N_{max}^{Bali} \text{（Visitor number constraints）} \\ C + I + M \le N(t) * \mathrm{p} * (1 + \mathrm{tax}) \text{(Income balance constraints）} \\ N^{Bali\_church}(t) \le N_{max}^{Bali\_church} \text{（Cultural heritage protection constraints）} \end{cases} \tag{24}$$

5.1.4 Optimization Algorithm Integration

In order to improve the efficiency of finding the optimal solution, we introduce the graph attention mechanism (GAT) in quantum behavioral particle swarm optimization (QB-PSO). [7] Replacing the simple socially optimal solution (gBest) with the weighted neighbor information obtained by GAT enables the updating process to not only consider the global optimal solution, but also pay attention to the local information that is closely related to the current particle, and ensures that the new method can both efficiently explore the entire solution space and quickly converge to a quality solution, thus accelerating the process of finding the best solution that satisfies all constraints and the most important optimization measures.

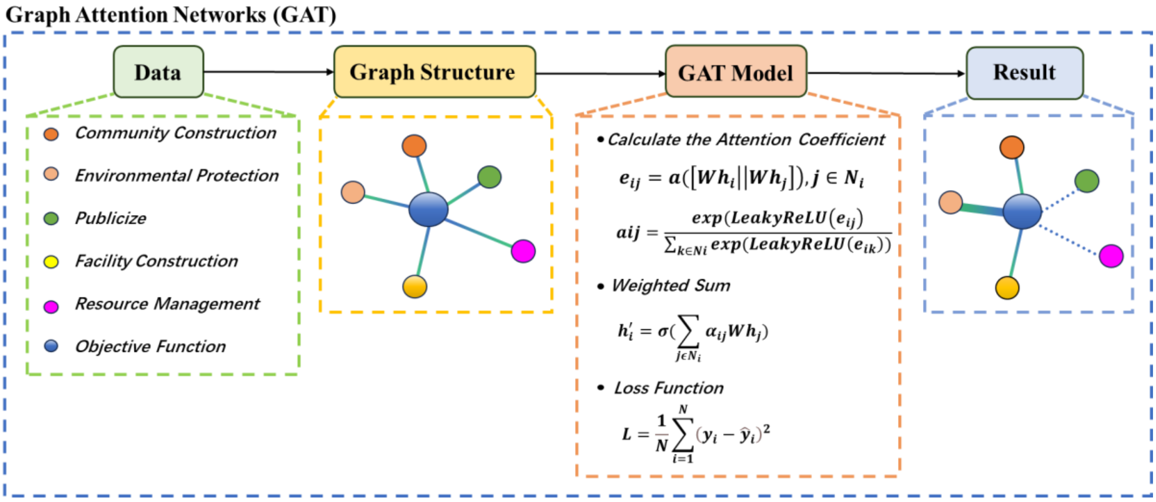

Figure 10 GAT Networks

Firstly, we find out the data of the factors that may be associated with the central node, define the edges of the nodes to indicate the correlation between the nodes, construct the GAT model after the standardization of the collected node features, use the LeakyReLU as its activation function, and introduce the mean-square error loss function as a feedback mechanism to train the GAT model. The results illustrate that Publicize and Resource Management are poorly correlated with the objective function, and Environmental Construction has the greatest influence on the objective function, so we need to allocate more expenditures for environmental protection.

Enhancing the QB-PSO algorithm with GAT makes it smarter to explore the solution space and reduces the number of unnecessary iterations, thus accelerating the process of finding the best solution that satisfies all constraints.

5.2 Influence of location on the selection of the most important optimization measures

1、According to the urban relocation strategy in the first question, we can analyze the influence of location on the selection of the most important optimization measures：

①The relative speed of economic, social and ecological development of tourist cities varies, and the weighting scheme in the objective function is therefore different: for example, for a city with a unique cultural heritage such as Paris, the objective of cultural preservation is a dimension that needs to be re-established and needs to take precedence over the other objectives in order to ensure that the most important influencing factor in attracting tourists - the -

historic buildings are not damaged.

