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## From TBMP to TSMP:Juneau's Tourism Never Ends

With the development of tourism in Juneau, tourists are pouring into the city in an endless stream. While creating huge wealth, the living space of local residents has been squeezed. At the same time, the Mendenhall Glacier is gradually retreating. To resolve these contradictions, we develop a **sustainable tourism measure plan (TSMP)**, aiming to balance tourism development with the well-being of local residents and environmental protection.

Several models are established: Model II: Multi-Objective Optimization Model for Sustainable Tourism; Model I: Expenditure-Feedback Model for Additional Revenue; Model III: Expansion Model for the Maldives

For Model I: We built a multi-objective optimization model, aiming to maximize fiscal revenue, minimize environmental damage, and maximize residents' satisfaction. **Regression analysis, the analytic hierarchy process (AHP)** were used to construct the objective functions. The **NSGA-II Algorithm** was applied to search for the Pareto-optimal solution set. Taking the data of 2023 as an example, the optimal measures for the next year was obtained: limit the tourist flow to **around 1.43 million**, increase the tourist fee by **72.4 USB per person**, and increase the hotel tax rate by 0.08.

For Model II: This model refines Model I by expending the extra revenue from its optimal measures for circular benefits. By examining the decision variables in the optimal solution of Model II, we found that the variables related to **road area** and **infrastructure carrying capacity** are always near initial upper-bounds, highlighting their significance for overall efficiency. Therefore, we constructed an **expenditure allocation model** for these two indicators and a **feedback model** regarding residents' satisfaction was constructed.

Before promoting the model, we conducted a **sensitivity analysis** using the **local perturbation method** and presented the results in a **heatmap**. We measured the importance of decision variables by comparing correlation coefficients. The results show that limiting the number of tourists is the most important indicator. Increasing tourist fees is more important than hotel taxes. Additionally, tourist diversion also needs to be taken into account.

For Model III: To verify the generalizability of the model, we applied it to the **Maldives**, which also faces tourism sustainability issues. The model was adjusted to get the optimal solution, and a sensitivity analysis was conducted. The results showed both **consistency** with Juneau and **reasonable differences**, like a higher correlation between residents' satisfaction and tourist numbers. This fully shows the model's **universality**.

In addition, we also discussed the applicability of the model in low-tourist-volume areas and offered feasible plans for sustainable tourism development, based on previous findings.

**Keywords:** Sustainable Tourism; Multi-Objective Optimization; NSGA-II Algorithm; Sensitivity Analysis

## 从 TBMP 到 TSMP：朱诺的旅游业永不停歇

随着朱诺旅游业的发展，游客如潮水般涌入这座城市。在创造巨大财富的同时，当地居民的生活空间却日益紧缩。与此同时，门登霍尔冰川也在逐渐消退。为解决这些矛盾，我们制定了**可持续旅游行动计划（TSMP）**，旨在平衡旅游业发展与当地居民福祉及环境保护。

建立的模型有：模型I：可持续旅游多目标优化模型；模型II：额外收入支出反馈模型；模型III：马尔代夫扩张模型

针对模型I：我们构建了一个多目标优化模型，旨在实现财政收入最大化、环境损害最小化以及居民满意度最大化。通过**回归分析和层次分析法（AHP）**构建目标函数，并运用**NSGA-II算法**搜索帕累托最优解集。以2023年数据为例，得出明年的优化措施：将游客流量控制在**约143万人次**，将**人均旅游税提高72.4美元**，并将酒店税率上调0.08个百分点。

针对模型II：该模型通过将最优措施产生的额外收入用于循环效益，对模型I进行了优化。通过分析模型I最优解中的决策变量，我们发现与**道路面积和基础设施承载能力**相关的变量始终接近初始上限，凸显了其对整体效率的重要性。因此，我们针对这两个指标构建了**支出分配模型**，并建立了反映居民满意度的**反馈模型**。

