Problem Chosen	2025 MCM/ICM Summary Sheet	Team Control Number
B		**2520023**

Towards Sustainable Tourism: A Dynamic Optimization Model for Locations in Trouble

Summary

Juneau, Alaska, a city which regards tourism as a pillar, has seen a rapid increase in visitor numbers. This surge has brought significant economic benefits while leading to overcrowding and environmental challenges. On the other hand, cities with insufficient tourist traffic face their own difficulties, including underutilized infrastructure, limited economic growth, and challenges in maintaining and promoting local cultural and natural attractions. Therefore, many destinations must balance tourism's **benefits** and **drawbacks**, implementing measures like visitor limits, fees, and conservation efforts while addressing underdeveloped tourism potential, sparking debates on achieving long-term sustainability. In order to handle these challenges, we develop a sustainable scoring model and adjust methods accordingly to address specific issues.

For problem 1, we establish a sustainable scoring model which consists of four factors: economy, environment, society, and model stability. We optimize investment in different factors to maximize the sustainability score. Then we use the model to optimize the sustainability of Juneau's tourism industry and use the SARIMAX model to predict Juneau's sustainability score from 2025 to 2028. The results indicate that the highest sustainability score of 234.81 can be achieved when the proportion of scores (obtained through investment) for environment, economy, and society are set at 47.1%, 13.5%, and 39.4%, respectively. Finally, we conduct a sensitivity analysis of the model results and provide some suggestions for the sustainable development of tourism in Juneau.

For problem 2, we adapt the model from the first question to address areas affected by overtourism and to optimize sustainable development scores for locations with fewer visitors. The results show that at Sagrada Família, the highest sustainability score of 168.67 can be achieved with the proportion of scores (obtained through investment) 20.3% in the economy, 35.1% in the environment, and 44.6% in society. At Bunkers del Carmel, the optimal investment proportions of 51.8% in the economy, 24.5% in the environment, and 23.7% in society can achieve the highest sustainability score of 198.96. We observe that different attractions within the same city are impacted by their environment to varying degrees. Therefore, we assign different weights to economic, environmental, and social scores when determining the initial values and optimization targets. For our analysis, we focus on La Sagrada Família and Bunkers del Carmel, both located in Barcelona, Spain. We apply the model to evaluate their sustainable scores and identify the optimal solution for each.

Furthermore, we tested the sensitivity and transferability of our model. The results showed that it performed well not only in Juneau but also in other destinations impacted by overtourism, such as Hawaii Island, and in cities with conditions quite different from those in Juneau. This demonstrates a high level of transferability for the model. Additionally, although changing cities resulted in noticeable differences in the data, the model remained stable in its scoring, indicating it is not highly sensitive to varying inputs. Finally, we prepared a memo for the Tourist Council of Juneau to present our predictions, the effects of various measures, and our recommendations for optimizing outcomes.

Keywords: Sustainable Tourism, Constraint Optimization, SARIMAX, Scoring, Threshold

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1 Introduction

1.1 Problem Background

Juneau, Alaska, is a stunning and vibrant city with a population of around 30,000 residents. Known for its breathtaking natural beauty, including the iconic Mendenhall Glacier, whale watching, and lush rainforests, it draws tourists from all over the world. The city's rich landscape and unique attractions make it a top travel destination, significantly contributing to its thriving economy and local culture.

Figure 1: The Natural Scenery of Juneau.

However, the growing number of visitors has created problems like overcrowding, infrastructure strain, and environmental damage. The Mendenhall Glacier is receding due to climate change and over-tourism, raising concerns about sustainability. Additionally, the rising demand for housing and resources has led to resident dissatisfaction. In response, the city has implemented visitor limits and conservation measures. Balancing economic growth with environmental protection remains a challenge for the future.

1.2 Restatement of the Problem

For the requirements and tasks given, we restate them to help better position the focus of our work.

- A sustainable tourism model is developed by incorporating key factors such as tourist numbers, environmental impact, resident acceptance, and overall stability to ensure a balanced and responsible approach to tourism development.
- Clearly define optimization and constraint factors.
- How additional expenditures impact the model.
- Conduct a sensitivity analysis on the above factors.
- Extend this model to other tourist attractions.

1.3 Literature Review

The Sustainable Tourism[1][2] Indicator (STI) system[3] is based on standardized indicators established by organizations such as the United Nations World Tourism Organization and the Global Sustainable Tourism Council to quantitatively assess the sustainability of tourist destinations. This method is widely used for destination sustainability evaluation and policy regulation, offering advantages such as high international recognition and ease of cross-regional comparison. However, the system relies on fixed assessment frameworks, which may pose limitations in addressing the specific needs of individual regions.

The optimization-based approach[4] employs mathematical modeling techniques such as Linear Programming , Nonlinear Programming, and Multi-objective Optimization to achieve an optimal balance among environmental, economic, and social objectives. This method is primarily applied to resource allocation optimization and environmental impact minimization, providing scientifically sound decision support under given constraints. While optimization models can effectively guide resource distribution, their applicability depends on the accuracy of input data and the validity of modeling assumptions.

1.4 Our Work

To address the mentioned issues, our work can be illustrated with the following flowchart:

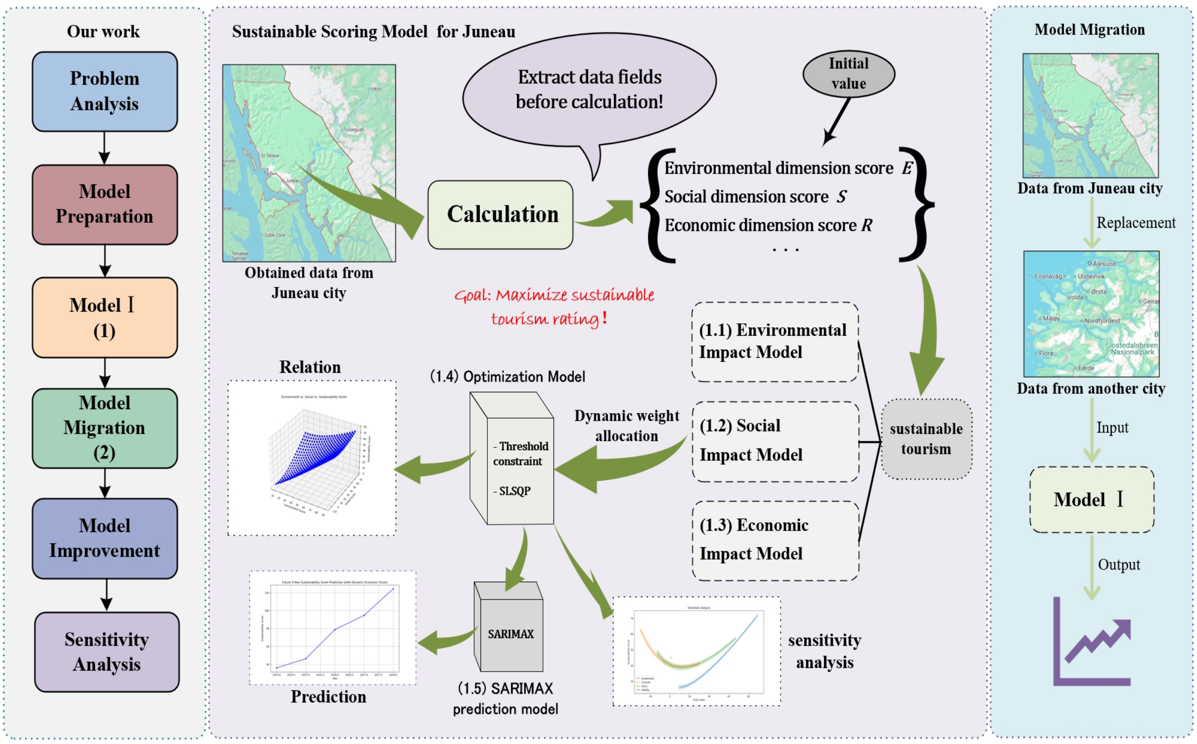


Figure 2: The Framework of Our Work

2 Assumptions and Notations

2.1 Assumptions

Before establishing a mathematical model for sustainable tourism, we made several assumptions to facilitate its implementation.

