

Analysis of Tourism Management Based on Genetic Algorithm and Simulated Annealing Algorithm

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Abstract

Based on genetic algorithm and simulated annealing algorithm, this paper constructs a strategy for sustainable urban tourism management. Firstly, the dynamic relationship between tourist flow, environmental impact and resource consumption is modeled by differential equations, in which the tourist number model realizes flow regulation through seasonal function and fare sensitivity coefficient; secondly, genetic algorithm is introduced for multi-objective optimization to maximize the tourism revenue under the premise of satisfying the capacity constraints of the attractions, and its evolutionary process is evaluated visually through the fitness function; lastly, simulated annealing algorithm is used to deal with complex nonlinear constraints, balancing global search and local optimization through temperature decay mechanism, and realizing synergistic optimization of minimizing environmental impact and rationalizing resource utilization. This study provides a quantifiable decision support framework for smart tourism management.

Keywords

Tourism Management, Genetic Algorithm, Simulated Annealing Algorithm.

1. INTRODUCTION

In this paper, an optimization framework integrating genetic algorithm[1] and simulated annealing algorithm[2] is proposed for the complex dynamic regulation[3] in sustainable tourism management. Firstly, the dynamic coupled system of tourist flow, environmental impact and resource consumption is constructed through differential equation modeling, in which the tourist number model realizes the dynamic response mechanism of flow regulation through the seasonal function and the fare sensitivity coefficient; secondly, the multi-objective collaborative optimization model based on genetic algorithm[4] is designed, and the group evolution mechanism is used to maximize the revenue solution under the capacity constraints of the attractions; lastly, the simulated annealing algorithm is introduced to deal with nonlinearities. simulated annealing algorithm to deal with nonlinear constraints, using temperature decay strategy to balance the global search and local development, to achieve the multi-objective optimization of environmental impact and resource consumption[5]. This study breaks through

the static planning limitation of traditional management mode and provides intelligent decision-making support with adaptivity for complex tourism systems[6].

2. ANALYSIS OF SUSTAINABLE TOURISM

In order to promote sustainable tourism development, this section constructs a mathematical model that balances factors such as passenger flows, environmental impacts, resource consumption, infrastructure needs and social stability.

2.1. Visitor quantity model

The number of visitors $N(t)$ changes over time and is influenced by various factors such as tourism policies, ticket prices, seasonal variations, and external factors (e.g., weather, pandemics). The rate of change in visitor quantity can be described by the following differential equation:

$$\frac{dN(t)}{dt} = \alpha \cdot P_{\text{ticket}}(t) \cdot f_{\text{season}}(t) \quad (1)$$

$P_{\text{ticket}}(t)$ is the ticket price at time t , which is a key factor controlling visitor flow. Higher prices may reduce the number of visitors. $f_{\text{season}}(t)$ is a seasonal function representing the variation in visitor numbers during different times of the year, with peak seasons attracting more visitors and off-peak seasons attracting fewer. α alpha is the sensitivity factor, representing how the visitor flow responds to ticket pricing and seasonal changes. The number of visitors $N(t)$ directly impacts total revenue, resource consumption, and infrastructure demand.

2.2. Total revenue model

Total revenue $R(t)$ is primarily generated from visitor payments, such as ticket fees, accommodation fees, and transportation costs. We assume that each visitor's average expenditure $P_{\text{average}}(t)$ may vary over time. The total revenue is given by:

$$R(t) = P_{\text{average}}(t) \cdot N(t) \quad (2)$$

$P_{\text{average}}(t)$ is the average expenditure per visitor, which includes ticket fees, accommodation, dining, and transportation costs. This expenditure may be influenced by seasonality and tourism policies.

$N(t)$ is the number of visitors, meaning that total revenue increases as visitor numbers increase.

Figure 1 below shows the flow of visitors over a period of time.

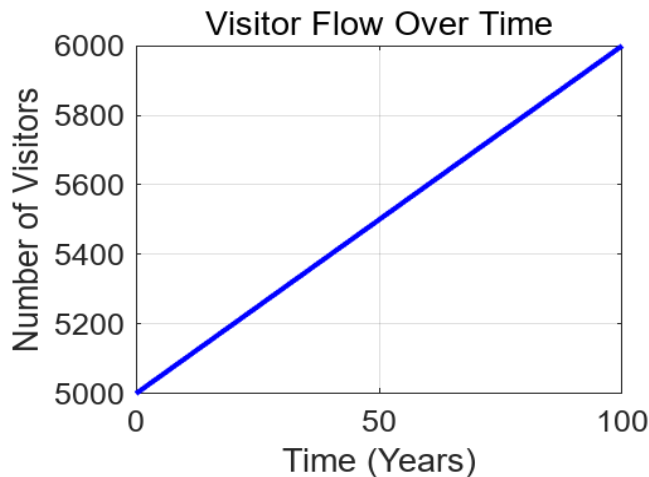


Figure 1. Visitor traffic over time

2.3. Environmental impact model

The environmental impact $E(t)$ is assumed to be directly proportional to the number of visitors $N(t)$. Suppose each visitor contributes a constant environmental impact β , then the environmental impact can be expressed as:

$$E(t) = \beta \cdot N(t) \tag{3}$$

β is the environmental impact factor per visitor, taking into account greenhouse gas emissions, ecological damage, and other environmental factors.

