Problem Chosen	2024 MCM/ICM Summary Sheet	Team Control Number
B		2504110

Pain-Free Tourism: A Zonal Approach to Overtourism

Juneau, the capital of Alaska, the United States, boasts a rich natural environment and attracts millions of tourists annually. The prosperity of the tourism industry has brought both economic benefits and environmental challenges as well as infrastructure strain. To address these challenges, we propose a **zonal approach** to planning sustainable tourism in Juneau, aiming to attain a long-term development of the tourism industry while protecting the natural environment and reducing the negative impacts on local communities.

In order to depict the complex impacts of tourism on Juneau, we introduce a **zonal model** that make a division of the city into areas characterized by different levels of tourism intensity and environmental sensitivity. We model the distribution of tourists in each area, the associated costs and hidden costs, and the revenue generated by the tourism industry. Additionally, we quantify local residents' satisfaction, infrastructure capacity, and environmental limits, which are problems that need to be addressed in the sustainable development of tourism. The overall net benefit of tourism is defined as the optimization goal, which reflects the overall balance between economic growth and environmental protection in next 20 years.

We divide Juneau into areas of three categories: **tourism-intensive areas**, **tourism-affected areas**, and **residential areas**. Tourism-intensive areas are further divided into environmentally sensitive and insensitive attractions. Environmentally sensitive attractions, like Mendenhall Glacier, depend heavily on the natural environment and are important for environmental protection. In contrast, environmentally insensitive attractions, such as the Alaska State Museum, are less affected by tourism. This zonal approach forms the foundation of our model, allowing for the quantification of impacts, costs, revenues, and resident satisfaction for each area category.

We model the number of tourists in each area based on the attractiveness of attractions, the capacity of the areas, and the distances between attractions and residential areas. The **costs and hidden costs** of tourism are quantified based on the number of tourists in each area. We introduce **residents' satisfaction** as a constraint in the optimization model, aiming to protect the benefits of local residents while also promoting the sustainable development of tourism. As a summary of our work, we propose an **expenditure plan** to enhance sustainable tourism in Juneau, as well as a memo to the city council to explain the model, the plan, and optimal mesures.

Our model provides a comprehensive framework for planning sustainable tourism in Juneau, which can be adapted to other cities facing similar overtourism challenges. Specifically, we demonstrate the generalizability of the model by **adapting it to Charleston, South Carolina**, and discuss the potential benefits and challenges of implementing the model in other cities.

Finally, **sensitivity analysis** shows that our model is stable and robust. We deviates the parameters to test the model's performance, and the results show that the model is reliable and has a good generalizability.

By adopting a zonal approach to planning sustainable tourism, we are confident that our model can help Juneau and other tourist cities make optimal decisions to achieve a balance among economic growth, environmental protection, and local community benefits, promoting the long-term prosperity of the tourism industry.

Keywords: sustainable tourism, zonal approach, hidden costs, optimization model

Contents

1 Introduction

1.1 Background

Juneau, Alaska's capital, is home to 30,000 residents and attracts over 1 million tourists annually, making it a hub of tourism and an environmentally sensitive area. Key attractions like Mendenhall Glacier and Tongass National Forest fuel the tourism industry but raise concerns about sustainability. In 2023, the city hosted a record 1.6 million cruise passengers, boosting revenue but exacerbating issues like glacier retreat, infrastructure strain, and local life disruptions.

These challenges represent the *hidden costs* of tourism, which, though often overlooked, significantly impact the long-term economic and environmental health of destinations. This paper presents a model to quantify these hidden costs and offers strategies for Juneau's sustainable development.

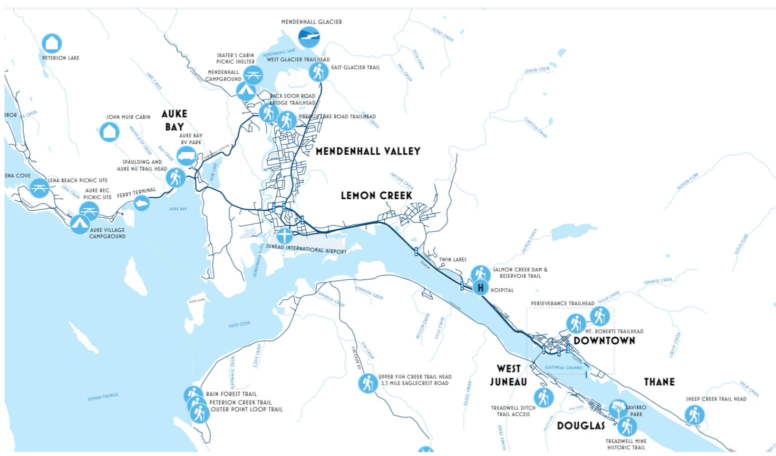


Figure 1: Juneau Road Map

1.2 Literature Review

Sustainable development in Juneau has been widely discussed, especially regarding the balance between tourism and environmental protection. A study from UNC[1] reveals mixed attitudes among residents toward tourism, highlighting its economic benefits but also concerns over environmental impact. Research on glacier loss[2] shows that tourists are willing to pay $648 annually to slow glacier retreat. Community-based tourism has also been identified as a solution to address economic, environmental, and social inequalities[3].

1.3 Restatement of the problem

The goal is to develop a model for sustainable tourism in Juneau, Alaska, by addressing the hidden costs of tourism and proposing strategies, an expenditure plan, and methods to enhance sustainability. We consider the problem an optimization task, aiming to maximize the net benefit of tourism while balancing economic growth with environmental protection.

Hidden costs, such as environmental degradation, infrastructure strain, and social impacts, are treated as negative externalities. The net benefit is defined as the revenue from tourism minus these hidden costs. Constraints include infrastructure capacity, environmental carrying capacity, and local resident satisfaction, ensuring these factors remain within acceptable limits to avoid unbalanced development.

We further divide the problem into the following steps:

1. **Build** a model that takes into account benifits and hidden costs of tourism in Juneau.
2. **Draft** an expenditure plan to improve sustainable tourism in Juneau and show how the plan improves sustainable tourism in Juneau.
3. **Analyze** the sensitivity of the model to the parameters.
4. **Demonstrate** the generalizability of the model by adapting it to other cities.
5. **Write** a memo to the city council to explain the model and the plan.

2 Assumptions and Justifications

To objctify the problem, we make the following assumptions, followed by justifications.

- **The behavior of tourists is stable over a predictable period.**

  Justification This assumption is based on the fact that the tourism resources in Juneau are dependent on the natural environment, which show relatively small variations over time. For instance, the distribution of tourists in different seasons should be stable, and the average hidden costs generated by each tourist should be consistent.

- **No significant natural disasters or public health emergency occur.**

  Justification We noticed that the COVID-19 pandemic has a significant impact on the tourism industry, but the pandemic can be seen as an exception and will not happen again in several decades. We also assume that other natural disasters will not occur.

- **There is no new attraction built in Juneau.**

  Justification The construction of a new attraction will change the distribution of tourists in Juneau, which is unpredictable and out of the scope of our model.

- **The economic environment in Juneau is stable and is unaffected by outside factors.**

  Justification Although tourism is often highly dependent on the outside economic environment, the change in the economic environment is unpredictable and out of the scope of our model. Our model is designed to be used in a relatively stable economic environment.

- **Each sector we divide Juneau into is homogeneous.**

  Justification Because real conditions in Juneau are complex and difficult to quantify, we simplify the problem by dividing Juneau into several sectors, each of which is homogeneous. This assumption is necessary for the model to be solvable.