- **Assumption 1:** Tourism revenue is equal to the product of the number of tourists and the average spending per tourist.

  Justifications: Due to the varying spending levels of tourists, tourism revenue is calculated by multiplying the number of tourists by the average spending per tourist.

- **Assumption 2:** Sustainable tourism model is influenced only by four factors: society, environment, economy, and stability.

  Justifications: The sustainability of tourism is influenced by various factors; however, this paper considers only the four key factors mentioned above.

- **Assumption 3:** The collected time series data is recorded yearly.

  Justifications: Collecting time series data at annual intervals helps enhance data stability and comparability, providing reliable support for long-term planning and decision-making.

- **Assumption 4:** The set score thresholds and budget thresholds are determined based on local actual conditions.

  Justifications: The economic conditions, tourist numbers, and other related data vary across different tourist destinations.

- **Assumption 5:** In function (6) and (7), α_e = 0.0002 and α_s = 0.0002.

  Justifications: Based on the validation of experimental data, they are reasonable.

2.2 Notations

We have provided explanations for the key variables in the table below.

Table 1: Symbol definitions and descriptions.

Symbols	Description
E	Updated environmental dimension score
R	Updated economic dimension score
S	Updated social dimension score
T	Stability score
I_e	Environmental investment
I_i	Infrastructure investment
I_p	Policy support investment
S_{total}	Sustainability score
w_i	Weights for different dimensions
y_t	Predicted number of tourists

3 Model Preparation

3.1 Data Overview

We have gathered a significant amount of data related to tourism in Juneau. This includes key indicators such as per capita income, the number of tourists, residents' acceptance of tourism, the average number of household members involved in the tourism industry, the impact of tourists on residents in 2023, and cruise ship revenue in 2023. This data serves as a solid foundation for mathematical modeling, enabling a thorough analysis of influencing factors, the development of scientifically sound models, and the assurance of their validity and accuracy.

3.2 Data Collection

Table 2: Data and Database Websites

Database Names	**Database Websites**
Population	https://www.census.gov/data.html
Temperature	https://akclimate.org/data/data-portal/
Annual Per Capita Income	https://www.census.gov/data.html
Cruise Ship Data	https://https://juneau.org/wp-content/uploads/2024/01/

3.3 Data Preprocess

In this paper, Data preprocessing includes three aspects: data integration, cleaning, and indicator calculation.

First, multiple data sources are integrated by removing redundant information and handling missing values and outliers to ensure data completeness. Then, key variables such as tourism impact, residents' income, social evaluation, and employment status are extracted for different data categories and standardized to ensure consistency and comparability. Finally, core indicators such as total revenue and average tourist spending are calculated to further extract data value.

Additionally, appropriate error-handling mechanisms are incorporated to ensure the stability and reliability of the data processing workflow.

4 Models and Solutions of Problem 1

4.1 Problem Analysis

In this problem, we need to design a sustainable tourism development model for Juneau, identify the optimization factors and constraints in the model, and rationally plan the investment of additional income.

Figure 4 provides a more intuitive representation of our problem-solving approach, helping you better understand the overall solution and key steps.

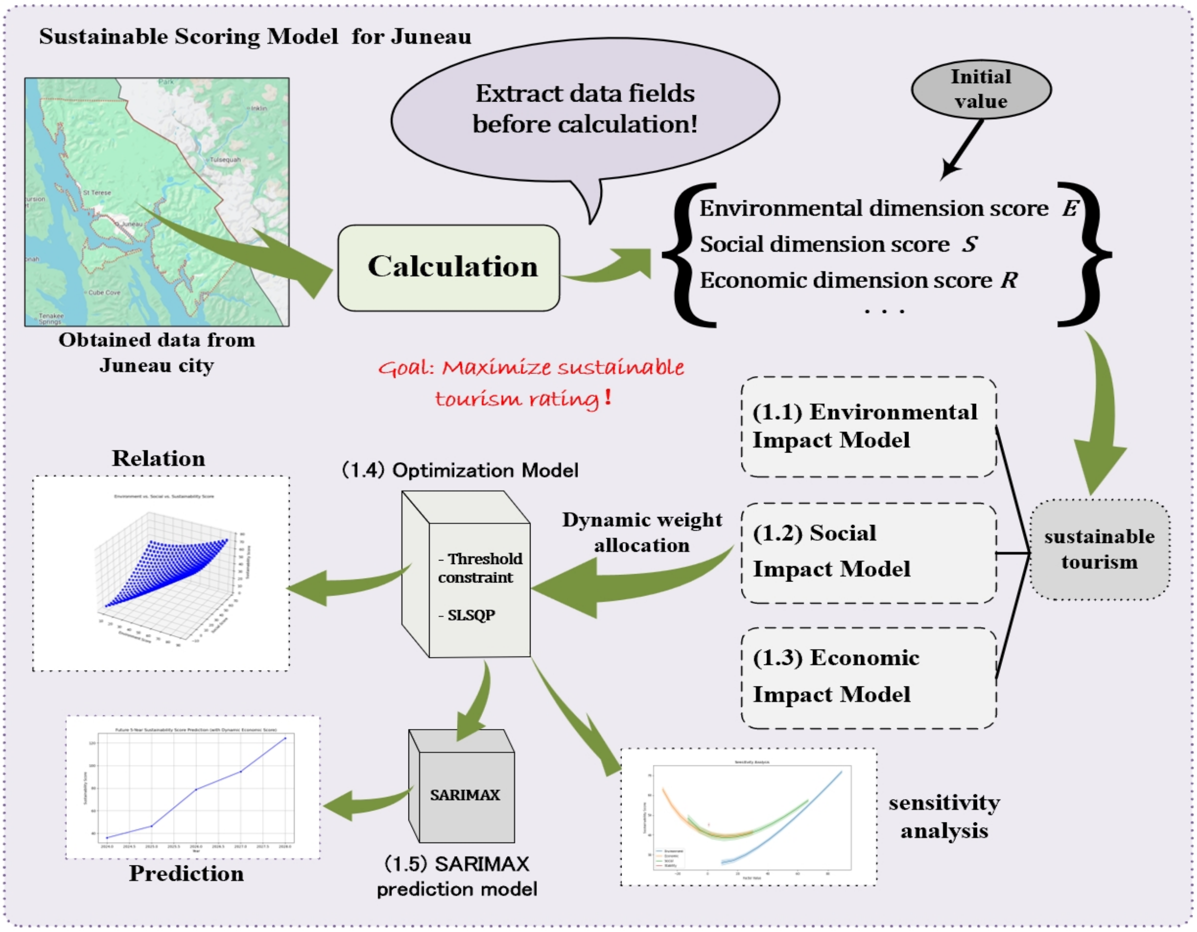


Figure 3: Model Concept Diagram

4.2 Establishment of the model

4.2.1 Model Dimension Decomposition

Overview

In this section, we developed a sustainable scoring model to assess the sustainable development of Juneau's tourism industry. The model evaluates four key dimensions: economic, environmental, social, and stability. It comprehensively considers the impact of various factors on the sustainable development of the local tourism sector. Additionally, the different dimensions are interrelated, and ultimately, a sustainable development score is calculated as the primary objective of the optimization process.

