Sustainable Tourism in Juneau Based on a Multi-objective Model

Jialiang Yang*

School of Engineering, Rice University, Houston, USA, 77005

*Corresponding author: jy105@rice.edu

Abstract. Juneau, Alaska, USA has become a popular tourist destination in recent years. While tourism spurs economic growth, it also brings significant pressure on the environment and local infrastructure. To help address the sustainability issues related to tourism, a multi-objective dynamic programming model is constructed that optimizes economic, environmental, and social outcomes for tourism management. Specifically, this paper builds three models corresponding to the three objectives: the economic model, the environment model, and the social impact model. The tourist volume is estimated through the tourist demand model. This paper stimulates the results over a 5-year period by the model and recommends a dynamic tax rate in a range of 3.2% to 5.0%, with a schema of government expenditures with large portions of environmental protection and infrastructure construction. This study can inform evidence-based strategies to balance tourist growth and sustainable goals. The findings can serve as a model for other communities facing challenges from tourism.

Keywords: Multi-objective Model, Dynamic Programming, Sustainable Tourism.

1. Introduction

Juneau, Alaska has become a popular choice for visitors with its glacier, wild animals, museums, and historic districts. This remote town with a population of about 30,000 set a record of 1.6 million cruise passengers in 2023. While the huge number of tourists has brought unprecedented development for the local economy, people should attach importance to the negative environmental and social impacts simultaneously. A lot of tourist destinations, in addition to Juneau, has been suffering from the costs of over-tourism. Therefore, sustainable tourism has become a topic with growing concerns. Schuler and Pearson's case study from Juneau demonstrated that whale-watching tourism had measurable conservation benefits, showing the potential of ecotourism in sustainability promotion [1].

Banerjee et al. proposed an approach to promoting sustainability by including carbon emissions, destination popularity, and seasonal demand into tourist recommender systems [2]. Baloch et al. offered a framework for ecotourism focused on environmental protection in the context of Pakistan [3]. In addition, Jia and Liu utilized a quantitative approach with analytic hierarchy processes and genetic algorithms to support decision-making in tourism management [4]. Yoshioka constructed a mathematical model with the mean field Jacobi process to investigate the dynamics in tourism sustainability [5]. Meanwhile, new approaches such as astrotourism were presented to meet the long-term sustainability goals [6]. At the operational level, Naqvi et al. examined the implementation of sustainable tourism practices in Maldivian resorts, using sustainability principles and a Triple Bottom Line approach [7]. Broader conceptual work includes a review by Pérez and López, identifying trends such as the rising importance of data-driven planning and destination resilience [8]. Alam et al. investigated structural and policy-related constraints in South Asia, while Bindawas studies the relationship between workforce skills and the achievement of Sustainable Development Goals [9-10].

Several limitations still exist despite these contributions. Most existing studies focus on either broad theoretical frameworks or specific applications in isolated settings. They lack integration across environmental, social, and economic metrics locally. Moreover, empirical studies of sustainability strategies remain limited, especially in small-scale destinations such as Juneau. This research aims to bridge these gaps by constructing a multi-objective model accounting for economic, sociological, and environmental factors to achieve the goals of sustainable tourism.

2. The basic fundamental of the multi-objective model

2.1. The tourist demand model

The tourist demand model estimates the number of visitors to Juneau over time. This model accounts for economic conditions, taxation policies, and external demand shocks. The number of tourists is influenced by the tourism growth rate, the tax rate applied to tourism revenue, and random demand shocks that reflect external influences. Furthermore, the model includes the demand elasticity parameter, which captures the negative impact of taxation on tourism growth. Specifically, the formulation assumes that tourism demand grows at a predictable rate, where tax increases result in reduced tourist arrivals based on the effect of elasticity. The inclusion of stochastic demand shocks accounts for uncertainties such as economic downturns or geopolitical events, ensuring a more realistic model representation according to economic theories.