3 Notations and Terminology

3.1 Notations

Major notations used in this paper are listed in Table 1.

Table 1: Notations

Symbol	Meaning
P^t	Total number of tourists in Juneau in year t
$P_{\text{sen}}^{i,t}$	Number of tourists in environmentally-sensitive attraction i in year t
$P_{\text{in}}^{j,t}$	Number of tourists in environmentally-insensitive attraction j in year t
$P_{\text{com}}^{k,t}$	Number of tourists in local community area k in year t
$C_{\text{sen}}^{i,t}$	Total costs of environmentally-sensitive attraction i in year t
$C_{\text{in}}^{j,t}$	Total costs of environmentally-insensitive attraction j in year t
$R^{m,t}$	Residents' overall revenue in area m in year t
$S_{\text{crowd}}^{m,t}$	Crowding level in area m in year t
$S^{m,t}$	Residents' overall satisfaction in area m in year t
$Q_{\text{in}}^{j,t}$	Capacity of environmentally-insensitive attraction j in year t
R^t	Total government revenue of tourism in Juneau in year t
$E_{\text{in}}^{j,t}$	Government expenditure on environmentally-insensitive attraction j in year t
$E_{\text{com}}^{k,t}$	Government expenditure on local community area k in year t
B^t	Overall net benefit of tourism in Juneau in year t

3.2 Terminology

a) **Hidden costs of tourism:**

The negative externalities generated by the tourism industry, which are not included in the costs of the tourism products but have a significant impact on the long-term development of the tourism destination. Hidden costs include the expenditure on environmental protection, the costs of infrastructure maintenance, and the degradation of the natural environment.

b) **Residents' satisfaction level:**

The satisfaction of the local residents with the tourism industry, which is an important factor in the optimization model. The satisfaction level is determined by the residents' life costs, the satisfaction with the infrastructure, the bearing level of overcrowding, etc.

c) **Overall net benefit of tourism:**

The difference between the revenue generated by the tourism industry and the hidden costs of tourism. It is the objective of the optimization model to maximize the overall net benefit of tourism.

4 Data

4.1 Data Overview

The problem requires data of various aspects of the tourism industry in Juneau, some of which are obtainable on the Internet, while others need to be collected on site. However, due to the limitation of the competition, we are unable to collect data on site, so there are some assumptions and simplifications in the model. The data about Juneau we collected are listed in Table 2 with the source.

Table 2: Data about Juneau

Description	**Source**
Population	https://datacommons.org/explore
Number of tourists	https://www.commerce.alaska.gov/web
Government budget	https://juneau.org/category/budget
Attraction information	https://www.traveljuneau.com/things-to-do/top-attractions
Map	https://www.traveljuneau.com/plan-your-trip/maps-and-travel-tools

We also collected data about data about Charleston, South Carolina as a comparison to Juneau, which is listed in Table 3.

Table 3: Data about Charleston

Description	**Source**
Population	https://datacommons.org/explore
Number of tourists, revenue, etc.	https://www.postandcourier.com

5 Model Design

5.1 Model Overview

To address the complex impacts of tourism on Juneau, we adopt a sectoral approach by categorizing areas into tourism-intensive, tourism-affected, and residential zones. Tourism-intensive areas are further divided into environmentally-sensitive and insensitive attractions. We model tourist distribution, associated costs, hidden costs, and tourism-generated revenue for each area. Additionally, we quantify local resident satisfaction, infrastructure capacity, and environmental limits which are crucial indicators of sustainable tourism. Ultimately, we calculate the overall net benefit of tourism in the next 20 years as the optimization goal and propose an expenditure plan to enhance sustainable tourism in Juneau.

We summarize our work in Figure 2.

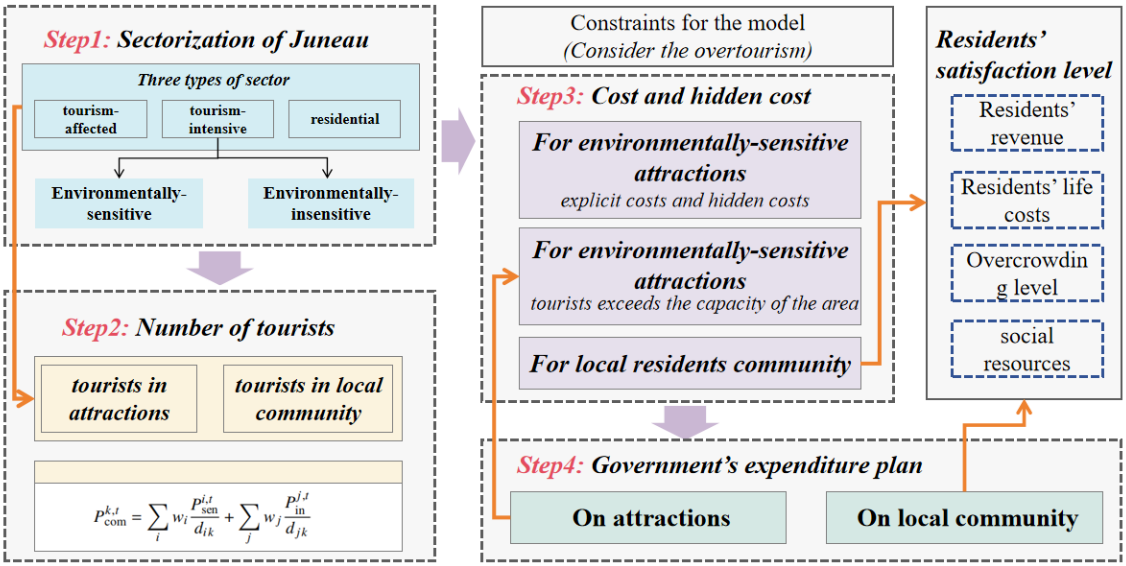


Figure 2: Flowchart of the model

5.2 Sectorization of Juneau

5.2.1 Modeling ideas

Tourism impacts different areas of Juneau in varying ways, making direct quantification challenging. To simplify the analysis, Juneau is divided into sectors with relatively homogeneous characteristics, based on the locations of attractions and their proximity to residential areas.

We divide Juneau into three categories: tourism-intensive areas, tourism-affected areas, and residential areas. Tourism-intensive areas are further divided into environmentally sensitive and environmentally insensitive attractions. Environmentally sensitive attractions, like Mendenhall Glacier, depend heavily on the natural environment and are highly susceptible to tourism impacts. In contrast, environmentally insensitive attractions, such as the Alaska State Museum, are less affected by tourism.

This sectorization forms the foundation of the model, allowing for the quantification of impacts, costs, revenues, and resident satisfaction for each sector type.

5.2.2 Sectorization

Figure 3 shows the sectorization of the area close to Downtown Juneau, where most of the attractions and population are located. The figure is adapted from the *Street & Property Atlas* by the City and Borough of Juneau, where the black lines represent the boundaries of the sectors of street blocks. We fill the sectors with different colors to represent the different categories of sectors. The red sectors are tourism-intensive areas, whose name and category are listed in Table 4. The orange sectors are tourism-affected areas, which are close to the tourism-intensive areas and are affected by the tourism industry to a certain extent. The white sectors are residential areas, where the local residents live.