Economy

The economic dimension primarily assesses the tourism system's economic performance. This includes evaluating income levels, tourist expenditures, and their contributions to the local economy. This dimension is commonly used to gauge the economic health of the tourism industry, as well as its direct and indirect benefits to local residents, businesses, and governments. The formula for calculating the Revenue from tourism is as follows:

$$R = \alpha \cdot R_0 + (1 - \alpha) \cdot \left(\frac{D_0}{D_b} + \kappa \cdot (E + S) \right) \tag{1}$$

where R is the economic dimension score; R_0 is Previous economic dimension scores; D_0 is current revenue; D_b is the Baseline revenue; α is the smoothing coefficient; κ is the impact coefficient of environmental and social scores on the economic dimension.

Environment

The environmental dimension is an essential aspect of the sustainable tourism model. It evaluates how tourism activities affect the natural environment and measures the effectiveness of investments and policy initiatives in mitigating negative impacts. This dimension highlights the significance of ecological protection in the overall sustainability score, making it a crucial component of assessing tourism sustainability. The environmental dimension score calculation formula is as follows:

$$E = E_0 + \alpha \cdot \ln(1 + I_e) \tag{2}$$

where E is the updated environmental score after investment;E_0 is the initial environmental score;$\ln(1 + I_e)$ is the logarithmic diminishing return effect;α is the impact coefficient per unit investment.

Society

The social dimension is a vital part of the sustainable tourism model, assessing both positive and negative impacts on local communities. It focuses on tourism's potential to enhance social well-being while addressing challenges. Key factors include employment opportunities, income generation, cultural preservation, traffic congestion, and overall quality of life. Its goal is to measure the social benefits of tourism and inform policy and investment decisions.

$$S_0 = P_s - N_s \tag{3}$$

$$S = S_0 + \beta \cdot \ln(1 + I_i) + \gamma \cdot I_p \tag{4}$$

where S is the updated social score;S_0 is the initial social score $\ln(1 + I_i)$ is the logarithmic function simulating diminishing returns of investment;P_s is Positive social impact; N_s is Negative social impact; I_p is Policy support investment; γ is the Impact coefficient of policy support; β is the Impact coefficient of infrastructure investment;

Model Stability

The stability dimension is used in the sustainable tourism model to evaluate the operational stability and risk resistance of the tourism system. It focuses on the volatility of key indicators such as the number of tourists and employment levels, and aims to measure the sustainable operation capacity of the tourism system under different external conditions.

$$T = 1 - \frac{\sigma_v}{\mu_v} - \frac{\sigma_e}{\mu_e} \tag{5}$$

where T is stability score;σ_v is visitor volatility;σ_e is employment volatility;μ_v is visitor mean;μ_e is employment mean.

4.2.2 The construction of the scoring system.

Dynamic Weights

Before calculating the weight coefficients, it is essential to clearly define the social and environmental impact factors to ensure accurate updates to the weight coefficients.

$$\delta_e = \alpha_e \cdot E \tag{6}$$

$$\delta_s = \alpha_s \cdot S \tag{7}$$

where α_e is the environmental impact coefficient;α_s is the social impact coefficient;E is the environmental score; and S is the social score. We set α_e = 0.0002,α_s = 0.0002. (For details, please refer to the assumptions in Section 2.)

The introduction of dynamic weights is designed to adjust the importance of economic, environmental, and social factors according to varying conditions, allowing for a more accurate reflection of real-world situations. Different baseline weights are established for peak and off-peak seasons to respond to fluctuations in tourism demand.

When revenue increases, the economic weight rises while the environmental and social weights decrease to balance development needs. Conversely, when environmental and social ratings improve, the economic weight is accordingly compressed to emphasize sustainability. This dynamic adjustment mechanism enables the optimization of resource allocation based on real-time conditions, facilitating more rational decision-making.

$$w_e = w_e + 0.5 \cdot \delta_e \tag{8}$$

$$w_s = w_s + 0.5 \cdot \delta_s \tag{9}$$

$$w_r = w_r - (\delta_e + \delta_s) \tag{10}$$

where w_e is environment weight;w_s is social weight;w_r is revenue weight;δ_e is environmental adjustment factor;δ_s is social adjustment factor.

Sustainable Scoring Model

The Sustainable Scoring Model integrates four key factors—revenue, environment, society, and stability—to provide data-driven decision support, helping Juneau's tourism industry achieve a balance between economic growth and its environmental and social impacts.

$$S_{\text{total}}(I_e, I_i, I_p) = w_r \cdot R + w_e \cdot E + w_s \cdot S + w_t \cdot T \tag{11}$$

where S_t is the sustainability score; w_r, w_e, w_s, w_t are weights for economic, environmental, social, and stability dimensions;R is the revenue score;E is the environmental score;S is the social score;T is stability score.

Optimization Model

In the optimization model, we continuously adjust the values of I_e, Ii, and $_p$ to maximize the output of S_{total}, thereby achieving the optimization goal. **It is clear that $S_{\textbf{total}}$ serves as the optimization factor, while the environmental score, social score, and budget thresholds act as constraint conditions.**

$$\max S_{\text{total}}(I_e, I_i, I_p) \tag{12}$$

$$\text{s.t.} \quad \begin{cases} E(I_e) \geq 14 \\ S(I_i, I_p) \geq 20 \\ I_e + I_i + I_p \leq 6,600,000 \end{cases}$$

where I_e is environment investment;I_i is infrastructure investment;I_p is policy support investment.