$$T(t) = T(t-1)(1 + g(t) - \gamma\tau(t) + \delta(t)) \tag{1}$$

where $T(t)$ is the number of tourists in year t, $g(t)$ is the tourism growth rate, γ is the demand elasticity parameter, $\tau(t)$ is the tax rate, and $\delta(t)$ is the random demand shock.
The change of tourism demand is affected by government policies such as visitor caps and promotional efforts. The model incorporates policy-driven adjustments to the tourism growth rate.

$$g(t) = g_{base} - \beta C_{max}(t) + \theta M(t) \tag{2}$$

$$M(t) = \lambda G(t) \tag{3}$$

where g_{base} represents the baseline tourism growth rate, β represents a sensitivity parameter, $C_{max}(t)$ represents a visitor cap, θ represents the effectiveness of marketing and promotional efforts in raising tourism demand, and $M(t)$ represents a proportion of government expenditures on tourism. The formula shows that a higher cap results in reduced growth due to negative effects of tourism such as perceived congestion, and a lower cap can help developing sustainable tourism. Government expenditures on tourism are implemented to increase demand by increasing attractiveness and public visibility.

2.2. The economic benefit model

The economic benefit model takes into account the tourism revenue and the tourism cost. Tourism revenue is primarily dependent on the number of tourists and their average spending. The total tourism revenue is modeled as a function of the number of tourists, with a constant of the average revenue per tourist.

$$R(t) = rT(t) \tag{4}$$

where $R(t)$ is the total tourism revenue, r means the average revenue per tourist, and $T(t)$ demonstrates the number of tourists.

In addition to the revenue, the operational costs associated with tourism must be simultaneously considered to assess net economic benefits. The total cost is composed of fixed costs and variable costs that scale with the number of tourists.

$$C(t) = c_{fixed} + c_{variable}T(t) \tag{5}$$

where $C(t)$ is the operational tourism cost, c_{fixed} means the fixed cost, $c_{variable}$ means the variable cost, and $T(t)$ represents the number of tourists.

After modeling the revenue and the cost, the net profit from tourism can be formulated by subtracting the cost from the revenue.

$$P(t) = R(t) - C(t) \tag{6}$$

where $P(t)$ is the net profit, $R(t)$ means the revenue, and $C(t)$ represents the operational cost.

2.3. The environment impact model

The environment impact is measured by an environment index. The environmental index is computed by integrating various environmental variables, including temperature, snowfall, ocean temperature, and ocean pH level. The methodology consists of several key steps. First, each environmental variable is normalized to the range from 0 to 1 to eliminate unit bias.

$$x_{normalized} = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{7}$$

where x is the original value of the variable, $x_{normalized}$ is the normalized variable, x_{max} is the max value of the variable, and x_{max} is the min value of the variable.

Then different weights are assigned to each variable according to their effect on environment quality. Temperature and ocean temperature, which have negative impacts, are assigned a weight of −1. Snowfall and ocean pH, which have positive impacts, are assigned a weight of +1. The importance of each variable is determined using entropy- based weighting. The use of entropy weighting prioritizes variables with greater variability, ensuring that the index remains sensitive to significant environmental changes.

$$e_i = -\sum p_i \log(p_i) \tag{8}$$

$$\omega_i = \frac{1 - e_i}{\sum(1 - e_i)} \tag{9}$$

where e_i is the entropy of the variable, p_i means the normalized value of the variable, and ω_i represents the entropy weight of the variable i.

Last, the environmental index is calculated by combining the normalized and weighted environmental data.

$$E_i = \frac{\sum \omega_i x_i - E_{min}}{E_{max} - E_{min}} \tag{10}$$

where E_i is the environment index, ω_i is the entropy weight of the variable, x_i is the normalized value, E_{min} is the min environment index, and E_{max} is the max environment index.