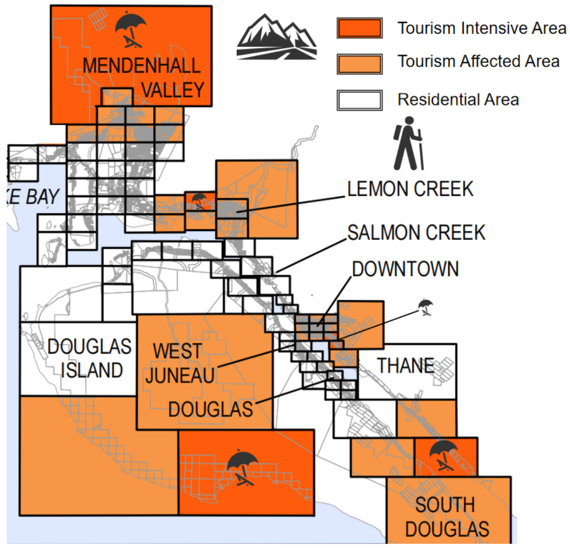


Figure 3: Sectorization of Juneau

Table 4: Sectorization of Juneau

Attractions	Category
Mendnehall Galcier & Nugget Falls	Environmentally-sensitive
Glacier Gardens Rainforest Adventure	Environmentally-sensitive
Mount Roberts Goldbelt Tram	Environmentally-insensitive
Alaska State Museum	Environmentally-insensitive
Whale Watching and Cruise Ship Terminal	Environmentally-insensitive

5.3 Number of tourists

5.3.1 Modeling ideas

The number of tourists is a key factor in our model, significantly influencing other elements such as revenue, costs, and hidden costs. We model the distribution of tourists in Juneau based on the attractiveness of attractions and the *flowing-out* phenomenon, where tourists visiting an attraction also explore neighboring areas in certain proportions. This results in a sectoral distribution of tourists. The number of tourists in each sector is determined by the attractions' attractiveness, the capacity of the sectors, and the distances between attractions and residential areas.

5.3.2 Supplementary assumptions

To quantify the number of tourists in each sector better, we make some additional assumptions:

a) **The attractiveness of attractions is stable over time.**

We assume that the attractiveness of attractions is stable over time. This assumption is necessary because we cannot predict the changes in the attractiveness of attractions in the future.

b) **The number of tourists in an environmentally-sensitive attraction is always equal to the limitation of the capacity.**

We assume that the number of tourists in an environmentally-sensitive attraction is always equal to the limitation of the capacity mentioned in the previous assumption. Because the overuse of environmentally-sensitive attractions is a problem to be solved at present as long as the number of tourists is stable in the future, the capacity should be almost fully utilized.

5.3.3 Total number of tourists

The total number of tourists in Juneau over the future years is seen as a value predictable by the historical data. We denote it as P^t, where t is the year. We apply linear regression and logistic regression to predict the total number of tourists in Juneau in the future 20 years, based on the historical data from 2010 to 2019. We specifically removed data from 2020 because we failed to collect the data due to the COVID-19 pandemic. The prediction is shown in Figure 4.

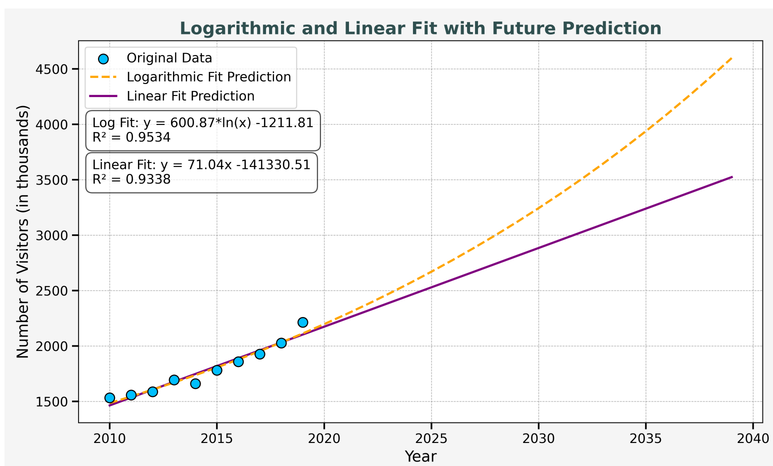


Figure 4: Prediction of the total number of tourists in Juneau

While both regression models seem to fit the historical data well, we consider the logistic regression model is more practical. This is not only because the growing curve of tourists usually shows a sigmoid curve where the growth rate is high at the beginning, but also because the R^2 value of the logistic regression model (0.9534) is slightly higher than that of the linear regression model (0.9338).

In light of the fact that different attractions have different attractiveness to tourists, we further assign weights to each attraction to reflect their attractiveness. Larger weights indicate higher attractiveness, thus attracting more tourists. The relationship between the total number of tourists and the number of tourists in each attraction is represented by the following equation:

$$P^t = \sum_i \alpha_i P_{\text{sen}}^{i,t} + \sum_j \alpha_j P_{\text{in}}^{j,t} \tag{1}$$

where $P_{\text{sen}}^{i,t}$ is the number of tourists in environmentally-sensitive attraction i in year t, $P_{\text{in}}^{j,t}$ is the number of tourists in environmentally-insensitive attraction j in year t, and α_i and α_j are the weights of the attractions.

5.3.4 Number of tourists in environmentally-sensitive attractions

The number of tourists in environmentally-sensitive attractions is denoted as $P_{\text{sen}}^{i,t}$, where i is the index of the attraction and t is the year. We assume that the number of tourists is limited by the capacity of the attraction simultaneously, so we have the following constraint:

$$P_{\text{sen}}^{i,t} \leq Q_{\text{sen}}^{i,t} \tag{2}$$

where $Q_{\text{sen}}^{i,t}$ is the capacity of the attraction i in year t. The capacity of an environmentally-sensitive attraction is determined not by statistical methods but by the observation of the capacity of the natural environment. For example, there is an urge to limit the number of tourists in the Mendenhall Glacier, because the glacier is retreating substantially due to the impact of tourism. In addition, by assumption b), we have the following equation:

$$P_{\text{sen}}^{i,t} = Q_{\text{sen}}^{i,t} \tag{3}$$

which means that the capacity of the attraction is always fully utilized.

5.3.5 Number of tourists in environmentally-insensitive attractions

The number of tourists in environmentally-insensitive attractions is denoted as $P_{\text{in}}^{j,t}$, where j is the index of the attraction and t is the year. Based on the assumption that the distribution of tourists in non-tourism-intensive areas is exclusively determined by the distance, this number is not limited, but will cause hidden costs when it exceeds the capacity of the area.

5.3.6 Number of tourists in local community areas

The number of tourists in local community areas is denoted as $P_{\text{com}}^{k,t}$, where k is the index of the area and t is the year. This number is determined by the number of tourists in neighbouring attractions and the distance between the area and the attractions. The more tourists in the neighbouring attractions and the closer the area to the attractions, the more tourists go to the area and the more hidden costs are generated.

We make an approximation that there is a reciprocal relationship between the number of tourists in an area and the distance between the area and the attractions. Formally, we have the following equation:

$$P_{\text{com}}^{k,t} = \sum_i w_i \frac{P_{\text{sen}}^{i,t}}{d_{ik}} + \sum_j w_j \frac{P_{\text{in}}^{j,t}}{d_{jk}} \tag{4}$$

where d_{ik} is the distance between the area k and the attraction i, and d_{jk} is the distance between the area k and the attraction j. The coefficients w_i and w_j are the weights of the attractions, which reflect the attractiveness of the attractions to the area k. This equation forms the core of our model that simulates a flowing-out phenomenon of tourists from attractions to neighbouring areas.