Based on the analysis of Juneau's annual tourism industry report, the threshold values for environmental score, social score, and government budget are set at 14, 20, and 6,600,000, respectively. In other words, we need to perform **constrained optimization**.[5]

The schematic diagram of constrained optimization is shown below:

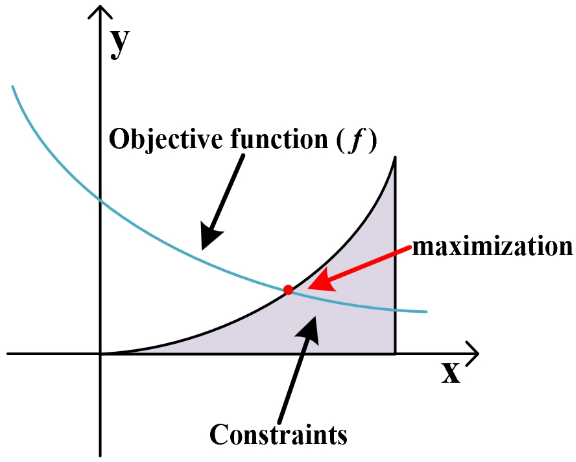


Figure 4: Model Concept Diagram

SARIMAX Prediction Model

The SARIMAX Prediction Model[6] is used to forecast the number of tourists in Juneau, considering seasonality and the impact of policy investments. It helps optimize resource allocation, balance economic, environmental, and social sustainability, formulate scientific budget plans, and prevent resource waste.

$$(1-\phi_1 B)(1-B)y_t = (1+\theta_1 B)\varepsilon_t + (1-\Phi_1 B^2)(1-B^2)\chi_t\beta_1 + \varepsilon_t \tag{13}$$

where y_t is number of tourists;B is Lag operator;ϕ_1 is Non-seasonal autoregressive (AR) coefficient;θ_1 is Non-seasonal moving average (MA) coefficient;ε_t is Error term (white noise);Φ_1 is Seasonal autoregressive (SAR) coefficient;χ_t is Exogenous variable (e.g., policy investment);β_1 is Regression coefficient of exogenous variable.

4.3 Evaluation Results and Analysis

4.3.1 Correlation Analysis

The Spearman and Pearson correlation matrices indicate that the environmental score has the strongest positive correlation with the sustainability score (Spearman 0.90, Pearson 0.89), highlighting the critical role of environmental factors in enhancing sustainability. The economic score also shows a strong positive correlation (Spearman 0.82, Pearson 0.83), suggesting that economic growth contributes positively to sustainability; however, a balance between economic development and environmental protection is essential.

The social score exhibits a weaker correlation (Spearman 0.27, Pearson 0.28), indicating its limited impact on sustainability. The stability score shows no significant correlation (Spearman 0.01, Pearson 0.00), suggesting minimal contribution to sustainability. Overall, balancing environmental, economic, and social factors is crucial for improving sustainability, while the impact of stability remains relatively low.

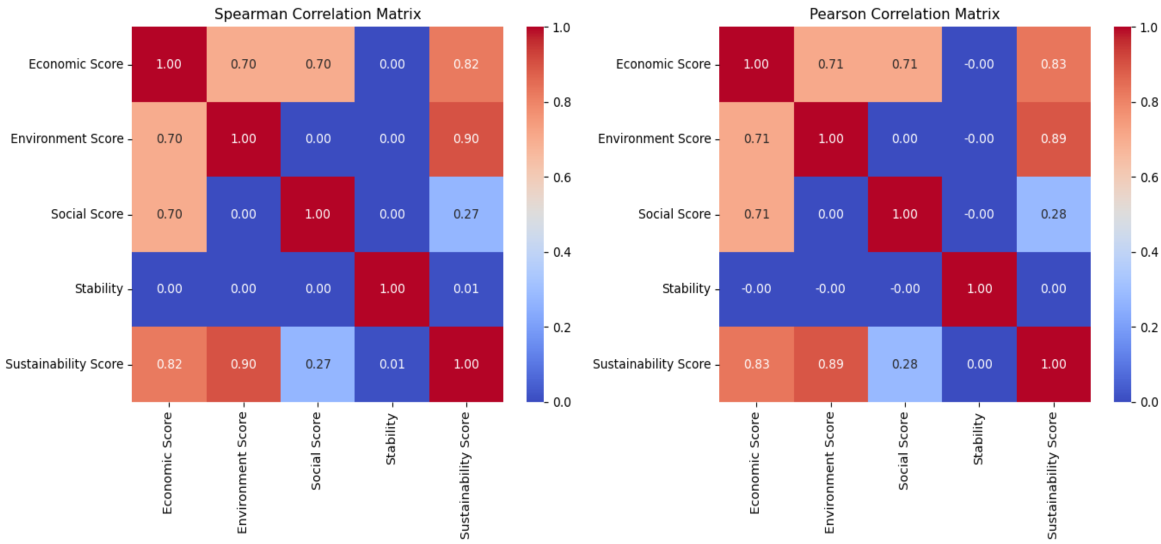


Figure 5: Correlation Matrix

We use a scatterplot matrix to present the distribution and pairwise relationships of four variables: economic score, environmental score, social score, and stability.

The diagonal sections display the distribution of each variable, where the economic score exhibits an approximately normal distribution, while the environmental and social scores show a more uniform distribution. In contrast, the stability score presents a discrete multi-modal distribution.

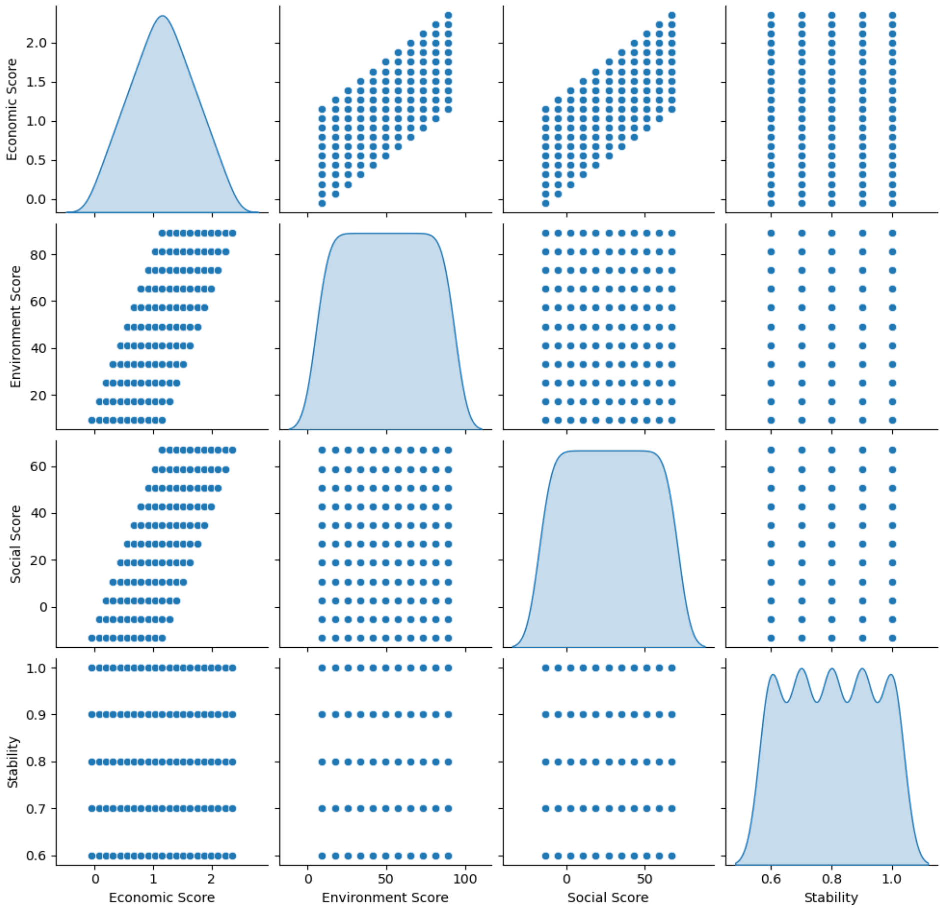


Figure 6: Scatterplot Matrix

The Figure 6 in the off-diagonal sections reveals the correlations between variables. The economic score shows a certain positive correlation with both environmental and social scores, suggesting that economic development may be accompanied by improvements in environmental and social aspects. However, the stability score exhibits a lower correlation with other variables, indicating its relatively independent influence within the model.