To control the negative effects of tourism on the environment, a fraction of government revenue from tourism taxation is reinvested into environmental conservation. The improved environmental index is calculated by applying government intervention.

$$E_{sub}(t) = E(t) + \alpha M(t) \tag{11}$$

where $E_{sub}(t)$ is the improved environment index, $E(t)$ means the environment index, α stands for the sensitivity of environment to government expenditures, and $M(t)$ represents the government expenditures.

This study assumes that the environment has a natural recovery rate that helps restore its quality over time. However, tourism activities continuously exert pressure on the ecosystem at the same time, as a function of the environmental harm factor caused by tourism and the carrying capacity.

$$E(t+1) = E_{sub}(t) + r(1 - E_{sub}(t)) - h(\frac{T(t)}{T_{max}}) \tag{12}$$

where r is the natural recovery rate, h means the environment degradation factor, $T(t)$ stands for the tourist number, and T_{max} represents the max tourist capacity.

2.4. Resident satisfaction model

Resident satisfaction is influenced by the number of tourists, the environment index, and the tax rate applied to tourism revenue. This study assumes that an optimal level of tourism exists, beyond which further increases in the tourist volume negatively impacts resident satisfaction. In addition, increased taxation on tourism revenue leads to lower resident satisfaction due to potential financial burden and rising costs.

$$Q(t) = \omega_1 \left(1 - \frac{|T(t) - T_{opt}|}{T_{opt}}\right) + \omega_2 E(t) - \omega_3 \tau(t) \tag{13}$$

where $Q(t)$ is the residents' satisfaction, ω is the weighting coefficient for each factor, T_{opt} is the optimal level of tourist volume, $E(t)$is the environment index, and $\tau(t)$ is the tax rate on tourism revenue.

2.5. Model solving using dynamic programming

The model in this paper aims to maximize the profit derived from tourism while ensuring environment sustainability and maintaining resident satisfaction.

$$\max_{\tau,M}(P(t) + \omega_1 E(t) + \omega_2 Q(t)) \tag{14}$$

where τ is the tax rate, and M represents the government expenditures on tourism.

The optimization is subject to constraints in economic, environmental, and social dimensions.

$$T(t) \le C_{max} \tag{15}$$

$$E(t) \le E_{min} \tag{16}$$

$$Q(t) \ge Q_{min} \tag{17}$$

$$M(t) \le G(t) \tag{18}$$

where C_{max} is the maximum carrying capacity of Juneau's infrastructure, E_{min} is the minimum acceptable environment index to ensure sustainability, and Q_{min} is the minimum threshold for resident satisfaction.

To get a solution to the model, the system of state transition equations needs to be solved using dynamic programming. Recursion is applied to compute the optimal solution by solving the equations iteratively. At last, the solution involves tracing back the optimal government decisions.

3. Results

3.1. The simulation of tourist volume

The data related to the tourism in Juneau is obtained from City and Borough of Juneau (CBJ)'s *Tourism Survey Report 2023*. Then an annual tourist count is simulated over a five-year period (from 2024 to 2028). The model forecasts a controlled growth in annual tourist numbers in Juneau from 1.537 million in 2024 to 1.683 million in 2028, as shown in Table 1. This reflects the successful enaction of adaptive taxation and policy feedback to manage tourist inflows while maintaining economic viability. Notably, Year 3 features a slight drop in growth due to a temporary increase in tourism tax to 5.0%. This responsiveness shows the elasticity of tourist demand with respect to price, which is an important insight for balancing economic benefit with sustainability.

Moreover, the government's strategy of allocating advertising funds early in the five-year period helps accelerate recovery from post-COVID downturns, with promotional efforts declining over time as the tourist base stabilizes. In Year 5, the tourist volume reaches at a peak of 1.683 million, approaching the carrying capacity of Juneau's tourism.