5.4 Costs and hidden costs

5.4.1 Modeling ideas

The costs and hidden costs of tourism are the negative externalities generated by the tourism industry, such as the expenditure on environmental protection, the costs of infrastructure maintenance, and the degradation of the natural environment. We separately research the costs and hidden costs of environmentally-sensitive attractions, environmentally-insensitive attractions, and local community areas, and quantify them based on the number of tourists in each area.

5.4.2 Supplementary assumptions

To quantify the costs and hidden costs of tourism better, we make some additional assumptions:

- **The costs of environmentally-sensitive attractions are fixed.**

  We assume that the costs of environmentally-sensitive attractions are fixed because the maintenance costs of the attractions are relatively stable over time. Considering the scope of our model, we will not consider factors like inflation and labor costs.

- **The hidden costs of environmentally-sensitive attractions are a linear function of the number of tourists.**

  We assume that the hidden costs increase linearly with the number of tourists. This assumption is reasonable because the hidden costs are generated by the impact of tourists, and the average hidden costs generated by each tourist should be consistent.

5.4.3 Costs and hidden costs of environmentally-sensitive attractions

As the number of tourists in environmentally-sensitive attractions is limited to the capacity of the attraction, the (explicit) costs there are determined by the number of tourists as a fixed cost. We denote the costs as

$$C^{i,t}_{\text{sen,fix}} = C^i_0 \tag{5}$$

where i is the index of the attraction, t is the year, and C^i_0 is a constant.

The hidden costs of environmentally-sensitive attractions are caused by tourists' impact on the natural environment. Two of the noticeable hidden costs are the expenditure on environmental protection and the carbon footprint generated by the transportation of tourists. We consider the hidden costs as a linear function of the number of tourists in the attraction, and denote it as $C^{i,t}_{\text{sen,hid}}$. Further, noticing that the accumulation of impact on the natural environment can cause increasing degradation, we decide to use a shifted exponential function to model the hidden costs:

$$C^{i,t}_{\text{sen,hid}} = k_1(e^{\beta_1 P^{i,t}_{sen}} - 1) \tag{6}$$

where k_1 and β_1 are constants, and $P^{i,t}_{\text{sen}}$ is the number of tourists in environmentally-sensitive attraction i in year t.

5.4.4 Costs and hidden costs of environmentally-insensitive attractions

As environment degradation is less likely to be caused by the tourists in environmentally-insensitive attractions, the hidden costs are mainly generated by the costs of maintaining the infrastructure and other social expenses when the number of tourists exceeds the capacity of the area. We denote the costs as

$$C_{\text{in}}^{j,t} = C_0^j + k_2(P_{\text{in}}^{j,t} - Q_{\text{in}}^{j,t}) \tag{7}$$

where k_2 is a constant, and $Q_{\text{in}}^{j,t}$ is the capacity of the attraction j in year t.

5.4.5 Costs and hidden costs of local community areas

Local community areas that has no tourist attractions are also affected by the tourism industry, but in a different way. Less tourists go to these areas than to the attractions, so the extra epenses are not considered as hidden costs. Rather, the will quantify the hidden costs as the impact on the residents' life quality, such as noise pollution, traffic congestion, overcrowding, and so forth. They are researched in the coming section.

5.5 Residents' satisfaction level

5.5.1 Modeling ideas

Too many tourists in residential areas can disrupt local life, although residents also benefit from the tourism industry's prosperity. These two factors create a contradiction that must be balanced. While costs and hidden costs can be easily quantified in monetary terms, residents' satisfaction is more subjective and harder to measure. We will develop a model to quantify residents' satisfaction, using both objective and subjective factors, and incorporate it as a constraint in the optimization model.

The following sections will explore the factors affecting residents' satisfaction and how to quantify them.

5.5.2 Residents' revenue

The residents' revenue is a factor that can be influenced by the tourism industry. The revenue can be divided into two parts: the revenue generated by the tourism industry and the revenue generated by other industries. The former is directly related to the number of tourists in the area, while the latter is relatively stable but can also be influenced to some extent.

We denote the residents' tourism revenue in area m in year t as $R_{\text{tour}}^{m,t}$, and the residents' non-tourism revenue in area m in year t as $R_{\text{non}}^{m,t}$. We model the two kinds of revenue as follows:

$$R_{\text{tour}}^{m,t} = R_2 + \gamma_t P^t \tag{8}$$

$$R_{\text{non}}^{m,t} = R_1(1 - e^{-\gamma_n P^t}) \tag{9}$$

where R_1, R_2, γ_t, and γ_n are constants. The two equations imply that the residents' tourism revenue grows linearly with the number of tourists, while the residents' non-tourism revenue also grows with the number of tourists but at a decreasing rate. This is because the growth of the tourism industry can bring more job opportunities and stimulate the local economy, but the influence on other industries is limited.

Further, we suppose that in different kind of areas, the composition of the residents' revenue is different. We simulate this by assigning different weights to the two kinds of revenue in different areas. We show the weights in Table 5. Larger weights indicate higher proportion of tourism or non-tourism industry in the area.

Table 5: Weights of the residents' revenue in different areas

Area	**Weight of tourism revenue**	**Weight of non-tourism revenue**
Tourism-intensive area	4/5	1/5
Tourism-affected area	1/2	1/2
Residential area	1/5	4/5

Utilizing the weights and Equations 8 and 9, we represent the residents' overall revenue in each area as follows:

$$R^{m,t} = w_{\text{tour}} R^{m,t}_{\text{tour}} + w_{\text{non}} R^{m,t}_{\text{non}} \tag{10}$$

where w_{tour} and w_{non} are the weights of the tourism revenue and the non-tourism revenue in the area m.

5.5.3 Residents' life costs

The residents' life costs are the costs that the residents need to pay for the impact of the tourism industry, including the costs of transportation and housing, and inflation caused by the growth of the tourism industry. We model the residents' life costs as a logistic function of the number of tourists:

$$S^{m,t}_{\text{cost}} = k_3 \log(1 + P^t + P_0) \tag{11}$$

where k_3 is a constant and P_0 denotes the population of Juneau.

With the concepts of the residents' revenue and life costs, we define the residents' net revenue as the difference between the revenue and the life costs.

5.5.4 Overcrowding level

The overcrowding level is a factor that reflects the bearing level of the residents on the number of tourists. The more tourists in the area, the more crowded the area is, and the more negative impact on the residents. We model the overcrowding level as a logistic function of the number of tourists:

$$S^{m,t}_{\text{crowd}} = k_4 \log(1 + P^t + P_0) \tag{12}$$

where k_4 is a constant, and P_0 denotes the population of Juneau.

5.5.5 Satisfaction with social resources

Social resources are the resources that the residents can use in their daily life, such as the quality of the infrastructure, the availability of public services, and the convenience of transportation. Influx of tourists can lead to the degradation of social resources, which can affect the residents' satisfaction level. On the other hand, government's expenditure on the social resources can improve the residents' satisfaction level. We model the residents' satisfaction with social resources as a linear function of the government's expenditure and the number of tourists:

$$S_{\text{res}}^{m,t} = S_0 + k_5(1 - e^{-\gamma_s E_{\text{com}}^{m,t-1}}) - k_6(P^t + P_0) \tag{13}$$

where S_0, k_5, k_6, and γ_s are constants. S_0 denotes base satisfaction level without the influence of the government's expenditure and the number of tourists.