Overall, the synergy between environmental and social scores may have a positive impact on sustainability, while the role of stability in this model appears to be limited.

4.3.2 Results Analysis

Prediction result

The future sustainability score predictions, based on the combined sustainable tourism evaluation model and the SARIMAX forecasting model, are illustrated in the following figure.

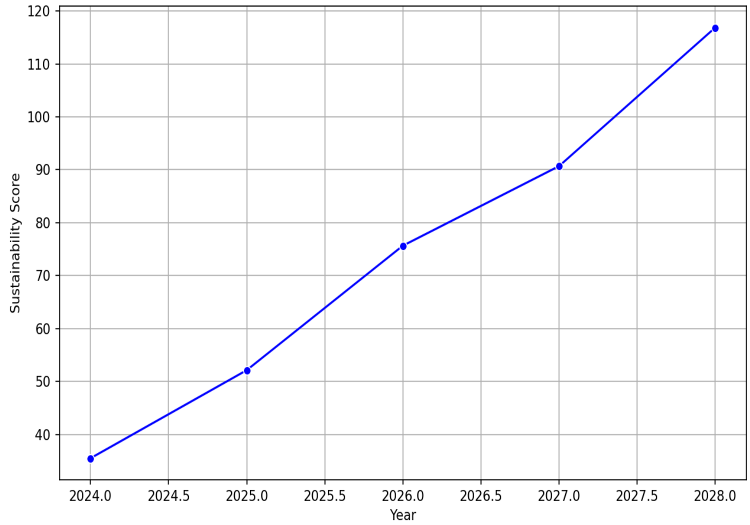


Figure 7: Prediction Result

Figure 7 shows that from 2024 to 2028, the sustainability score exhibits a continuous upward trend, indicating that sustainability levels are expected to steadily improve during the forecast period. The score gradually increases from approximately 40 to over 110, suggesting that relevant factors may have a positive impact on sustainable development in the coming years.

The overall trend demonstrates that the growth rate of the sustainability score remains stable over time, reflecting the optimistic outlook of the prediction model for future development. This result provides a valuable reference for formulating long-term sustainability strategies.

Optimization result

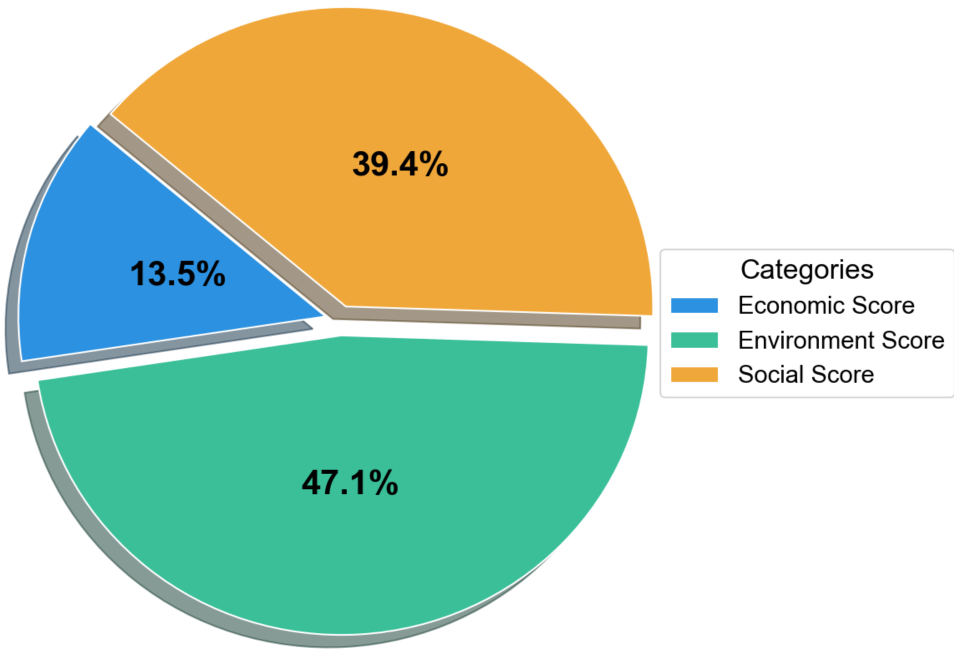


Figure 8: Optimization Result

Table 3: Optimized Sustainable Score of Juneau

Economic	Environment	Social	Sustainability
34.0104	118.08	99.08	234.81

Table 4: Investment of Juneau (unit: USD)

Policy Support	Environment Investment	Infrastructure Investment
1,688,300	2,368,000	2,543,700

Juneau's environmental score is the highest, accounting for 47.1%, with an environmental investment of \$2,368,000, alongside policy support funding of \$1,688,300. This indicates that environmental protection is a key focus of the region's sustainable development strategy. The government is actively driving ecological improvements through policy and financial support. However, to ensure long-term sustainability, further optimization of resource allocation is needed to address ongoing environmental challenges effectively.

The social score accounts for 39.4%, with a score of 99.08, aligning with an infrastructure investment of \$2,543,700, reflecting sufficient investment in social development. This investment has effectively improved residents' well-being and enhanced the visitor experience. While the current strategy has yielded positive results, continuous improvements are required to meet the evolving social demands. On the other hand, the economic score, the lowest at 13.5%, with a value of 34.0104, indicates a relatively smaller contribution to overall sustainability.

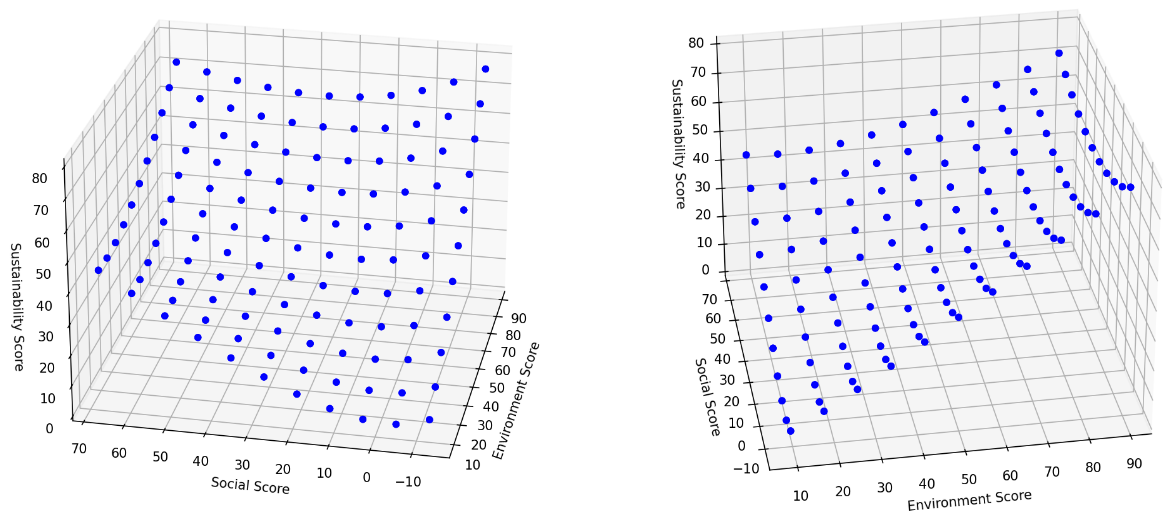
This suggests that insufficient economic investment may limit tourism competitiveness and financial stability. To achieve a more balanced and sustainable development, increased economic investments should be prioritized, fostering industrial upgrades and long-term economic resilience.