在推广该模型前，我们采用**局部扰动法**进行了**敏感性分析**，并将结果以**热图形式呈现**。通过比较相关系数评估决策变量的重要性，结果显示**限制游客数量是最重要的指标**，提高旅游费用的重要性超过酒店税，此外还需考虑游客分流问题。

关于模型III：为验证模型的普适性，我们将其应用于同样面临旅游业可持续发展问题的**马尔代夫**。通过调整模型获得最优解，并进行敏感性分析。结果显示，**与朱诺的结论保持一致**，同时存在**合理差异**，例如居民满意度与游客数量之间的相关性更高。这充分证明了该模型的**普适性**。

此外，我们还探讨了该模型在低游客量地区的适用性，并基于先前的研究成果，提出了可持续旅游发展的可行方案。

**关键词：**可持续旅游；多目标优化；NSGA-II算法；敏感性分析

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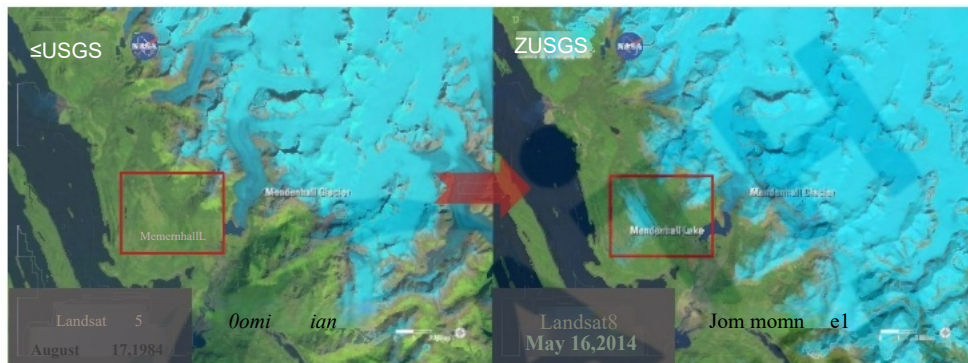
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# 1 Introduction

## 1.1 Problem Background

Located in one of the largest wilderness areas in the U.S., Juneau, Alaska, is home to vast national parks, glaciers, and a coastline stretching 6,640 miles [1]. Cruise tourism is the city's pillar industry, annually generating over \$100 million in wealth for Juneau. However, with crowds sailing in in record numbers, a series of problems gradually emerge. Socially, pressures resulting from overcrowding continue to plague the locals. Environmentally, the melting of glaciers is exacerbated by rising temperatures, which is caused by overtourism in part. The situation of glacier ablation is shown in the following figure 1.



**Figure 1: Comparison Chart of the Ablation of Mendenhall Glacier**

*The data above comes from the website of USGS [2]. It clearly shows that Mendenhall Lake expanded significantly from 1984 to 2014 due to glacier ablation.*

Since 1997, Juneau has implemented the Tourism Best Management Practices (TBMP) to better manage the tourism industry [3]. In recent years, faced with more severe tourism problems, Juneau has taken measures including controlling the number of tourists, increasing tourism fees, and so on... However, Due to their short-sightedness and one-sidedness, the measures have not won the trust of the residents. Designing a Tourism Sustainable Management Plan (TSMP) is what locals eagerly anticipate.

## 1.2 Restatement of the Problem

We are tasked with building an optimization model for sustainable tourism in Juneau, Alaska. **Our objective is to balance economic, social, and environmental concerns.**

Consequently, the problem can be analyzed as follows:

- **Model Building for Juneau's Sustainable Tourism**

- ◇ Construct an optimization model for the sustainable tourism industry in Juneau, Alaska.

The model should balance multiple factors.

Develop a plan for the utilization of additional revenue and elaborate on how it promotes sustainable tourism within the model.

- ◇ Conduct a sensitivity analysis for the model based on the discussion of key factors.