5.5.6 Overall satisfaction level

The residents' overall satisfaction level is a comprehensive reflection of the residents' satisfaction with the impact of the tourism industry. We normalize the residents' satisfaction level in each area to a value between 0 and 1, and denote it as Y_i:

$$Y_i = \frac{X_i - \min(X_i)}{\max(X_i) - \min(X_i)} \tag{14}$$

where X_i is the residents' overall satisfaction level in area i. The constants in Equations 8–11 are determined by historical data, and that in Equations 12–13 are set to be 1 for simplicity. This choice is arbitrary and can be improved by field research or other methods.

Next, we apply analytic hierarchy process (AHP) to determine the weights of the factors that affect the residents' satisfaction level. The AHP is a method to quantify subjective factors by comparing the importance of the factors. We set the decision matrix as

$$A = \begin{bmatrix} 1 & 1/2 & 1 \\ 2 & 1 & 3 \\ 1 & 1/3 & 1 \end{bmatrix} \tag{15}$$

The eigenvector, weights, maximum eigenvalue, and consistency index (CI) are shown in Table 6. The random index (RI) is 0.58, and the consistency ratio (CR) is 0.0155, which is less than 0.1, indicating that the weights are consistent. Note that we normalize the final weights to make the sum of them equal to 100 rather than 1 here.

Table 6: Weights of the factors that affect the residents' satisfaction level

Factor	**eigenvector**	**Weight**	**Max. eigenvalue**	**CI**
Residents' net revenue	1.145	24	3.018	0.009
Overcrowding level	2.621	55		
Satisfaction with social resources	1	21		

Using the weights, we calculate the residents' overall satisfaction level as follows:

$$S^{m,t} = 24Y_{\text{revenue}} + 55Y_{\text{costs}} + 21Y_{\text{crowd}} \tag{16}$$

where Y_{revenue}, Y_{costs}, and Y_{crowd} are calculated from $R^{m,t}$, $S_{\text{cost}}^{m,t}$, and $S_{\text{crowd}}^{m,t}$ respectively, normalized by Equation 14. We will constrain the residents' overall satisfaction level in the optimization model to be greater than a certain value, which is set to be 80 for simplicity.

We visualize the proportion of components in the residents' satisfaction level in Figure 5 in a pictogram.

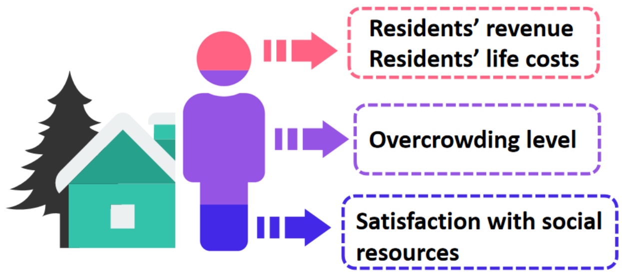


Figure 5: Proportion of components in the residents' satisfaction level

5.6 Government's revenue from tourism industry

The government's revenue from the tourism industry comes directly from the taxes and fees collected from the tourism industry. We fit the government's revenue to the number of tourists using a linear regression model, a quadratic regression model, and a cubic regression model. The fitting results shown in Figure 6 show that all three models fit the historical data well with R^2 values greater than 0.9. For simplicity, we choose the linear regression model to predict the government's revenue in the future 20 years. We denote the government's revenue in year t as R^t, and model it as follows:

$$R^t = k_7 P^t \tag{17}$$

where k_7 is a constant.

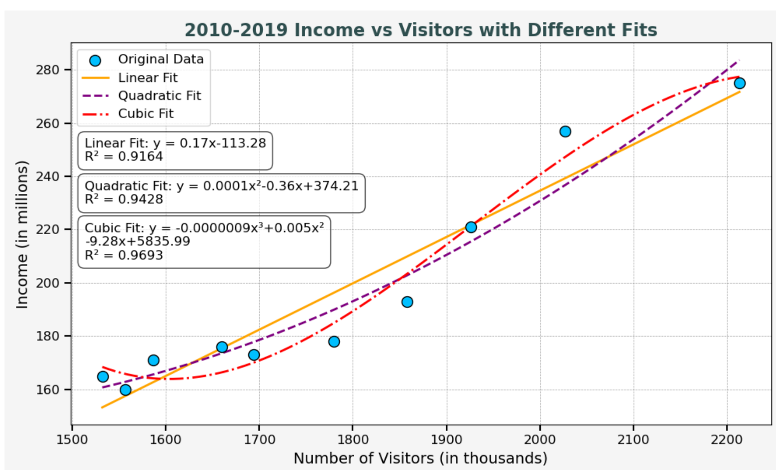


Figure 6: Prediction of the government's revenue from the tourism industry

5.7 Government's expenditure on attractions and local community areas

Government expenditure is an optimization variable in the model, aimed at promoting the sustainable development of the tourism industry. We divide the expenditure into two categories: one for environmentally-insensitive attractions and one for local community areas. The expenditure on attractions is used to maintain infrastructure and social resources, while the expenditure on community areas is focused on improving residents' quality of life.

We denote the government's expenditure on environmentally-insensitive attraction j in year t as $E_{\text{in}}^{j,t}$, and the government's expenditure on local community area k in year t as $E_{\text{com}}^{k,t}$. The effect of the government's expenditure on local community areas has been cxonsidered in Equation 13. We model the effect of the government's expenditure on environmental-insensitive attractions as Equation 18:

$$Q_{\text{in}}^{j,t} = k_8(1 - e^{-\gamma_e E_{\text{in}}^{j,t-1}}) \tag{18}$$

where k_8 and γ_e are constants. This equation implies that the capacity of the environmentally-insensitive attractions can be improved by the government's expenditure, thus reducing the hidden costs generated by tourists.

Imposing limitations on environmental-sensitive attractions will cause the tourists to flow to other areas, which will increase the hidden costs in these areas. To prevent this, the expenditure on environmentally-insensitive attractions and local community areas should be increased properly to improve the capacity or social resources in these areas. We will show in the next section how to balance the government's expenditure to maximize the overall net benefit of the tourism industry.

5.8 Overall net benefit of tourism

The overall net benefit of tourism in year t is the government revenue generated by the tourism industry subtracted by costs and hidden costs as well as the expenditure. We denote it as B^t:

$$B^t = R^t - \sum_i C_{\text{sen}}^{i,t} - \sum_j C_{\text{in}}^{j,t} - \sum_j E_{\text{in}}^{j,t} - \sum_k E_{\text{com}}^{k,t} \tag{19}$$

The objective of the optimization model is to maximize the overall net benefit of the tourism industry for the future 20 years. To optimize the objective, we are going to formally build the optimization model and solve it in the next section.

6 Optimization and Analysis

6.1 Model Formulation

Based on the model design, we build the optimization model to maximize the overall net benefit of the tourism industry in Juneau for the future 20 years:

$$\max \quad B = \sum_t^{20} B^t$$

And constraints are from Equation 1–13, 16–19. The optimization variables are the government's expenditure on environmentally-insensitive attractions and local community areas, $E_{\text{in}}^{j,t}$ and $E_{\text{com}}^{k,t}$, as well as the limitation to be imposed on the number of tourists in environmentally-sensitive attractions, $Q_{\text{sen}}^{i,t}$.