Table 1. Simulation of tourist volume over 5 years

Year	Tourist volume (thousand)
1	1537
2	1548
3	1522
4	1583
5	1683

3.2. The simulation of environment index

The data of environment qualities, including temperature, snowfall, ocean temperature, and ocean pH level, are collected from *Juneau Climate Trends and Data* by Alaska Climate Research Center. As shown in Table 2, the environmental index demonstrates significant improvement, rising from 0.029 in Year 1 to 0.181 in Year 5. This reflects the compounding effects of environmental investment and moderated tourist growth, achieving the goal of sustainable tourism. Government spending on ecological protection is shown to mitigate environmental degradation across key indicators, including temperature, snowfall levels, ocean temperature, and ocean pH, which are modeled as components of a composite environment index.

In particular, the decision to increase environmental spending each year reflects a long-term commitment to restoring ecological balance. The modeled index reveals a continuous and stable improvement pattern. These results underline the importance of sustained investment, even when immediate benefits are not visible, and validate the design of environmentally conditional spending policies.

Table 2. Simulation of environment index over 5 years

Year	Environment index
1	0.029
2	0.076
3	0.123
4	0.170
5	0.181

3.3. The simulation of residents satisfaction

As shown in Figure 1, residents’ satisfaction increases steadily across the five-year horizon, from 0.882 to 0.917. The model incorporates three primary drivers of satisfaction: environmental quality, tourist volume, and the benefits received through tourism revenue. Year 3 records a minimum in satisfaction to 0.832, attributable to heightened taxation pressure, but this is soon reversed as tourist numbers and environmental quality improve, and tax rates decline in subsequent years.

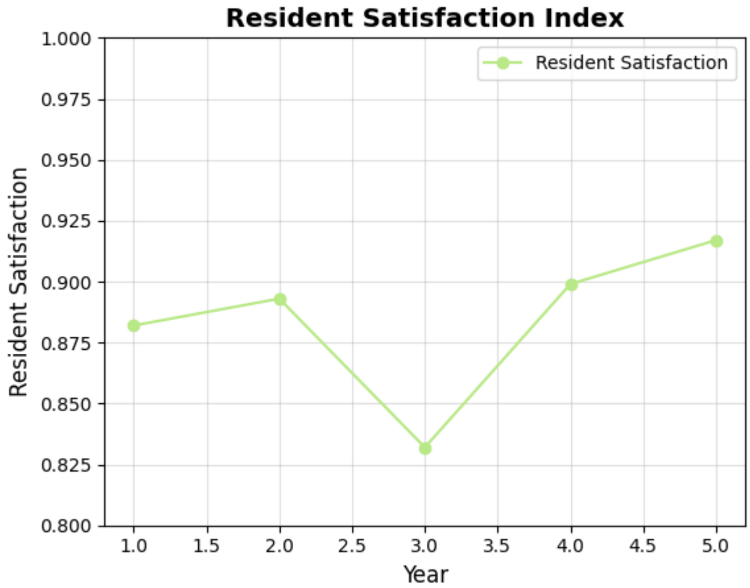

Figure 1. Simulation of resident satisfaction over 5 years

The result demonstrates that satisfaction is more sensitive to environmental degradation and congestion than to taxation, given that tax revenues are reinvested into public services. The increase in resident satisfaction validates the assumption that higher environmental and infrastructural conditions can outweigh short-term economic costs to local residents. This also implies that public communication of policy benefits is essential to maintain social license for tourism.

3.4. The optimal government decisions

The optimal level of government's policy actions is demonstrated in Figure 2, which exhibits dynamic adaptation throughout the simulation. Tax rates are adjusted annually, peaking at 5.0% in Year 3 before decreasing to 3.2% in Year 5. These changes are strategically designed to counterbalance tourist numbers and protect resident satisfaction. Revenue generation from the taxation ranges from $11.71 million to $16.6 million, also shown in Figure 2, enabling a reallocation toward multiple sustainability dimensions.