One of the optimization objectives is to minimize the environmental impact $E(t)$ by controlling visitor numbers and adopting environmental protection measures.

2.4. Resource consumption and infrastructure demand model

The number of visitors $N(t)$ directly affects local resource consumption and infrastructure demand. Let's assume that each visitor consumes resources at a rate γ and demands infrastructure at a rate δ . The total resource consumption and infrastructure demand are then given by:

$$\begin{aligned} R_c(t) &= \gamma \cdot N(t) \\ I(t) &= \delta \cdot N(t) \end{aligned} \tag{4}$$

$R_c(t)$ is the total resource consumption, which increases as the number of visitors increases, including water, electricity, waste management, and other resources. $I(t)$ is the infrastructure demand, which increases as more visitors require more transportation, accommodation, public services, and facilities.

The model must balance resource consumption and infrastructure demand to avoid overloading these systems.

2.5. Expenditure plan and fund allocation model

With the growth in tourism revenue, city can reinvest additional income into environmental protection, infrastructure development, and community projects. A portion of the total revenue $R(t)$ is allocated to the following three expenditures:

Environmental protection expenditure $S_{env}(t)$.

Infrastructure development expenditure $S_{infra}(t)$.

Community development expenditure $S_{comm}(t)$.

The expenditure model is as follows:

$$\begin{aligned} S_{env}(t) &= \lambda_1 \cdot R(t) \\ S_{infra}(t) &= \lambda_2 \cdot R(t) \\ S_{comm}(t) &= \lambda_3 \cdot R(t) \end{aligned} \quad (5)$$

$\lambda_1, \lambda_2, \lambda_3$ are expenditure proportions, representing the income allocation to environmental protection, infrastructure, and community development, where $\lambda_1 + \lambda_2 + \lambda_3 = 1$.

These expenditures will feed back into the model in the following ways:

Environmental protection expenditure: Reduces environmental load $E(t)$ and helps to preserve the ecosystem.

Infrastructure development expenditure: Increases resource capacity and infrastructure, supporting the sustainable development of tourism.

Community development expenditure: Enhances local residents' acceptance of tourism and reduces social tensions, ensuring social stability.

2.6. Optimization objectives and constraints

2.6.1 Optimization objectives

The optimization objectives of the model are:

Maximize total revenue $R(t)$, while ensuring sustainable development and improving economic benefits.

(2) Minimize environmental impact $E(t)$, by controlling visitor numbers and implementing environmental protection measures.

(3) Maximize social welfare, by ensuring a balanced allocation of funds for infrastructure, environmental protection, and community development.

2.6.2 Constraints

(1) Upper limit on visitor flow: Due to environmental and resource constraints, we set an upper limit N_{max} on the number of visitors, i.e.:

$$N(t) \leq N_{max} \quad (6)$$

(2) Resource consumption limit: Due to the limited availability of resources, the total resource consumption $R_c(t)$ must not exceed the maximum supply R_{max} , i.e.:

$$R_c(t) \leq R_{max} \quad (7)$$

(3) Infrastructure capacity limit: To prevent overcrowding and overload of facilities, infrastructure demand $I(t)$ must not exceed the capacity I_{max} , i.e.:

$$I(t) \leq I_{max} \quad (8)$$

(4) Expenditure Constraints: The total revenue $R(t)$ must be divided among the expenditures, where:

$$S_{env}(t) + S_{infra}(t) + S_{comm}(t) = R(t) \tag{9}$$

2.7. Genetic algorithm model

1.Objective: Maximize tourism revenue using a population of potential solutions (visitor distributions).

$$\text{Maximize } Z = \sum_{i=1}^n c_i x_i \tag{10}$$

Where: x_i are the visitor numbers at each spot, subject to constraints.

2.Constraints

Visitor capacity constraints: Each tourist spot has a maximum capacity.

$$x_i \leq \text{capacity}_i \quad \forall i \tag{11}$$

Total visitor constraints: Total visitor numbers must be equal to the desired number.

$$\sum_{i=1}^n x_i = \text{Total visitors} \tag{12}$$

Figure 2 below shows the evolutionary visualization of the genetic algorithm fitness.