6.2 Model Solution

6.2.1 Solving method

We solve the optimization model using the simulated annealing algorithm (SA). The SA is a heuristic optimization algorithm that is used to approximate the global optimum of a given function. It is suitable for our model because it can handle the non-convex and non-linear constraints in the model, and can find an approximate global optimum in a reasonable time.

The algorithm of SA is described as the following pseudo-code:

Algorithm 1 Simulated Annealing Algorithm

```
current ← initial solution
for t = 1 to ∞ do
    T ← schedule(t)
    if T = 0 then
        return current
    end if
    next ← neighbour(current)
    ΔE ← energy(current) - energy(next)
    if ΔE > 0 or exp(ΔE/T) > rand(0, 1) then
        current ← next
    end if
end for
```

6.2.2 Data using

In the process of solving the model, all data related to the number of tourists come from real data searched online. Other data related to the economy are based on estimates from collected data.

6.2.3 Solution

By applying the SA algorithm to the optimization model, we obtain a solution that maximizes the overall net benefit of the tourism industry in Juneau for the future 20 years. The solution includes the government's expenditure and the limitation of number of tourists on environmentally-sensitive attractions. The search path of the SA algorithm is shown in Figure 7, with 2,000 iterations.

The optimization objective corresponding to the solution is shown in Figure 8. The result shows that the net benefit first decreases in the first few years, then increases steadily higher than the initial value. This shows a positive effect of the sustainable development in long-term. We will see that the initial decrease is caused by the increase in the government's expenditure on the protection of the environment and the improvement of the infrastructure.

One of the optimization variables, the government expenditure for improvement of the infrastructure, is shown in Figure 9a. The result shows that more expenditure is allocated to tourism-intensive areas, which shows the government's effort to improve the infrastructure of local community, which can conciliate the residents who are experiencing the overtourism. In addition, the trend after the first 5

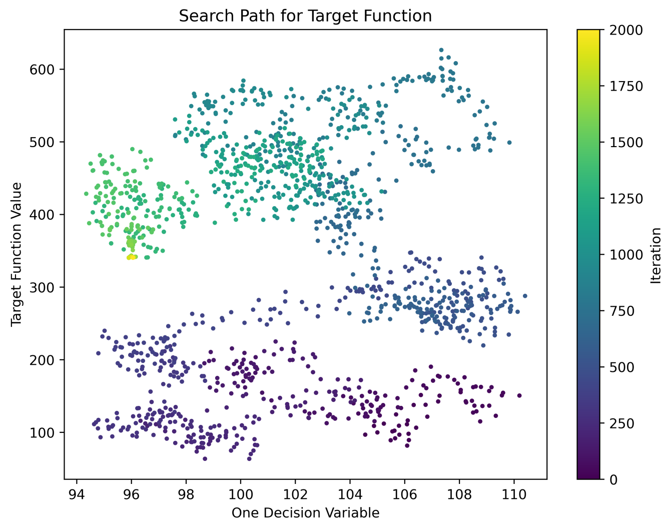


Figure 7: Search path of the SA algorithm

years is highly stable, which indicates that the expenditure has reached a balance between the protection of the environment and the improvement of the infrastructure.

The other optimization variable, the limitation of number of tourists in all environmentally-sensitive attractions, is shown in Figure 9b with the number of tourists in all environmentally-insensitive attractions. It can be observed that the number of tourists in environmentally-sensitive attractions has slightly decreased, while the number of tourists in environmentally-insensitive attractions has significantly increased. This indicates that over the next 20 years, due to the government's restrictions on environmentally-sensitive attractions, an increasing number of tourists will visit the latter, resulting in a shift shown in Figure 10.

6.3 Sensitivity Analysis

To test the robustness of the model, we conduct a sensitivity analysis on the model parameters. We vary parameters in the model and observe the changes in the net benefit of the tourism industry. The parameters include: the weights of the attractions, the satisfaction level of the residents, and other secondary parameters. The relationship between the parameters and the net benefit is shown in Figure 11.

- **Influence of the weights of the attractions:** Figure 11a shows that when the number of tourists remains constant, the net benefit of the tourism industry increases first and then decreases with the increase of the weights of a kind of attractions. This indicates that lower weights decrease the number of tourists in the attractions, thus reducing the revenue and so the net benefit, while higher weights increase the hidden costs, thus reducing the net benefit. The model is sensitive to the weights of the attractions, which reflects the real-world situation that the government should balance the attractiveness of the attractions to tourists and the impact on the environment.

- **Influence of the satisfaction level of the residents:** Figure 11b shows how the net benefit of

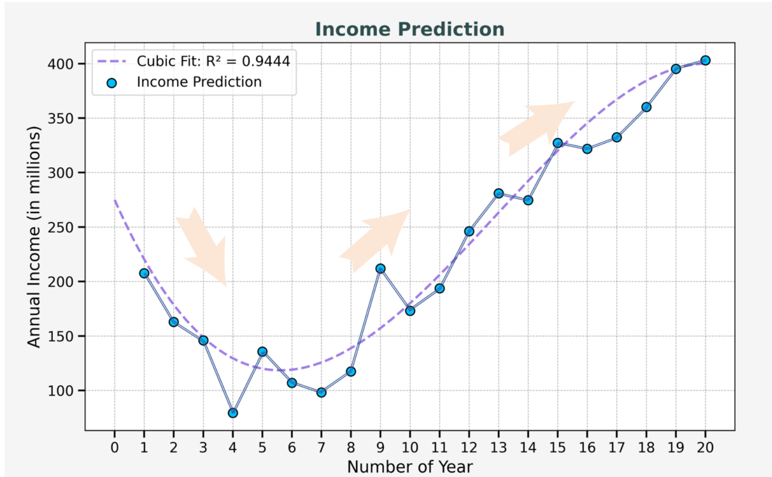
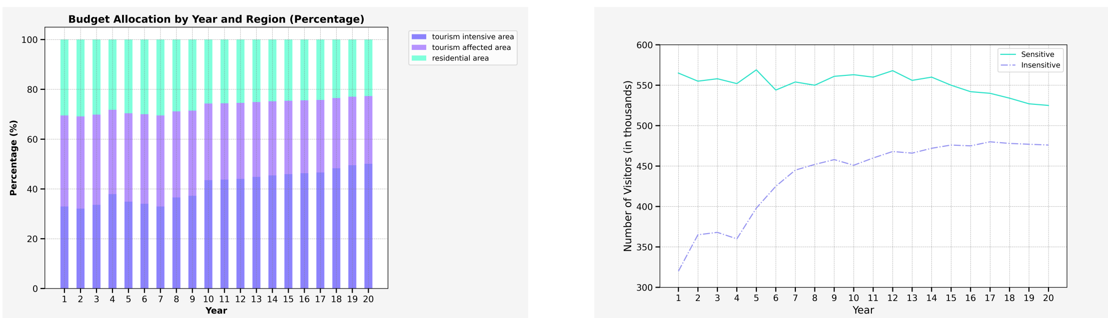


Figure 8: Prediction of the net benefit



(a) Plan of the government's expenditure (b) Number of tourists in different attractions

Figure 9: Results of the optimization model

the tourism industry changes with the satisfaction level constraint set at different values. When the satisfaction level deviates from the optimal value, the net benefit decreases. We consider higher constraint values cause the government to have less freedom to allocate the expenditure and focus on the protection of the environment, thus suppressing the development of the tourism industry. Lower constraint values may allow more tourists to flow to the local community areas, thus increasing the hidden costs and reducing the net benefit.