②The relative strength of constraints (impact coefficients) varies depending on the degree of ecological vulnerability of the tourist city: for example, for the risk of flooding in the Swiss Alps, the corresponding constraints need to be strengthened, e.g., by restricting the number of tourists during periods of melting of snow-covered mountains or by strengthening the emergency preparedness.

2、conclude：

The migration strategy we apply in this problem is not limited to directly copying the successful tourism management model, but more importantly, making appropriate adjustments according to the actual situation of the target city to ensure the effectiveness and adaptability of the model. By combining the time series similarity calculation of DTW, static feature analysis, data dimensionality reduction processing of GNN, and the graph attention mechanism in QB-PSO, we have constructed a migration framework that is both flexible and efficient. This framework can not only help other tourist-oriented cities facing similar challenges to quickly implement effective management measures, but also provide strong technical support and theoretical basis for sustainable tourism development on a global scale.

5.2 Optimization of Tourists Assignment Based on Network Flow Theory

The problem aims to address how to use the model to promote attractions and locations with fewer visitors to achieve a better balance. We first find data on the number of visitors to different locations in Juneau and calculate the optimal visitor capacity for each area based on the particle swarm optimization model developed above. Comparing the found data with the calculated optimal visitor capacity, we analyzed which areas need to reduce the number of tourists and which areas need to increase the number of tourists, and in order to analyze the feasibility of the direction of flow and the exact path of flow, we established an optimization model for the distribution of passenger flow based on the network flow theory [8].。

5.2.1 Modeling

We begin by treating each attraction or area in the city of Juneau as a node in the network flow graph, the paths between the attractions as edges, and the point of minimum passenger flow between two attractions as the maximum flow value for that edge. We assign higher weights to the importance of development at the point of maximum passenger flow to try to make the passenger flow at that point converge to the optimal passenger flow point calculated by the particle swarm algorithm.

5.2.2 Model coupling

Traffic dynamic allocation model: Using the previously established LSTM prediction model to predict the future passenger flow and its distribution, and combined with the seasonal fluctuation function to generate time series inputs, to make a pre-selected plan for passenger flow allocation in advance, so as to achieve dynamic planning for the future distribution of passenger flow. Among them, the seasonal fluctuation function is:

$$N(t) = N * b + a * \sin\left(\frac{2\Pi t}{365}\right) \tag{25}$$

2、Improvement of Particle Swarm Algorithm: In order to quickly process higher dimensional features so that they can be processed faster and produce final results in practical applications, we have improved the initial particle swarm algorithm, and the following are the improvements made to the initial particle swarm algorithm：

（1）Constraints: the node capacity should be limited to the optimal visitor interval of attraction j, the current total number of visitors to the city can be conserved before and after the particle swarm algorithm is performed, the edge capacity between attractions needs to be less than the maximum path capacity, and the network flow algorithm also constrains the problem of transferring the number of visitors between attractions.

（2）In order to avoid local optimization, we adopt the PSO algorithm. However, the PSO algorithm has a high number of iterations and low efficiency, so we adopted a dynamic parameter adjustment approach, i.e., focusing on global search at the initial stage to prevent falling into local optimality, and focusing on local development at the later stage to facilitate fast convergence. Based on this, we design suitable adaptive weights and learning factors.

3、System dynamics model update：

We can feed the network flow allocation results back into the previously established tourism ecological and economic models, dynamically update the dynamics model, and analyze the impact of path capacity on the objective function

（1）Adjusted: (Replacing overall visitation with the sum of visitation to each attraction, taking into account the weighting of each attraction's localized impact on the glacier)

$$\frac{\mathrm{dE}}{\mathrm{dt}} = -\sum_{i} \varphi_i \alpha_i N_i(t) + \beta\big(E_{max} - E(t)\big) - \gamma T + \lambda \omega_1 N_{total}(t) * tax \tag{26}$$