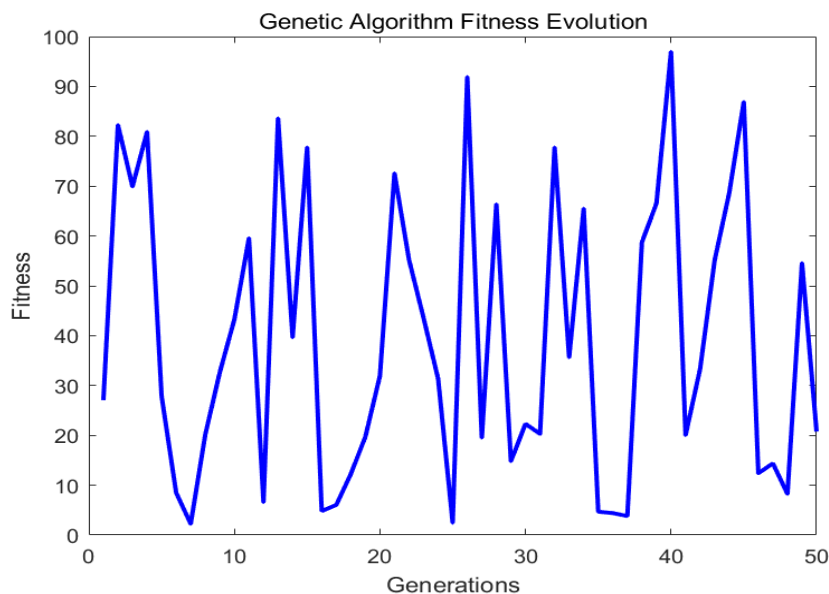


Figure 2. Genetic algorithm fitness evolution

3. TOURIST ATTRACTIONS MANAGEMENT ANALYSIS

3.1. Visitor flow model

For multiple tourist attractions, the visitor flow $N_i(t)$ at each attraction is influenced by ticket prices $P_i(t)$, the attraction's appeal A_i , and seasonal effects $S_i(t)$. The change in visitor flow is governed by the following differential equation:

$$\frac{dN_i(t)}{dt} = \alpha_i \cdot A_i \cdot S_i(t) \cdot P_i(t)^{-1} \cdot N_i(t) \quad (13)$$

α_i is the sensitivity coefficient to ticket prices for visitors. A_i is the attraction's appeal coefficient (e.g., the fame, uniqueness of the attraction). $S_i(t)$ is the seasonal function, representing the variation in visitor flow throughout the year, with higher visitor numbers during peak seasons. $P_i(t)$ is the ticket price, which may vary with policies or seasons. $N_i(t)$ is the number of visitors at attraction i at time t .

3.2. Resource consumption and infrastructure demand model

The visitor flow $N_i(t)$ at each attraction directly affects the resource consumption $R_i(t)$ and infrastructure demand $I_i(t)$. It is assumed that both resource consumption and infrastructure demand are linear functions of the visitor number:

Resource Consumption Model:

$$R_i(t) = \beta_i \cdot N_i(t) \quad (14)$$

Infrastructure Demand Model:

$$I_i(t) = \gamma_i \cdot N_i(t) \quad (15)$$

β_i is the rate of resource consumption per visitor (e.g., water, electricity, waste management). γ_i is the rate of infrastructure demand per visitor (e.g., transportation, accommodation, public services). $R_i(t)$ and $I_i(t)$ are the total resource consumption and infrastructure demand at attraction i at time t .

3.3. Environmental impact model

Each visitor causes environmental impacts, which are proportional to the number of visitors. The environmental impact $E_i(t)$ is given by:

$$E_i(t) = \delta_i \cdot N_i(t) \quad (16)$$

δ_i is the environmental impact coefficient per visitor (e.g., carbon emissions, ecological damage). $E_i(t)$ is the environmental impact at attraction i at time t .

3.4. Revenue and expenditure model

Revenue for each attraction is generated from the number of visitors and the ticket price. The total revenue across all attractions is:

Total Revenue Model:

$$R_{\text{total}} = \sum_{i=1}^n p_i(t) \cdot N_i(t) \quad (17)$$

Expenditure Allocation Model:

$$E_{\text{env}} = f_1 \cdot R_{\text{total}}, \quad E_{\text{infr}} = f_2 \cdot R_{\text{total}}, \quad E_{\text{comm}} = f_3 \cdot R_{\text{total}} \quad (18)$$

Where f_1, f_2, f_3 are the proportions of total revenue allocated to environmental protection, infrastructure development, and community programs, respectively, and satisfy the condition $f_1 + f_2 + f_3 = 1$.