- **Influence of secondary parameters:** We also apply a *correcting coefficient* (CC) to secondary parameters in the model, such as the distance between the attractions and the residential areas. A CC is a deviation from the original value such that $P_{\text{new}} = (1 + CC)P_{\text{old}}$, which is used to how the model is sensitive to the change of those parameters. Figure 12 shows that when the CC is between -0.4 and 0.6, the change in the net benefit is within 8%. This indicates that the model is robust to the change of the secondary parameters.

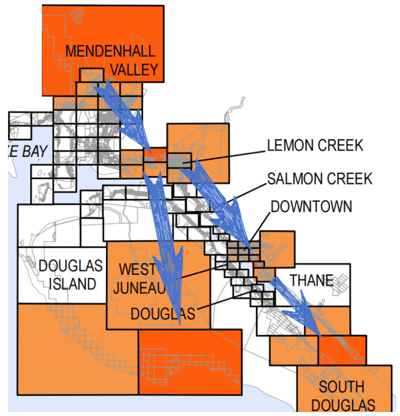
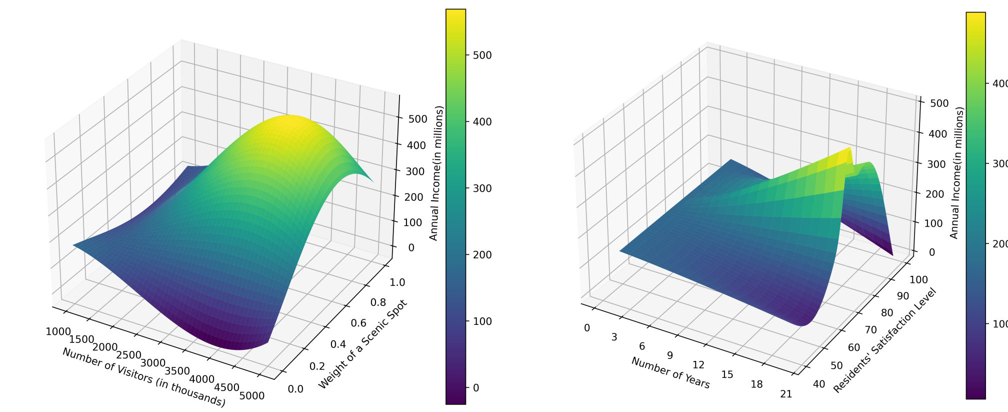


Figure 10: Shift of the number of tourists in different attractions



(a) Influence of the weights of the attractions

(b) Influence of the satisfaction level

Figure 11: Results of the sensitivity analysis

7 Adaptation to Charleston

To show the generalizability of our model, we adapt the model to Charleston, a city in South Carolina that is also a popular tourist destination. We modify the model by changing the parameters and the constraints to fit the local conditions in Charleston. The model is then applied to the tourism industry in Charleston to optimize the net benefit of the tourism industry.

7.1 Background and Analysis

Charleston is in South Carolina, the United States. It is a city boasting its rich history and old architecture dating back to the colonial era. The city is also famous for its beautiful beaches and the warm climate.[4]

Compared to Juneau, Charleston has 5 times larger population and a more developed tourism industry. Another substantial difference is that Charleston has no environmentally-sensitive attractions like Juneau, but its attractions are much more concentrated in the city center. The city is also facing the problem of overtourism, which brings serious strain for the residents and the infrastructure.[5]

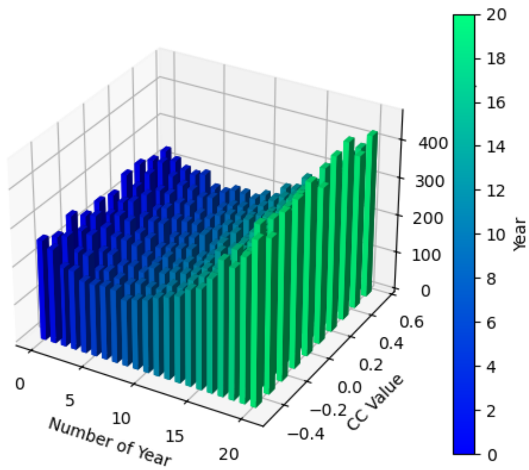


Figure 12: Influence of secondary parameters

7.2 Model Adaptation

7.2.1 Sectorization of Charleston

The first step of the model adaptation is to sectorize Charleston into different areas, since our model is based on the sectorization of a city. We divide Charleston into three kinds of areas the same as Juneau: tourism-intensive areas, tourism-affected areas, and residential areas. However, there are only environmentally-insensitive attractions in Charleston.

The sectorization is shown in Figure 13. A remarkable difference from Juneau is that the attractions are more concentrated in the city center, which is demonstrated more clearly in Figure 14. This condition is more likely to cause overtourism and hidden costs in areas around the city center, which we will show in the following sections.

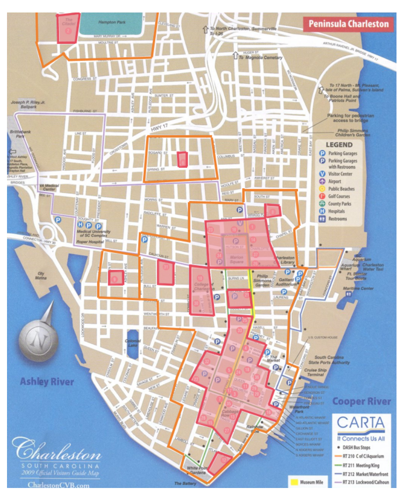


Figure 13: Sectorization of Charleston

(a) Distribution in Juneau

(b) Distribution in Charleston

Figure 14: Distribution of attractions in Juneau and Charleston

7.2.2 Results and Analysis

We apply the model to the tourism industry in Charleston and solve the optimization model to maximize the overall net benefit of the tourism industry.

The net benefit is shown in Figure 15. The result shows that the net benefit increases steadily over time, which indicates a positive effect of the sustainable development of the tourism industry in Charleston. That is not the case in Juneau, where the net benefit first decreases and then increases. This difference is caused by the fact that Charleston has no environmentally-sensitive attractions, so the hidden costs are smaller and the government does not need to allocate much expenditure to protect the environment.

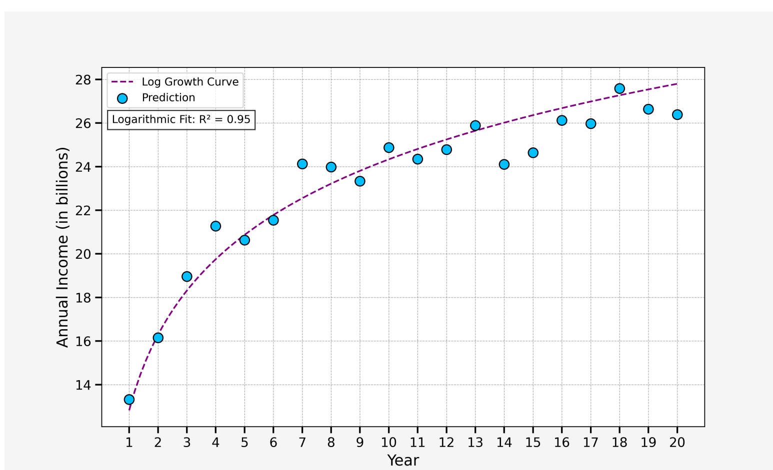
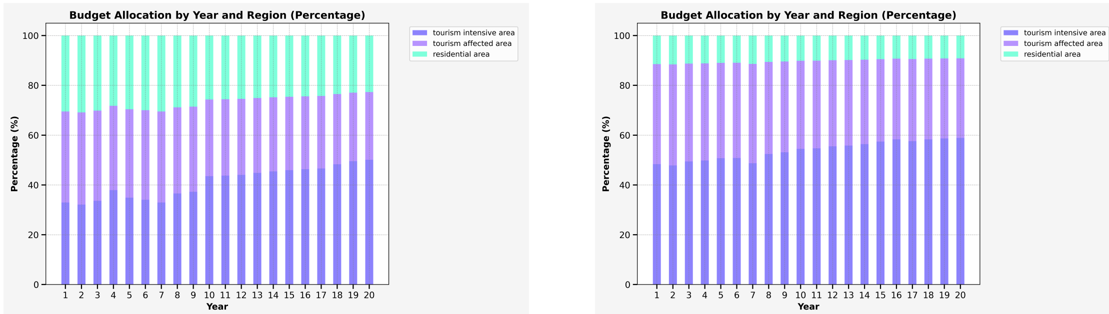