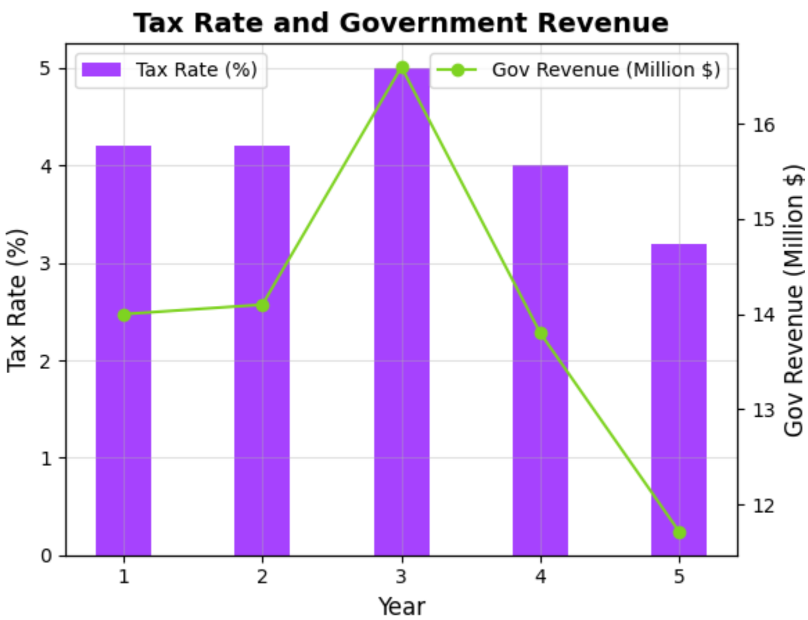

Figure 2. Prediction of optimal government decision over 5 years

In addition, this paper investigates the allocation plan for government expenditures on promoting tourism. It is assumed that the expenditures are divided into four main categories: environmental protection and recovery, infrastructure development, subsidies to reduce financial burdens, and advertising to promote tourism. The distribution of these expenditures is given by our model's predictions, taking into account the priorities and challenges faced in each year.

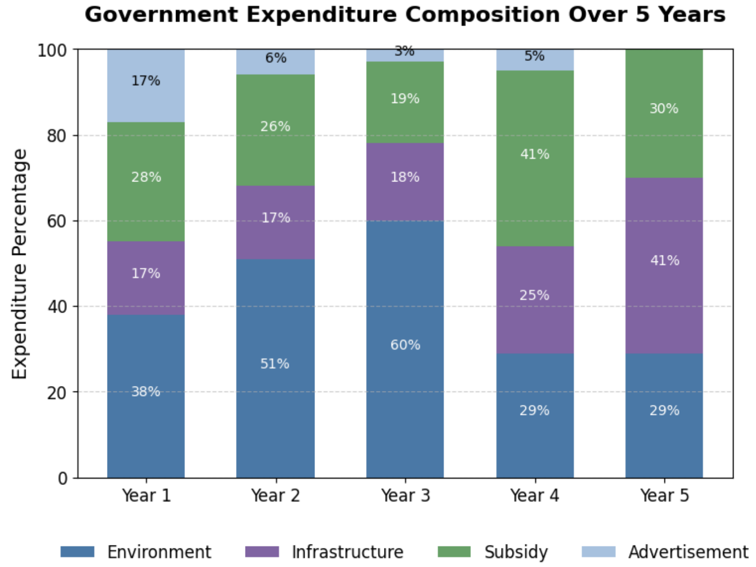

Figure 3. Composition of government expenditures

Investment in environmental protection increases significantly over the years, as shown in Figure 3, reflecting the importance of reducing the ecological impacts of tourism. These funds are directed toward projects such as preserving the Mendenhall Glacier, restoring biodiversity, and addressing pollution caused by tourist activities. Spending on infrastructure development grows in a steady rate, in order to improve accessibility, public transportation, and utilities to better accommodate the tourist population. Subsidies play an important role in reducing financial burdens on residents and motivating sustainable practices. Subsidies might include support for local businesses, discounted public transportation, or financial incentives for environment-friendly practices. Expenditure on advertisement and promotion starts at 17% in Year 1, focusing on attracting tourists to under-visited locations and highlighting off-peak seasons. As tourism stabilizes, the need for advertisement diminishes.