Addition makes the effect of visitor volume on glacier melt more accurate

（2）Update of the social impact model：

Adjusted: (breakdown of satisfaction by attraction and introduction of crowding (visitor experience))

$$A_i(t) = \frac{A_0}{1 + e^{-k(E_{max} - E(t))}} \left(1 - \frac{N_i(t)}{N_{i,max}}\right)^{\theta} * \prod_{j \epsilon nearbyscenery} (1 - D_{ij}(t)) \tag{27}$$

We introduced the network flow dynamic planning of the density distribution of tourists to solve a series of problems caused by the contradiction between the number of tourists and the tourist capacity of the attractions with fewer tourists as well as the locations with more tourists, and based on this, we made parameter adjustments to the originally established PSO model so that it can solve the current problem of the planning of the co-development of multiple attractions. Therefore, it can be said that after adjusting the parameters and adding appropriate models, our model is sufficient to plan relatively optimal solutions for the sustainable development of tourism in various regions with different situations.

6 Memorandum

Dear Juno Tourism Committee,

We are pleased to share with you the optimized measures for the tourism industry and their future impacts based on the establishment of a sustainable tourism system.

Our research is based on system dynamics models, using multi-objective planning methods as the main framework, and employs particle swarm optimization combined with Genetic

Algorithm Techniques (GAT) as an efficient exploration method. Additionally, we incorporate LSTM networks enhanced with Bayesian inference to assist in forecasting key indicators such as future tourist spending levels.Notably, to address the issue of uneven visitor flows across different attractions, we have utilized network flow theory to establish a network graph structure of the attractions. By monitoring the real-time visitor traffic at each attraction, we dynamically adjust visitor diversion strategies.

To promote the sustainable development of Juno City's tourism industry, we propose the following recommendations:

1. Increase Tourism Tax During Peak Seasons to Enhance Environmental Protection Investment: an 8% increase in tourism tax would only result in a 3% decrease in visitor numbers. However, the increased tax revenue, when invested in environmental protection could enhance environmental carrying capacity by 5%.

2. Reduce Tourism Tax During Off-Peak Seasons to Attract Visitors: A 10% reduction in tourism tax during off-peak seasons could lead to a 3% increase in visitor numbers and a 2% rise in tourism revenue, without significantly impacting the environmental carrying capacity during these periods.

3. Control Annual Visitor Numbers Within 1.65 Million This measure aims to improve visitor experiences and ensure the sustainability of the tourism industry.

4. Establish a Community Co-Governance DAO Platform to Increase Resident Support

Develop a block-chain-based community voting system, distributing 800 governance tokens quarterly and local residents use these tokens to vote on priorities for tax usage and decisions regarding new attraction developments.Token holders receive dividends from tourism profits.

5. Build an Anti-fragile Revenue Model:

Data-Driven Decision Making: Allocate part of the tax revenue to build real-time monitoring systems that track visitor numbers, environmental changes, and economic indicators, allowing timely adjustments to strategies.

Sincerely,
[Our Group]

7 Sensitivity Analysis

In order to facilitate the regulation of multivariate influenced factors such as the environment, we need to analyze the impact of each factor on the environment, and for this purpose, we constructed a small model for how to quantify the sensitivity factors:

Let the input parameter be X and the output variable be Y. Because of our construction of kinetic models and the introduction of the idea of feedback, these models are able to reflect the fact that a change in one variable may have a direct or indirect effect on more than one variable, and therefore we can analyze the ratio of the sensitivity factor between two variables to determine the extent and nature of the effect of one variable on the other. We introduce a simple calculation to compute the sensitivity factor of the output variable：

$$SF_{X \to Y_i} = \frac{\Delta Y_i}{\Delta X} \tag{28}$$

Calculate the sensitivity factor:

Let the change in the number of tourists be N(t), tourism revenue be R(t), the rate of glacier melt be dE/dt, tourist satisfaction be A(t), and environmental change be E(t).

