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SUSTAINABILITY TOURISM OPTIMIZATION BASED ON GENETIC ALGORITHM

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Abstract: This paper aims to develop an optimization model to balance tourist numbers, tourism revenue, and environmental impact, ensuring sustainable tourism development. Using a genetic algorithm, we optimize the model to maximize revenue and tourist flow while minimizing environmental impact and infrastructure pressure. Additionally, we propose a reinvestment plan where optimized tax revenue is allocated to environmental protection and infrastructure, forming a feedback loop that enhances sustainability. We successfully balances tourism revenue, tourist flow, and environmental impact in Juneau using an optimization model. The extra expenditure plan also ensures funding for long-term environmental and infrastructure sustainability, making this model a valuable reference for both Juneau and other destinations facing similar challenges.
Keywords: Sustainable tourism; Genetic algorithm; Feedback loop; Sensitivity analysis

1 INTRODUCTION

With the rapid growth of global tourism, over-tourism has emerged as a prevalent challenge for many popular destinations, especially in environmentally sensitive areas. However, the effectiveness of these measures remains uncertain, and there are differing opinions among residents regarding these policies. Thus, finding a way to foster economic growth while preserving the environment and enhancing social well-being has become a critical challenge[1]. This paper aims to develop a comprehensive sustainable tourism management model that optimizes the balance between visitor numbers, revenue, environmental protection, and social impact. The goal for Juno, Alaska is to optimize the balance between the number of tourists, total revenue, and environmental protection. The model considers factors such as tourist flow, revenue, environmental carrying capacity, and infrastructure strain. The model helps inform effective tourism management strategies for Juneau and offer valuable insights for other destinations facing over-tourism. The memorandum to the Juno Tourism Board should outline the model's predic- tions, the effects of different management measures, and suggest ways to optimize the balance between tourist numbers, revenue, and environmental protection to ensure the sustainable development of tourism.

2 PRELIMINARY

2.1 Assumption

The number of tourists is directly proportional to the environmental impact. Infrastructure is linearly related to the number of tourists. The tax expenditure coefficient is fixed. Resident satisfaction is linearly related to both the number of tourists and environmental impact[2]. All tourist sites have the same maximum carrying capacity. No external interventions are considered.

2.2 Notations

The symbols used in the paper are listed in Table 1.

Table 1 Symbols Notations

Symbols	Notation
et	The environmental impact in the time period
xt	The number of tourists in the time period
Ct	The expenditure per tourist
tt	The tourism output per tourist.
xij	The raw value of indicator i for region j

3 Sustainable tourism management

The concept of sustainable development was first introduced in 1987 by the World Com- mission on Environment and Development, defining it as a development model that "meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable tourism extends this concept, applying sustain- able development principles to the tourism industry[3]. This paper defines optimization factors and constraints based on scientific, comprehensive, targeted, and practical criteria to build a multi-objective optimization model (see Figure 1), which addresses the tourism management issues in Juno, Alaska.

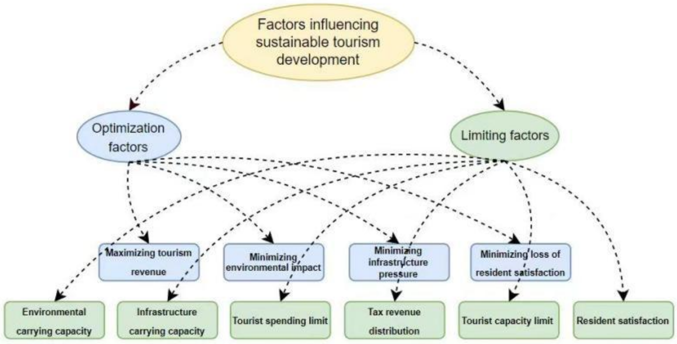

Figure 1 Optimization Factors and Constraints

3.1 Optimization Factors

The objective function represents the optimization factors mathematically. The model seeks to achieve sustainable tourism by balancing economic benefits with environmental impact[4], infrastructure pressure, and social effects on the community. The objective is to maximize revenue, minimize environmental impact, reduce infrastructure strain, and limit resident dissatisfaction. Tourism revenue, generated from tourist spending, directly determines the economic benefits of tourism[5]. By optimizing tourist numbers, tax policies, and infrastructure, total revenue can be increased. Based on relevant research and literature, we define the following:xt represents the number of tourists in the t-th time period. Ct represents the expenditure per tourist; tt represents the tourism output per tourist; pt and it represent the tax expenditure coefficients for environmental protection and infrastructure development, respectively, with values assumed to be 0.1.