4. Conclusions and outlooks

This study utilizes a multi-objective model to explore the sustainability of tourism management in Juneau, Alaska. The model incorporates dimensions of economic, environment, and society. The simulation results indicate that dynamic taxation, adaptive government spending, and data-informed decision making can effectively stabilize tourist volume, improve environment quality, and enhance resident satisfaction over a five-year period. The environment index constructed based on temperature, snowfall levels, ocean temperature, and ocean pH, increases significantly as a result of targeted conservation investments, showing the viability and importance of the efforts for sustainability. Meanwhile, tourist inflows remain within acceptable limits, avoiding the pitfalls of over-tourism. Resident satisfaction also improves due to visible reinvestment in infrastructure and environmental health, indicating that well-designed policy interventions can balance the needs of multiple stakeholders. These findings validate the core hypothesis that sustainability in tourism is achievable through feedback-driven governance and evidence-based planning.

However, some limitations still exist in this study. For example, the model relies on assumed parameter values for certain variables such as elasticity of tourist demand, which may not fully reflect real-world conditions. Future research should incorporate empirical data, such as surveys, government statistics, and environmental monitoring datasets, to calibrate and validate these parameters more precisely. Second, the current model simplifies the interaction between stakeholders by assuming uniform government behavior and passive resident responses. In the future, expanding the model to include more nuanced agent behaviors could enhance its realism and policy relevance.

References

[1] Schuler A R, Pearson H C. Conservation benefits of whale watching in Juneau, Alaska[J]. Tourism in Marine Environments, 2019, 14(4): 231–248.

[2] Banerjee A, Mahmudov T, Adler E, et al. Modeling sustainable city trips: Integrating CO_2 emissions, popularity, and seasonality into tourism recommender systems[J/OL]. arXiv preprint arXiv: 2403.18604, 2024[2025-03-23].

[3] Baloch Q B, Shah S N, Iqbal N, et al. Impact of tourism development upon environmental sustainability: a suggested framework for sustainable ecotourism[J]. Environmental Science and Pollution Research, 2023, 30(3): 5917–5930.

[4] Jia Z, Liu W L. Decision-making research on sustainable tourism development based on analytic hierarchy process and genetic algorithm[J]. Mathematical Modeling and Algorithm Application, 2025, 4(1): 17–23.

[5] Yoshioka H. A mean field Jacobi process for modeling sustainable tourism[J/OL]. arXiv preprint arXiv: 2409.20347, 2024[2025-03-23].

[6] Dalgleish H, Mengistie G, Backes M, et al. How can astrotourism serve the sustainable development goals? The Namibian example[J/OL]. arXiv preprint arXiv: 2109.04790, 2021[2025-03-23].

[7] Naqvi M H, Ahmed A, Pervez A. Implementing sustainable tourism practices in luxury resorts of Maldives: Sustainability principles & triple bottom line approach[J/OL]. arXiv preprint arXiv: 2311.18453, 2023[2025-03-23].

[8] Pérez M, López R. Four decades of sustainable tourism research: Trends and future research directions[J]. International Journal of Tourism Research, 2024, 26(2).

[9] Alam J, Nur Alam Q, Kalam A. Prospects and challenges for sustainable tourism: Evidence from South Asian countries[J/OL]. arXiv preprint arXiv:2211.03411, 2022[2025-03-23].

[10] Bindawas A M. Promoting sustainable tourism through employee skills: Contextualizing quality education and the human resource management perspective (SDG-4)[J]. Sustainability, 2025, 17(2): 748.