Calculate the impact factor for each output variable separately：

$$SF_{N(t)\to R(t)} = \frac{\Delta R(t)}{\Delta N(t)} \tag{29}$$

……

Here are the results of the calculations：

Figure 11 Sensitivity Analysis

Through the sensitivity analysis, we can intuitively get the relationship between the factors and take measures to make the future development of the scenic area in the direction of their own expectations: if we want to make the glacier melt slower, we need to look at the value of the third line, only the amount of environmental change is negatively correlated, so we need to invest in the environment to make the environment to the good development, and for the development of other variables we need to inhibit, especially the number of tourists has the greatest influence on the glacier melt rate. The number of tourists has the greatest impact on the rate of glacier melting, so we need to take measures to limit the number of tourists, such as increasing the price of tickets, and then improve the ecological environment of the region, so as to achieve all-round development of the economy and ecology.

8 Model Evaluation and Further Discussion

8.1 Strengths

1、Systematic: The model is constructed by comprehensively considering various factors such as tourism economy, ecology and society. The tourism economic model covers income composition, forecasting and constraints, the tourism ecological model involves glacier melting and environmental carrying pressure, and the social impact model takes into account fluctuations in tourist numbers, satisfaction, etc., which comprehensively reflects the complexity of the tourism system and makes decision-making more comprehensive.

2、Strong data processing and forecasting capabilities: When processing complex and high-dimensional data, GNN dimensionality reduction and feature extraction are applied to provide high-quality data for modeling. When predicting the per capita consumption of tourists in 2025, the LSTM time series prediction model is used to effectively capture the long-term dependence and the relationship between the characteristic variables, and quantify the prediction probability by combining with the Bayesian propagation to improve the accuracy and reliability of the prediction.

3、Algorithm optimization and fusion: the genetic algorithm combines the system dynamics model and sets appropriate parameters to simulate the changes of the influencing factors of the tourism system. Meanwhile, particle swarm algorithm is introduced to improve the genetic algorithm and prevent local optimization. The Quantum Behaved Particle Swarm Optimization model (QB-PSO) introduces graph attention mechanism to accelerate the search for optimal solutions.

8.2 Weaknesses

1、High model complexity: integrating multiple sub-models and multiple algorithms, the structure is complex. For example, the economic-ecological-social multi-objective planning model contains multiple formulas and constraints with numerous parameters. Complex models increase the difficulty of understanding and debugging, have high computational costs, are demanding on computational resources and time, and reduce model interpretability.

2、High data dependency: model building and running rely on a large amount of data, such as LSTM prediction requires multi-factor historical data, and calculating city similarity and model adjustment also rely on multi-faceted data in two places. Data quality, completeness and accuracy affect model performance, and missing or inaccurate data may lead to model bias or even error.

8.3 Improvements to the model

1、Algorithm Robustness Improvement

The particle swarm algorithm (PSO), although optimized for convergence speed, has not verified its stability under different parameter distributions. Adaptive variational strategies or multi-objective optimization frameworks (e.g., NSGA-II) can be introduced to avoid local optimums and enhance the diversity of solutions.

2、Real-time constraints

The current model can integrate real-time sensor data (e.g., visitor flow monitoring, environmental indicators) to build a dynamic constraint feedback mechanism.

8.4 Extension of the model

1. Multi-scenario applicability extension

The model can be extended from ecologically sensitive cities (e.g., Juneau) to cultural heritage cities (e.g., Paris) by adding new cultural preservation objective functions (e.g., damage rate of historic buildings), and then adjusting the weight allocation strategy.

2. Multidisciplinary Cross-application Expansion

Optimize the layout of attractions and the allocation of infrastructure investment by combining with urban planning models, e.g. dynamically planning the evacuation path of tourists based on the network flow model to alleviate the congestion problem.

9 Conclusion

Our proposed comprehensive optimization system has strong theoretical value in tourism sustainability analysis. It can be further optimized in terms of data diversity, algorithm robustness and multi-scenario applicability. In the future, a more intelligent and adaptive tourism management system can be constructed through real-time data sharing, providing scientific solutions for the ecological protection and economic balance of global tourist cities.

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