Figure 15: Prediction of the net benefit in Charleston

The government's expenditure is shown in Figure 16b, compared to that of Juneau. The result shows a remarkable difference from Juneau: the government's expenditure on tourism-intensive areas is much lower than that in Juneau, and the expenditure on tourism-affected areas and residential areas is much higher. We consider this result reasonable, as the higher expenditure in tourism-intensive area in Juneau is used to protect the environment, while in Charleston, the government can focus more on improving the infrastructure and the social resources in the tourism-affected areas and the residential areas.



(a) Plan of expenditure in Juneau (b) Plan of expenditure in Charleston

Figure 16: Comparison of the government's expenditure plan in Juneau and Charleston

It turns out that mesures to protect the environment is of great importance in Juneau, while in Charleston, the government should focus more on improving the infrastructure and the social resources in the tourism-affected areas and the residential areas. This difference is caused by the different conditions of the two cities, and the model is able to adapt different environmental and social conditions to optimize the net benefit of the tourism industry.

As for attractions that have fewer tourists, our model suggests that the government does not need to allocate much expenditure to protect the environment, but should focus on improving the infrastructure and the social resources in the areas. Certain measures can also be taken to attract more tourists to these areas, such as improving the transportation and the public services. Those kind of measures that improve the satisfaction of the residents turns out to be effective in attracting more tourists and increasing the net benefit of the tourism industry.

8 Advantages and Disadvantages

The proposed model demonstrates several notable advantages:

- It divides the city into distinct community areas, classifying them into three types for a more nuanced understanding of tourism's impact. This aids in crafting policies to balance tourism and residents' daily lives.
- The model categorizes tourist attractions into environmentally sensitive and non-sensitive types, allowing for a clearer distinction of overtourism's effects on each. This classification helps measure tourism costs from various perspectives, guiding governments in creating effective strategies to protect and develop different attractions.
- It optimizes tourism revenue in Juneau over the next 20 years, emphasizing a long-term and sustainable approach. This forward-looking perspective highlights the model's role in supporting the sustainable development of Juneau's tourism sector.
- The model exhibits strong generalizability, making it adaptable to other tourist cities with varying characteristics. It provides insights into sustainable tourism policies under diverse conditions, including differences in attraction distribution, attraction types, and tourist numbers.

Despite its advantages, the model has certain limitations:

- It heavily depends on detailed tourism-related data at the community level, which can be difficult to obtain. To address this, a series of assumptions and simulated data were employed, reducing the model's authenticity.
- The model does not precisely quantify the carbon footprint or environmental damage caused by overtourism to specific sensitive attractions. Instead, generalized formulas are used to represent potential environmental costs, which, while enhancing generalizability, sacrifice precision.

9 Conclusions

In this paper, we have developed a model to optimize the net benefit of the tourism industry in Juneau and Charleston. The model divides the cities into different areas and classifies the attractions into different types, and quantifies the costs and hidden costs of tourism in each area. The model also incorporates the residents' satisfaction level and the government's revenue and expenditure into the optimization model, and solves it using the simulated annealing algorithm.

The results show that the model is effective in optimizing the net benefit of the tourism industry in Juneau and Charleston. The model provides insights into the impact of tourism on different areas and attractions, and guides the government in making policies to promote the sustainable development of the tourism industry. The model is also generalizable to other tourist cities such as Charleston, and can be adapted to optimize the net benefit of the tourism industry in those cities.

Future research should focus on how to improve the model by relax some of the assumptions and incorporate more detailed data into the model. The model can also be extended to consider more factors that affect the tourism industry, such as the impact of the tourism industry on the local and external economy environment, and the impact of the tourism industry on the local culture.

References

[1] Juliellen Sarver. "Case Study: Environmental Impacts of Tourism in Juneau, Alaska". English. In: *Carolina Planning Journal* (Feb. 26, 2019).

[2] Brian Vander Naald. "Examining tourist preferences to slow glacier loss: evidence from Alaska". In: *Tourism Recreation Research* 45.1 (2020), pp. 107–117. DOI: 10.1080/02508281.2019.1606978.

[3] Tazim Jamal and Dianne Dredge. "6. Tourism and Community Development Issues". In: *Tourism and Development*. Ed. by Richard Sharpley and David J. Telfer. Bristol, Blue Ridge Summit: Channel View Publications, 2014, pp. 178–204. DOI: 10.21832/9781845414740-008.

[4] Rich Harrill and Thomas D Potts. "Tourism planning in historic districts: Attitudes toward tourism development in Charleston". In: *Journal of the American Planning Association* 69.3 (2003), pp. 233–244.

[5] Brian Roberts Turner. "Charleston's crisis of over-tourism and its regulatory response – a case study in destination management". In: *Ethical and Responsible Tourism*. London: Routledge, 2023. DOI: 10.4324/9781003358688.

Dear the tourist council of Juneau:

Juneau is a shining star in Alaska's tourism industry, and our team is delighted to be able to contribute to the sustainable development of Juneau's tourism. To address the impacts of overtourism in Juneau, after conducting an in-depth study of its past tourism development, we have established a practical optimization model to assist in providing decision support for **sustainable tourism** in Juneau.

Using historical data, we predicted the total number of tourists in Juneau for the next 20 years. The results indicate that the number of tourists in Juneau will continue to rise. This suggests that overtourism at various attractions in Juneau will become increasingly severe.

To establish the model, we **divided Juneau into three different areas** based on the degree of impact of tourism and **categorized all attractions into two types**. Then, we reasonably estimated the hidden costs generated by the two types of attractions under the condition of overtourism. To measure the extent to which local residents in Juneau are affected by tourism, we established a **satisfaction rating system** for Juneau residents' community. Also, our model considers expenditures on attractions and local community areas.

With the net revenue from Juneau's tourism over the next 20 years as the optimization objective, we have derived the results of the optimization model.

Inspired by the results, we will propose the following **advice** for the Juneau's sustainable tourism:

- *Further increase the restrictions on the number of visitors to environmentally sensitive attractions, such as Mendenhall Glacier.*
- *Increase expenditures in environmentally insensitive attractions to enhance their passenger capacity.*
- *For communities that are significantly affected by tourism, increase the expenditure on community resource construction and maintaning.*

Finally, we sincerely wish that Juneau will shine even brighter on the path of sustainable tourism development!

Sincerely

Team#2504110