4.4 Sensitivity Analysis

As described in Section 4, we use the sustainability scoring model and optimization function to achieve the maximum sustainability score. To evaluate the certainty of our results, we conducted a sensitivity analysis by varying the investment values in the optimization function across different factors (scores of various factors). The results are shown in the figure below.

3D scatter plots

In the sensitivity analysis, we utilize 3D scatter plots to visually present the relationships among three variables, enabling the identification of potential correlations and trends. Moreover, 3D scatter plots can reveal more complex nonlinear relationships, helping us gain deeper insights into the interactions between variables and providing valuable support for further analysis and decision-making.



(a) (b)

Figure 9: 3D Scatter Plot

Figure 9 illustrates the three-dimensional relationship between Social Score, Environment Score, and Sustainability Score. The two subfigures present the same data from different perspectives, providing a clearer understanding of the interactions between these factors.

The results show that the Sustainability Score increases with higher Social and Environment Scores, indicating their positive impact on sustainability. The Environment Score plays a particularly significant role in enhancing sustainability, while improvements in the Social Score also contribute positively.

The even distribution of data points suggests a synergistic effect between social and environmental factors on sustainability. Lower Environment Scores may lead to fluctuations in the Sustainability Score, highlighting the importance of environmental factors in ensuring sustainability stability.

Factor Sensitivity Plot

The Factor Sensitivity Plot shows the relationship between the Sustainability Score and key factors such as environment, economy, society, and stability. It evaluates how changes in these factors impact the score. The curves illustrate influence trends, while the shaded areas represent confidence intervals, indicating result uncertainty.

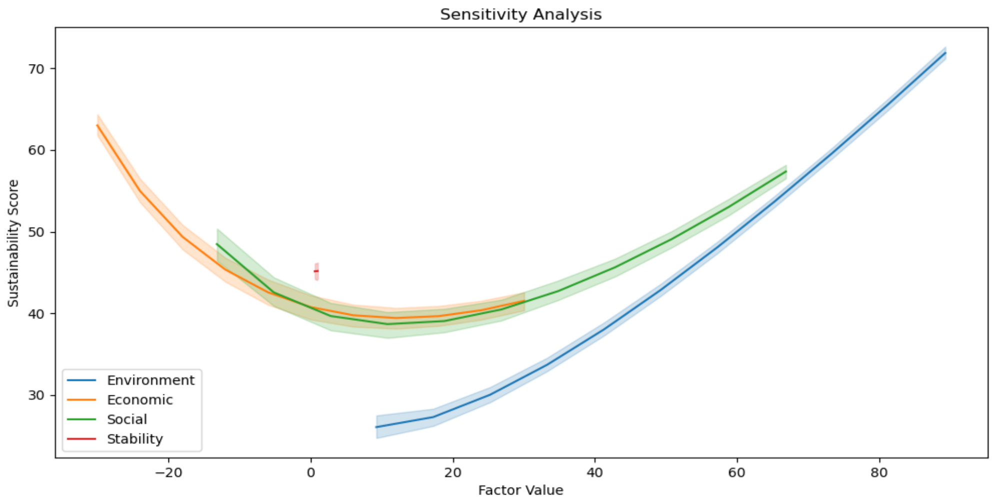


Figure 10: Factor Sensitivity Plot

The results from Figure 10 indicate that environmental, economic, and social factors exhibit a U-shaped trend. At lower values, they have minimal or negative impacts on the Sustainability Score, while at higher values, they contribute positively. Among these factors, environmental influence is the most significant.

Additionally, economic and social factors provide relatively stable contributions at higher values, whereas the impact of stability factors is minimal.

Overview

The sensitivity analysis clearly indicates that among the four factors, the **environment score is the most important and influential factor**. The results show that the environment score has the most significant impact on improving sustainability, whether through its negative effects at low values or its positive contributions at high values, surpassing other factors. Therefore, environmental factors should be given priority when formulating sustainability strategies.

5 Models and Solutions of Problem 2

5.1 Problem Analysis

To address the problem of overtourism in popular destinations and ensure a balanced distribution of visitors across various attractions, we will modify the sustainable tourism model. This involves adjusting the initial weights of the constraints based on the specific context of each tourist location, which will help optimize sustainable tourism development across different attractions within the same destination.

For our analysis, we choose Barcelona, Spain, as the primary case study. Additionally, to validate the applicability of our model, we will also examine sustainable tourism development in Hawaii. The Figure 11 shows our model adaptation process.

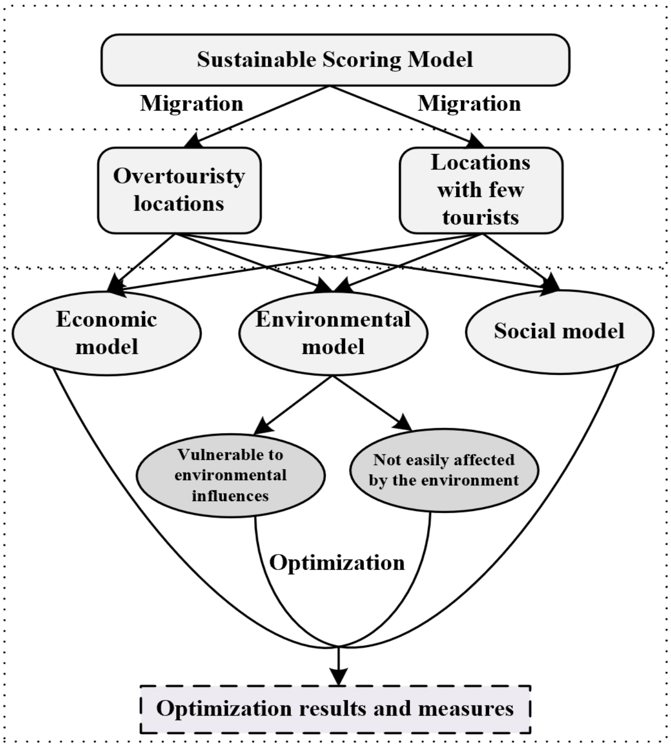


Figure 11: Model Adaptation Process

5.2 Balance between Different Tourist Attractions

5.2.1 Tourist Destination Selection

We choose Barcelona, Spain, which faces problems such as overloaded infrastructure, rising housing prices, environmental degradation and damaged cultural heritage due to overtourism. Popular attractions such as the Sagrada Família, Las Ramblas and Barceloneta Beach are crowded all year round, disrupting residents' lives and exacerbating garbage and noise problems. At the same time, the surge in short-term rentals has made it difficult for local residents to afford high rents, forcing them to move out of the city center. In addition, the influx of tourists has destroyed the beach ecology and historical buildings, and cultural experiences have gradually been replaced by commercialization. These problems have caused dissatisfaction among residents, and even a clear "anti-tourist sentiment" has emerged.