3.5. Tourism diversion model

To prevent over-congestion at certain attractions, we can adjust ticket prices $P_i(t)$ and promotional strategies to guide the distribution of visitors. Let the diversion coefficient for each attraction be $f_i(t)$, where $f_i(t) \in [0,1]$, and the visitor flow is adjusted as:

$$N_i(t) = N_i(t) \cdot f_i(t) \quad (19)$$

$f_i(t)$ is the diversion coefficient, which can be controlled by increasing ticket prices at popular attractions or promoting less-visited attractions.

3.6. Optimization objectives and constraints

3.6.1 Optimization objectives

Maximize total revenue:

$$\max R_{\text{total}} = \sum_{i=1}^n p_i(t) \cdot N_i(t) \quad (20)$$

Minimize environmental impact:

$$\min \sum_{i=1}^n E_i(t) \quad (21)$$

Balance resource consumption and infrastructure demand:

$$\sum_{i=1}^n R_i(t) \leq R_{\text{max}}, \quad \sum_{i=1}^n I_i(t) \leq I_{\text{max}} \quad (22)$$

3.6.2 Constraints

The number of visitors at each attraction cannot exceed its maximum capacity:

$$N_i(t) \leq N_{\text{max}} \quad (23)$$

The total resource consumption and infrastructure demand must not exceed the maximum capacity for each attraction:

$$R_i(t) \leq R_{\text{max}}, \quad I_i(t) \leq I_{\text{max}} \quad (24)$$

Revenue must be reasonably allocated:

$$f_1 + f_2 + f_3 = 1 \tag{25}$$

3.7. Simulated annealing algorithm

Simulated Annealing (SA) is another algorithm suitable for complex, nonlinear optimization problems, particularly when the search space is large and contains many local optima. SA mimics the physical process of heating and cooling, where the algorithm explores a wide range of solutions at the beginning and gradually focuses on refining the best solutions. SA is useful when optimizing tourism management in Juneau as it allows for exploration of different strategies and fine-tuning visitor allocations and resource usage.

Objective: Maximize tourism revenue while minimizing environmental impact and resource consumption.

Process: The algorithm randomly explores solutions by altering visitor distribution and accepts or rejects changes based on a cooling schedule (temperature function) to avoid local optima.

Constraints: Similar to LP and GA, with additional flexibility in managing nonlinear constraints and multiple optimization goals.

SA is ideal for complex scenarios where finding the global optimum is difficult due to a large number of variables and interactions between them.

Figure 3 below visualizes the simulated annealing temperature decay.

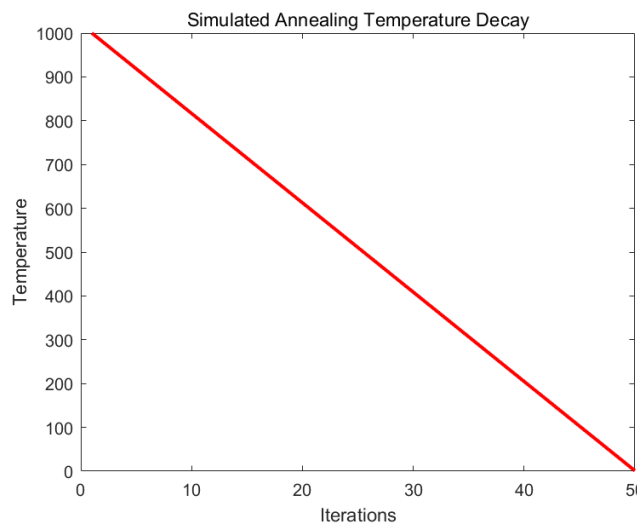


Figure 3. Simulated annealing temperature decay

4. CONCLUSIONS

The sustainable tourism management model proposed in this paper realizes the dynamic regulation and multi-objective balance of the tourism system through multi-dimensional mathematical modeling and intelligent algorithm co-optimization. The study shows that the environmental impact coefficient and resource consumption rate parameters introduced in the differential equation model effectively quantify the dynamic relationship between tourists' activities and ecological carrying capacity; the genetic algorithm validates the revenue optimization effect under the attraction capacity constraints through the visualization of the fitness function, and its population evolution mechanism is able to break through the limitation

of the locally optimal solution; and the simulated annealing algorithm's temperature attenuation strategy shows a stronger global search capability when dealing with nonlinear constraints, and achieves the environmental-resource-economic balance. The temperature attenuation strategy of the simulated annealing algorithm shows stronger global search ability when dealing with nonlinear constraints and realizes the multi-objective optimization of environment-resource-economy. The model framework shows good robustness in dynamic environments, and the constraint handling strategy and multi-objective optimization mechanism in the algorithm design provide a scalable technical solution for decision-making of complex systems.

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