Environmental impact is determined by the number of tourists and the environmental burden each tourist imposes. It is assumed that each tourist has an environmental impact coefficient α. Based on relevant research and literature[6,7], we define the following: et represents the environmental impact in the t-th time period. a represents the environmental impact coefficient per tourist. Resident satisfaction is influenced by the number of tourists, environmental impact, and infrastructure pressure. To avoid dissatisfaction among residents, we aim to minimize the loss of resident satisfaction.

3.2 Optimization Factors

In the optimization model, the constraint conditions ensure that the decisions are feasible in practice and meet real-world requirements. They limit the range of decision variables to ensure that the use of resources, environment, and infrastructure does not exceed their carrying capacities. Through these constraints, the model can balance multiple objectives and avoid unreasonable outcomes, thus achieving a sustainable optimization solution. The number of tourists in each time period can not exceed the maximum carrying capacity of the tourist attractions. This constraint ensures that the attractions do not host more tourists than their capacity, preventing overcrowding or excessive resource consumption. The number of tourists in each time period cannot exceed the environmental carrying capacity of the tourist attractions[8]. This constraint ensures that tourism activities at the attractions do not impose an unsustainable burden on the environment. The number of tourists in each time period cannot exceed the infrastructure carrying capacity of the tourist attractions (such as transportation, accommodation, sanitation facilities, etc.). This constraint ensures that the infrastructure does not become overloaded.

3.3 NSGA-II Algorithm Solutions

The model is solved using the NSGA-II algorithm[9], which is capable of optimizing multiple objectives simultaneously, such as maximizing revenue and minimizing risks. This approach overcomes the limitations of traditional optimization methods. By using non- dominated sorting and crowding distance selection, the NSGA-II algorithm ensures the diversity of solutions, avoids local optima, and can handle complex constraints, ensuring the feasibility of the solutions. Moreover, NSGA-II's flexibility and scalability make it suitable for various complex multi-objective optimization problems, making it an ideal choice for tourism management optimization. By applying the NSGA-II algorithm, we obtained the optimal solution for the objective function. The Pareto front was then plotted using this algorithm (see Figure 2)

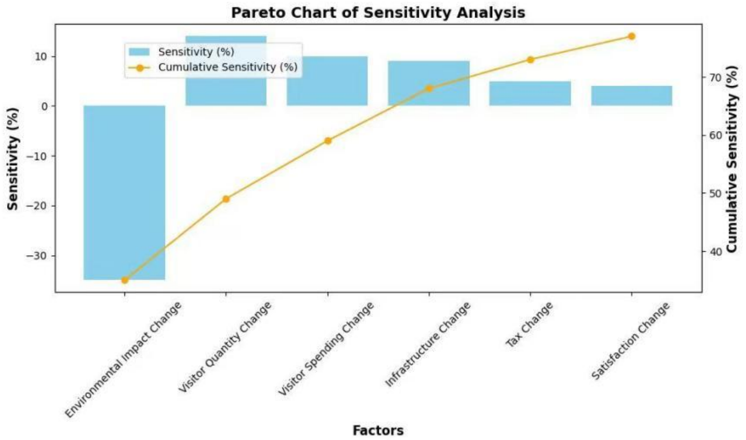

Figure 2 The Pareto Front

The number of tourists and their spending are the primary drivers of revenue growth. However, an increase in these factors can lead to greater environmental strain, so a balanced approach between tourist growth and environmental carrying capacity is essential. The rising environmental impact significantly reduces revenue, highlighting the critical role of environmental protection in sustainable tourism management. Therefore, effective environmental measures must be incorporated into policy to prevent the negative effects of environmental degradation on revenue. While infrastructure improvements do have a positive impact on revenue, their effect is relatively small. Thus, although infrastructure development is important, it should be considered in conjunction with other factors. Resident satisfaction has an indirect effect on revenue. Though its sensitivity is lower, enhancing resident satisfaction is vital for maintaining long-term. Community support and preventing social issues caused by over-tourism. Tax policies must be reasonably allocated to support infrastructure and environmental protection, ensuring sustainable tourism funding.

4 Sensitivity Analysis

By performing sensitivity analysis, we can identify which input variables have the greatest impact on the model's results, thereby facilitating more targeted decision-making and optimization[10]. According to Tan Fengjie, in large and complex systems, numerous uncertain factors can influence the model. Sensitivity analysis helps to treat variables with minimal impact as fixed, reducing uncertainty and computational time, ultimately improving efficiency. In this paper, both univariate sensitivity analysis and global sensitivity analysis are applied to assess the influence of key factors in the sustainable tourism model for Juno, Alaska. By analyzing the variation in different factors, this study identifies the most critical variables and provides scientific evidence for policy optimization.