## 1 介绍

### 1.1 问题背景

阿拉斯加朱诺市坐落于美国最大的荒野区域之一，坐拥广袤的国家公园、冰川群和绵延6640英里[1]的海岸线。作为当地支柱产业的邮轮旅游，每年为朱诺市创造超过1亿美元的经济收益。然而随着创纪录的游客数量涌入，一系列问题逐渐显现。社会层面，过度拥挤带来的压力持续困扰着当地居民；环境层面，气温上升加剧了冰川消融，而过度旅游正是导致这一现象的部分原因。冰川消融的现状如图1所示。



图1：门登霍尔冰川消融对比图

上述数据来源于美国地质调查局（USGS）网站[2]。数据显示，门登霍尔湖（Mendenhall Lake）在1984年至2014年间因冰川消融而显著扩大。

自1997年起，朱诺市实施了旅游最佳管理实践（TBMP），以更好地管理旅游业[3]。近年来，面对更加严峻的旅游问题，朱诺采取了包括控制游客数量、提高旅游费用等措施.....然而，由于这些措施的短视和片面性，未能赢得居民的信任。制定旅游可持续管理计划（TSMP）是当地居民迫切期待的。

### 1.2 问题的重述

我们的任务是为阿拉斯加朱诺市建立一个可持续旅游的优化模型。我们的目标是平衡经济、社会和环境问题。

因此，该问题可按以下方式分析：

#### ● 朱诺市可持续旅游的模式构建

◇ 构建阿拉斯加朱诺市可持续旅游产业优化模型，该模型应平衡多个因素。

制定额外收入的利用方案，并阐述该方案如何在该模式中促进可持续旅游。

◇ 基于关键因素的讨论，对模型进行敏感性分析。

### ● Applicability to Other Destinations

- ◇ Adopt the model to another crowded tourist destination and explore the impact of geographical location on measures.  
promote the model to less-visited attractions for the sake of a more balanced tourism distribution.

### ● One-Page Memo

Considering the results obtained above,prepare a one-page memo to Juneau's tourist council.

## 1.3 Literature Review

This task is an optimization problem.Firstly,we need to determine the model-building method and the solution algorithm.

Regarding the modeling methods,system dynamics[4],and multi-objective optimization methods[5]can be adopted.Considering the accuracy and universality of the model,we use the multi-objective optimization method.

Ma Xiaoshu et al.[5]compared to the traditional multi-objective optimization algorithms and multi-objective genetic algorithms.Based on this,we finally choose the NSGA-II algorithm.

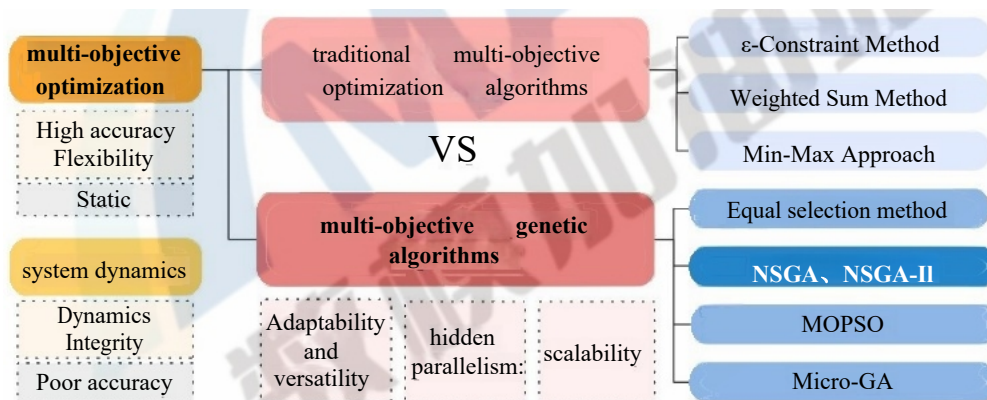


Figure 2:Literature Review Framework

## 1.4 Our Work

This task requires us to construct an optimized model for sustainable tourism with universal applicability,which mainly includes:

- 1.Construct a multi-objective optimization model with the goals of maximizing fiscal revenue,minimizing environmental damage,and maximizing resident satisfaction.
- 2.Solve the model using the NSGA-II algorithm and select the optimal combination of sustainable tourism measures.
- 3.Based on the benefit magnitudes of decision variables,construct an expenditure-feed-back model for additional revenue.