5.2.2 Different Attractions

We choose the La Sagrada Família and the Bunkers del Carmel for our analysis. The La Sagrada Família is the most famous landmark in Barcelona, drawing millions of tourists each year. However, it faces significant challenges, including overcrowding, traffic jams, pollution from litter, and the commercialization of the community due to the high volume of visitors. These issues greatly affect the lives of residents and the urban environment.

In contrast, the Bunkers del Carmel offers an open panoramic view of the city and a relatively peaceful atmosphere, making it an ideal location to alleviate the pressure of excessive tourism at Barcelona's popular attractions. Its natural setting and lack of commercialization appeal to niche travelers, helping to disperse tourist traffic and reduce the strain on the city's core areas.

Sagrada Família

$$\max S_{\text{total}}(I_e, I_i, I_p) \tag{14}$$

$$\text{s.t.} \quad \begin{cases} E(I_e) \geq 13.6 \\ S(I_i, I_p) \geq 16.89 \\ I_e + I_i + I_p \leq 13,700,000 \end{cases}$$

Bunkers del Carmel

$$\max S_{\text{total}}(I_e, I_i, I_p) \tag{15}$$

$$\text{s.t.} \quad \begin{cases} E(I_e) \geq 10.8 \\ S(I_i, I_p) \geq 12.25 \\ I_e + I_i + I_p \leq 3,500,000 \end{cases}$$

The investment budget for Sagrada Família and Bunkers del Carmel should reflect their differing environmental and community pressures. Sagrada Família experiences high visitor traffic, requiring more resources for environmental maintenance and social support. In contrast, Bunkers del Carmel has lower visitor numbers, so investment should aim to improve transportation and infrastructure to attract tourists while preserving its natural environment.

5.2.3 Model solution and result analysis

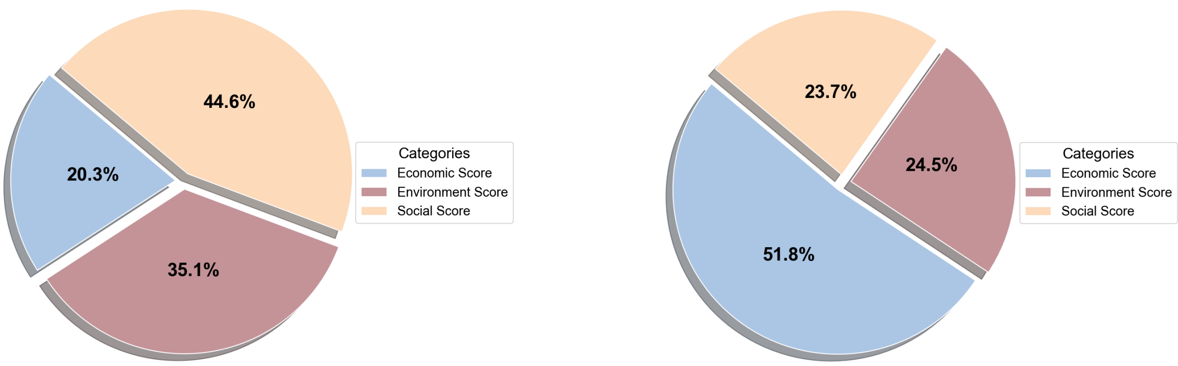
We set constraints based on the collected data to optimize the solution. The following two tables present the solution results of the model:

Table 5: Optimized Sustainable Score of Two Attractions

Attraction	Economic	Environment	Social	Sustainability
Sagrada Família	38.2065	66.15	84.1	168.67
Bunkers del Carmel	113.2553	55.01	58.06	198.96

Table 6: Investment of Two Attractions (unit: USD)

Attraction	Policy Support	Environment Investment	Infrastructure Investment
Sagrada Família	2,740,000	4,110,000	6,850,000
Bunkers del Carmel	1,802,600	854,100	843,300



(a) Optimization Result of Sagrada Família (b) Optimization Result of Bunkers del Carmel

Figure 12: Optimization Result

The optimization results from Tables 5 and 6, along with Figure 12 indicate that the investment focus of Sagrada Família is primarily on social impact ($6,850,000) and environmental maintenance ($4,110,000). This suggests that more resources are needed to alleviate community pressure and improve the environment to cope with the negative effects of high tourist flow. In contrast, economic investment is relatively low, indicating that there is room for improvement in its tourism-related economic benefits. In the future, efforts should focus on enhancing economic attractiveness while maintaining a balance between environmental and social factors.

The optimization results for Bunkers del Carmel show that economic investment accounts for $1,802,600, while environmental maintenance accounts for $854,100. This indicates that the site focuses on boosting economic appeal and improving infrastructure to attract more tourists. However, investment in environmental and social aspects remains relatively low. Future strategies should prioritize increasing investments in these areas to achieve a more balanced and sustainable development.

Therefore, Barcelona should promote the unique charm of Bunkers del Carmel to divert tourists from Sagrada Família and reduce pressure on the core area. Additionally, themed tourism routes can be designed to connect Sagrada Família and Bunkers del Carmel, guiding the distribution of tourists more effectively, unlocking the potential of lesser-known attractions, and fostering overall sustainable tourism development.

5.3 Adapted to Other Overtourism Destination

5.3.1 Tourist Destination Selection

We choose Hawaii as the second destination for our model due to its severe over-tourism, where tourist numbers far exceed the local population. This has led to environmental degradation, over-commercialization of cultural sites, and growing resentment among locals. Hawaii's dependence on tourism also makes its economy vulnerable. Our sustainability score model aims to encourage more sustainable tourism practices in the region. more sustainable tourism practices in Hawaii.

Similarly, we collect data related to Hawaii's tourism industry, including key indicators such as per capita income, number of tourists, residents' acceptance of tourism, and the average number of family members engaged in the tourism industry. We use this data as input to our model to optimize the sustainable tourism score.

$$\max S_{\text{total}}(I_e, I_i, I_p) \tag{16}$$
$$\text{s.t.} \quad \begin{cases} E(I_e) \geq 19 \\ S(I_i, I_p) \geq 26 \\ I_e + I_i + I_p \leq 2,000,000,000 \end{cases}$$

Hawaii's ecosystem is fragile, with about 85% of popular attractions suffering environmental damage, and residents' satisfaction with the tourism industry has dropped from 80% in 2010 to 55% in 2021. The commercialization of cultural sites and the increasing pressure on public services require increased investment to improve community life and cultural protection, and limit investment to 1% of total revenue to achieve a reasonable allocation of resources. Therefore, we set reasonable constraints.

5.3.2 Model solution and result analysis

We set constraints based on Hawaii's actual situation and combine the collected data to optimize the solution model.