4.1 Univariate and global sensitivity Analysis

Univariate sensitivity analysis is one of the most commonly used methods in sensitivity analysis. The basic approach involves changing one input variable at a time and observ- ing its effect on the model's output. Specifically, we examine the impact of the following six key factors on revenue changes.

Global sensitivity analysis considers the joint variation of multiple variables and assesses how their interactions affect the model's output. In this study, we calculated the variations in factors such as tourist numbers, tourist spending, environmental impact, infrastructure development, resident satisfaction, and tax revenue, and conducted a compre hensive analysis of these factors. Global sensitivity analysis provides insights into the contribution of each factor to the overall model results.

4.2 Heatmap and Bar Chart Analysis

To gain a deeper understanding of the factors that influence sustainable tourism in Juno, Alaska, this study uses two types of visualizations: heat maps and bar charts (see Figure 3 and Figure 4). These charts provide valuable information on the sensitivity of the factors.

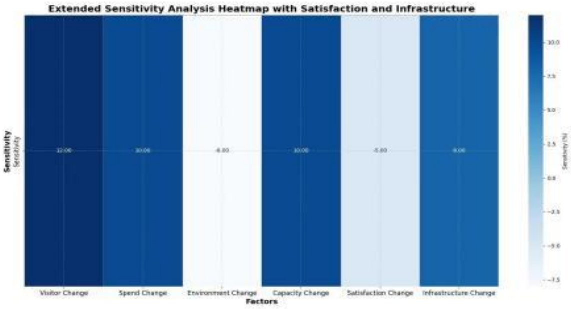

Figure 3 Heatmap of Sensitivity Analysis

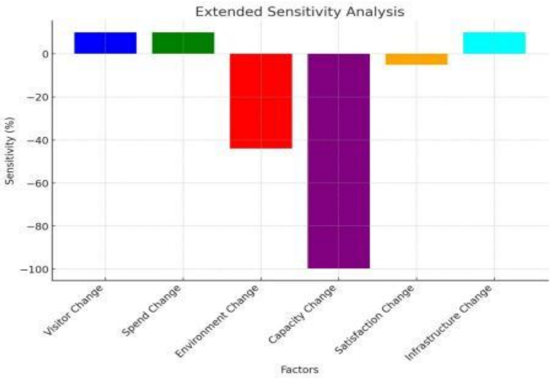

Figure 4 Bar Chart of Sensitivity Analysis

Based on the above results, we further quantified the impact of each factor on revenue changes. This table combines the rate of change of each factor, the initial revenue, the changed revenue, the percentage change in revenue, and the sensitivity value, providing a more comprehensive analysis and understanding of how these factors collectively influence revenue.

Overall, tourist numbers and spending are the key drivers of sustainable tourism growth in Juno, Alaska, while environmental protection and resident satisfaction are critical constraints that must be prioritized. Through effective management and optimization of these factors, tourism development can be effectively promoted while minimizing its negative impact on the environment and ensuring high resident satisfaction.

4.3 Gross Analysis

The model considers multiple factors, such as tourism revenue, environmental impact, infrastructure pressure, and resident satisfaction, providing a thorough evaluation of key issues in tourism management. By quantifying multiple influencing factors using AHP and TOP- SIS methods, the model offers specific optimization solutions for decision-makers, making it highly practical. It is adjusted to optimize strategies for different types of tourism destinations, making it suitable for both over-tourism and under-tourism scenarios. By using NSGA-II and genetic algorithms, the model can optimize multiple objectives simultaneously, overcoming the limitations of traditional optimization methods and ensuring global optimal solutions. The model's framework is versatile and can be applied to other cities or regions for sustainable tourism management, offering good scalability.

5 CONCLUSION

This paper successfully developed a comprehensive sustainable tourism management model for Juneau, Alaska, addressing the challenges of over-tourism, environmental degradation, and infrastructure strain. By leveraging a genetic algorithm, the model optimizes tourist numbers, revenue, and environmental impact, achieving a balanced approach to sustainable tourism development. The inclusion of a reinvestment plan, where tax revenue is allocated to environmental protection and infrastructure, creates a positive feedback loop that enhances long-term sustainability. Sensitivity analysis highlights the critical factors of environmental capacity, infrastructure capacity, and tourist spending ability, providing actionable insights for policymakers. This paper serves as a valuable reference for both Juneau and other destinations facing similar challenges, offering a framework for balancing economic benefits with environmental and social responsibilities..

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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