## ● 对其他目的地的适用性

◇ 将该模型应用于另一处拥挤的旅游目的地，探讨地理位置对措施效果的影响。

为实现旅游分布的更均衡，建议将该模式推广至游客较少的景点。

## ● 单页备忘录

根据上述结果，撰写一份单页备忘录提交给朱诺市旅游局。

### 1.3 文献综述

该任务是一个优化问题，首先需要确定模型构建方法和求解算法。

在建模方法上，考虑模型的准确性和通用性，采用系统动力学[4]和多目标优化方法[5]。

马晓树等人[5]比较了传统的多目标优化算法和多目标遗传算法，在此基础上，我们最终选择了 NSGA -II算法。

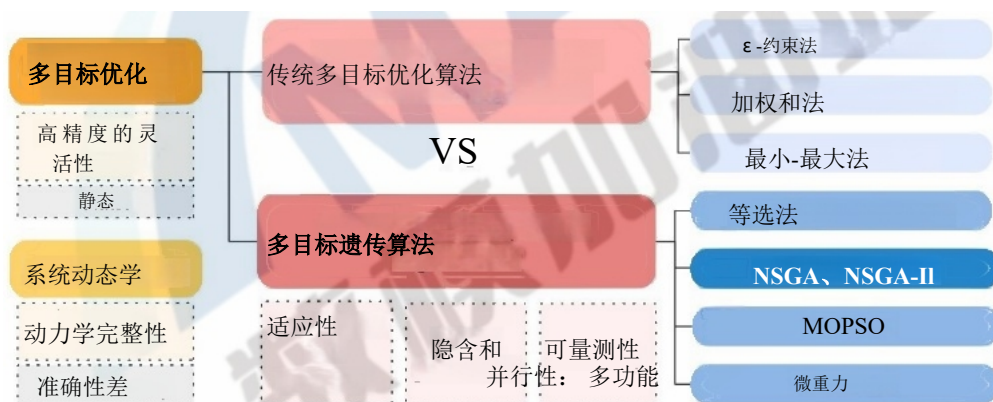


图2：文献综述框架

### 1.4 我们的工作

本任务要求我们构建一个具有普遍适用性的可持续旅游优化模型，主要包括：

1. 构建以财政收入最大化、环境损害最小化和居民满意度最大化为目标的多目标优化模型。
2. 使用 NSGA -II算法求解模型，选择可持续旅游措施的最佳组合。
3. 根据决策变量的效益量级，构建了附加收益的支出反馈模型。

4. Conduct a sensitivity test using the local perturbation method and analyze the importance of variables.

5. To test the universality of the model, we extended the model to the Maldives. In addition, suggestions for sustainable tourism development in low-tourist areas are provided.