Table 7: Optimized Sustainable Score of Hawaii

Economic	Environment	Social	Sustainability
27.83	82.80	119.37	216.83

Table 8: Investment of Hawaii (unit: USD)

Policy Support	Environment Investment	Infrastructure Investment
242,000,000	700,000,000	1,050,000,000

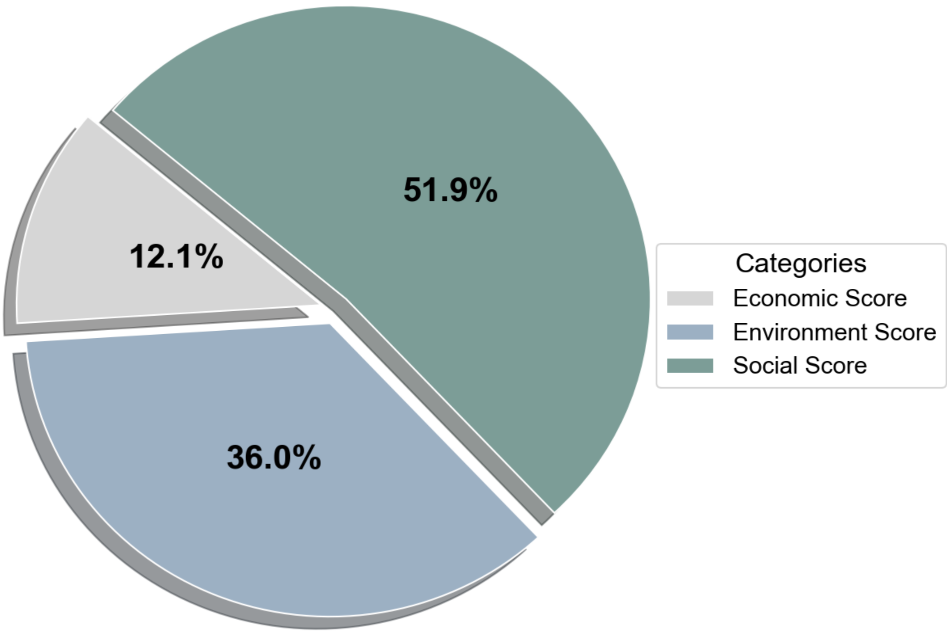


Figure 13: Optimization Result of Hawaii

The optimization results from Tables 7 and 8, along with Figure 13, show that Hawaii allocates $1,050,000,000 of its budget to the social sector, improving resident satisfaction and cultural heritage protection, achieving a social sustainability score of 119.37. The environmental sector receives $700,000,000 to protect ecosystems like coral reefs and rainforests, resulting in an environmental sustainability score of 82.80. The economic sector has the lowest allocation of $242,000,000, reflecting Hawaii's stable tourism economy, with an economic sustainability score of 27.83. This investment distribution results in a total sustainability score of 216.83, demonstrating an effective balance across social, environmental, and economic aspects.

In conclusion, the model demonstrates strong adaptability and can be applied to other tourist destinations to guide sustainable tourism management, promoting a balanced development of social, environmental, and economic aspects.

6 Strengths and Weaknesses

6.1 Strengths

- Our model designs the environmental, social, and economic scores to influence each other. By dynamically adjusting the weights (for example, different emphases in peak and off-seasons), it can more accurately reflect the linkage effects of multiple factors and improve the practical application value of prediction and decision-making.
- The model optimizes resource allocation and reasonably allocates it to environmental protection, infrastructure construction and policy support, while combining the logic of reinvesting additional income to ensure the sustainability of current resource utilization and promote long-term development.

6.2 Weaknesses

- Our model relies heavily on the completeness and accuracy of input data, such as historical data on tourism revenue, resident opinions, and the number of tourists. If the data is of low quality or unavailable, the model's predictions and optimization results may lose reliability.
- The model has high requirements on the accuracy and completeness of input data (such as environmental scores, social impacts, and number of tourists). If the data is not reliable or has many missing values, it may significantly affect the results of the model.

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Memo

To: Tourist Council of Juneau

From: Team 2520023

Subject: Sustainable Tourism Industry for Juneau

Date: January 27, 2025

Dear Tourist Council of Juneau,

We are honored to present our recommendations for the sustainable development of tourism in Juneau. Based on data analysis, we have developed a sustainable tourism scoring model that quantifies sustainability across four dimensions: social, environmental, economic, and stability. Additionally, we use an optimization model to find the best score and apply the SARIMX model to forecast future trends.

To enhance tourism sustainability, we offer the following recommendations:

- Based on the scoring model and the current state of Juneau's tourism industry, enhancing sustainable tourism scores can be achieved by increasing environmental investments, improving infrastructure, and providing policy support.
- Based on the results and correlation analysis, increasing environmental investment has the most significant impact on improving the sustainability score, whereas policy support and infrastructure investment have relatively weaker effects. Therefore, it is recommended to focus investment efforts on environmental initiatives to maximize sustainability outcomes.
- Based on the analysis of the scoring and optimization models, setting the investment proportions for environment, infrastructure, and government at 49.1%, 18.1%, and 32.8%, respectively, will maximize Juneau's sustainable tourism score.
- Based on the SARIMX prediction model, we have forecasted the future sustainability score of Juneau's tourism industry. After adjusting the investment proportions to the specified levels, the results indicate that the score will steadily increase at an approximate rate of 20 points per year. As shown in the chart in Section 4, this growth rate is quite significant.

Finally, we emphasize that humanity and nature are an inseparable whole. We hope you will adopt the above measures to promote the sustainable development of tourism in Juneau and work together to create a beautiful city where humans and nature coexist in harmony.

Report on Use of AI

The AI model used in this paper is ChatGPT 4.0, which was released by OpenAI on March 14, 2023.

1. **Query1:** How to efficiently find the maximum of an optimization function?

   Output: You can try the following steps.

   Step 1: Define the objective function and constraints.Clearly define the optimization goal (such as sustainability score) and constraints (such as environmental score, budget limits, etc.).

   Step 2: Choose an appropriate optimization method. Select the suitable optimization method based on the objective function and constraints, such as linear programming or nonlinear programming.

   Step 3: Use optimization tools to solve and obtain the optimal values of I_e, I_i, and I_p.Use optimization tools (such as Python or MATLAB) to solve the problem and obtain the optimal decision variables.

   Step 4: Maximize S_t to obtain the optimal sustainability score. Finally, calculate the sustainability score based on the optimal solution to provide decision support.

2. **Query2:** How the social rating model is constructed?

   Output: You should follow these steps.

   Step 1: Define the initial social score: determine the starting score S_0, which reflects the social condition before the tourism activity begins.

   Step 2: Identify and quantify key factors affecting social well-being, such as employment opportunities, income generation, cultural preservation, traffic conditions, and overall quality of life.

   Step 3: Select a suitable function (such as a logarithmic function) to update the social score, simulating diminishing returns on investment.

   Step 4: Update the social score.The social score is updated using the formula.

   Step 5: Optimize the impact of each factor on the social score by adjusting parameters β and γ, improving the model's accuracy and applicability.

   Step 6: Apply the model for decision support.Use the updated social score to inform policy making and investment decisions, ensuring maximum social benefits from tourism.

3. **Query3:** How to determine different thresholds based on different tourist attractions?

   Output: Based on different tourist attractions, you can adjust the thresholds according to the environmental impact, visitor numbers, and social influence of the attractions. Ecologically fragile attractions require higher environmental score thresholds, while attractions with high visitor density need higher social score thresholds. Budget thresholds should also be adjusted based on the size and needs of the attraction, with popular attractions having higher budgets and smaller ones having lower budgets. This approach allows for flexible threshold setting based on the characteristics of each attraction.