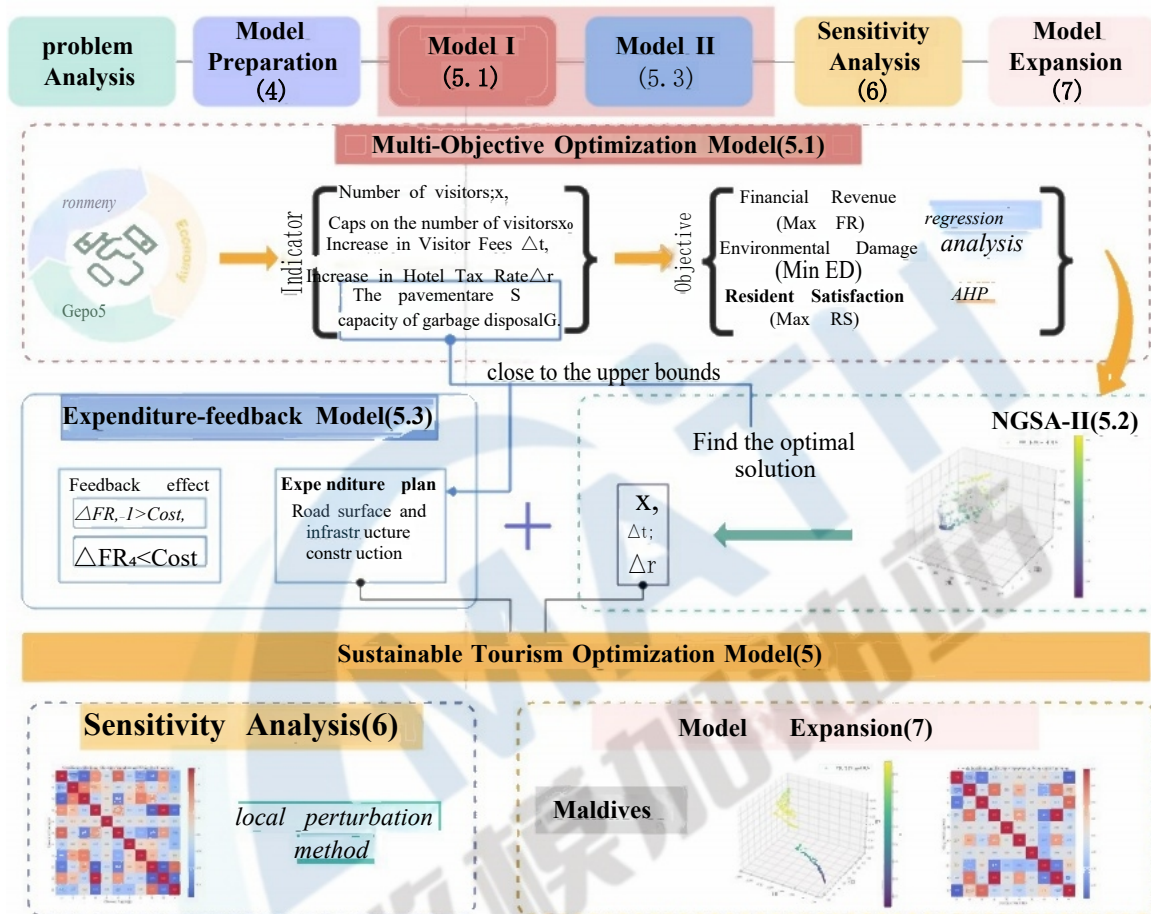


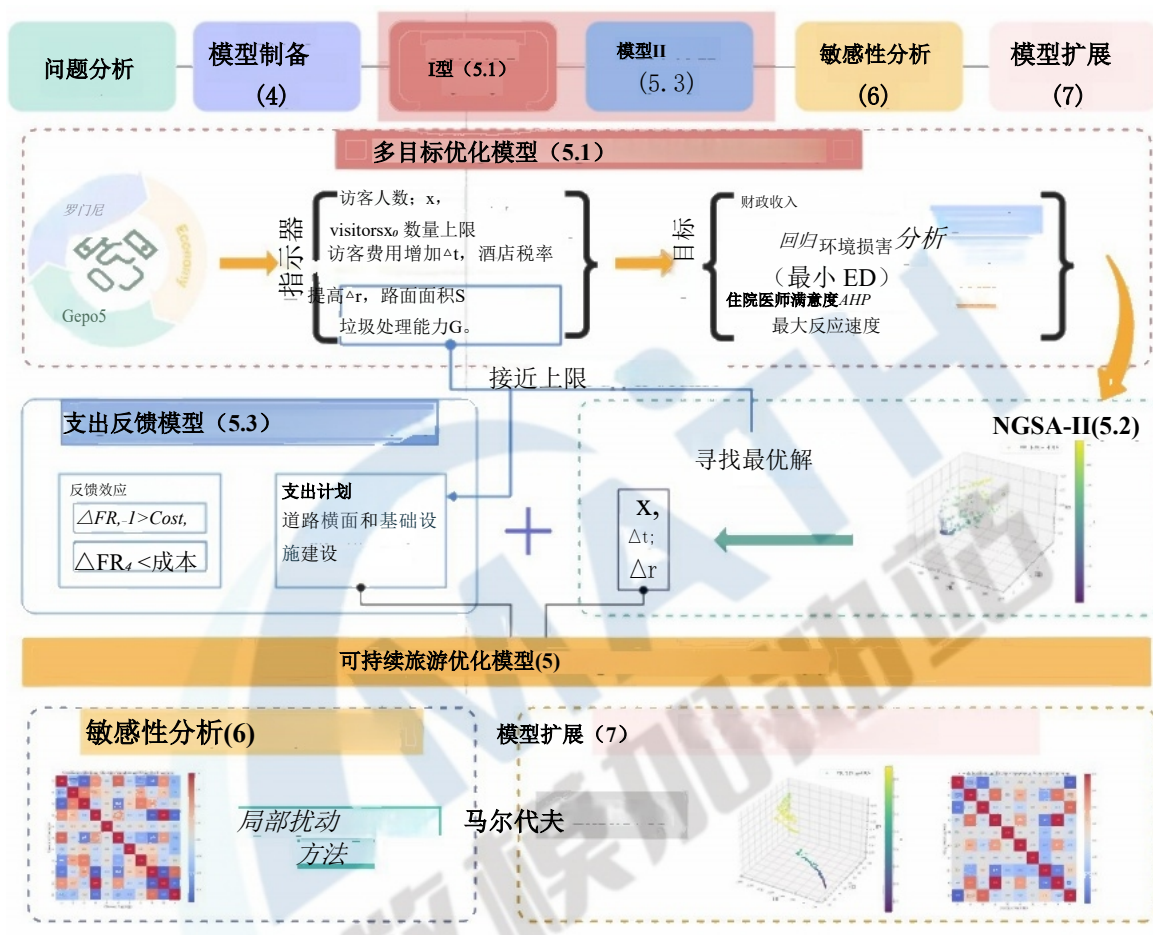
Figure 3:Flow Chart of Our Work

## 2 Assumptions and Justifications

- **Assumption 1:** The structure of the tourism market and the spending preferences of tourists remain relatively stable.  
**Justification:** Based on the empirical dimension, we assume that the consumer market and preferences are stable. Avoiding the instability of the model due to frequent changes in market structure and consumption preferences facilitates the construction and analysis of the model.
- **Assumption 2:** The tourist attractions in Juneau are somewhat independent, i.e., tourists' choices to visit a specific attraction aren't strongly influenced by others.  
**Justification:** This paper examines three major attractions in Juneau-Mendenhall Glacier, whale watching, and rain forests - that are independent of each other. We only need to

4. 采用局部扰动法进行灵敏度分析, 评估各变量的重要性。

5.为了检验模型的普遍性,我们将模型扩展到马尔代夫。此外,提出了低旅游地区可持续旅游发展的建议。



consider the separate impacts of each on sustainable tourism, omitting the complex inter-relationships between them to simplify the model.

● **Assumption 3: No extreme natural disasters or sudden major global events will occur in the short term.**

**Justification:** Such events are highly unlikely but can severely and unpredictably disrupt the tourism industry if they do. Excluding these factors allows the model to concentrate on regular tourism development trends.

● **Assumption 4: The actual number of tourists per day always meets the limit.**

**Justification:** Currently, Juneau has a visitor limit policy in place, so it is reasonable to assume that the policy is efficiently enforced to accurately control the number of tourists; at the same time, a stable tourist count provides reliable inputs to the regression analysis model, enhancing its reliability and predictive power.

**Note:** Additional assumptions are made to simplify analysis for individual sections. These assumptions will be addressed in the relevant locations.

### 3 Notations

The key mathematical notations used in this paper are listed in Table 1.

Table 1: Major notations

Notation	Description	Unit
$x_i$	Number of daily visitors to the attraction $i$	k/day
$\frac{7}{1}$	attraction $i$ Visitor Fees	USD/person
$\Delta t_i$	Increase in attraction $i$ Visitor Fees	USD/person
$r$	Hotel Tax	%
$\Delta r$	Increase in Hotel Tax Rate	%
$k$	Hotel Spending	USD/person
$x_0$	Caps on the number of daily visitors	k/day
$S$	The pavement area in Juneau	km <sup>2</sup>
$G$	The maximum carrying capacity of garbage disposal in Juneau	t
$AT$	Average Daily Temperature in Juneau	°C
$RS$	Resident Satisfaction	\
$FR$	Financial Revenue	USD/million
$ED$	Degree of Environmental Damage	\

考虑各因素对可持续旅游的独立影响，忽略其间的复杂相互关系以简化模型。

● 假设3：短期内不会发生极端自然灾害或突发重大全球性事件。

理由：这类事件虽然极不可能发生，但一旦发生，可能会严重且不可预测地破坏旅游业。排除这些因素，使模型能够集中于常规的旅游业发展趋势。

● 假设4：每天实际到访的游客人数始终满足限制。

理由：目前，朱诺市已实施游客限制政策，因此可以合理假设该政策能有效执行，从而准确控制游客数量；同时，稳定的游客数量为回归分析模型提供了可靠的数据输入，提高了模型的可靠性和预测能力。

注：为了简化对各个部分的分析，还做了其他假设。将在相关位置说明这些假设。

3 符号

本文所用的关键数学符号列于表1中。

表1：主要符号说明

符号	描述	单元
$x_i$	每日到访景点 <i>i</i> 的游客数量 景点 <i>i</i> 游客费用	天/日
$7$		美元/人
$1$		
$\Delta t$	游客费用的增加	美元/人
$r$	酒店税	%
$\Delta r$	酒店税税率上调	%
$k$	酒店消费	美元/人
$x_o$	每日访客人数上限	天/日
$S$	朱诺市6月的路面面积	km <sup>2</sup>
$G$	朱诺市垃圾处理最大承载量	t
$AT$	朱诺市六月平均气温	℃
$RS$	住院医师满意度	\
$FR$	财政收入	美元/百万
$ED$	环境损害程度	\

**Note:** There are some variables that are not listed here and will be discussed in detail in each section.

## 4 Model Preparation

### 4.1 Data Overview

Since the material doesn't directly offer data, we must determine which data to collect during the model-building process. After analyzing the problem, we find that we need to gather relevant information about Juneau, Alaska, including data like the number of tourists, sightseeing spending, carbon footprint, and mean temperature, among others. Given the large volume of data, instead of listing everything, we opt to visualize the data for presentation.

### 4.2 Data Collection

Table 2 Data and Database Websites

Database Names	Description
Number of visitors per year	<a href="https://www.traveljuneau.com/">https://www.traveljuneau.com/</a>
Attractions expenses	<a href="https://www.budgetyourtrip.com/">https://www.budgetyourtrip.com/</a>
Carbon footprint per year	<a href="https://www.noaa.gov/">https://www.noaa.gov/</a>
mean temperature per year	<a href="https://www.noaa.gov/">https://www.noaa.gov/</a>

### 4.3 Description of Tourism in Juneau

To build a more reasonable model, based on the collected data, we first analyzed the distribution of tourist attractions and the traffic conditions in Juneau.

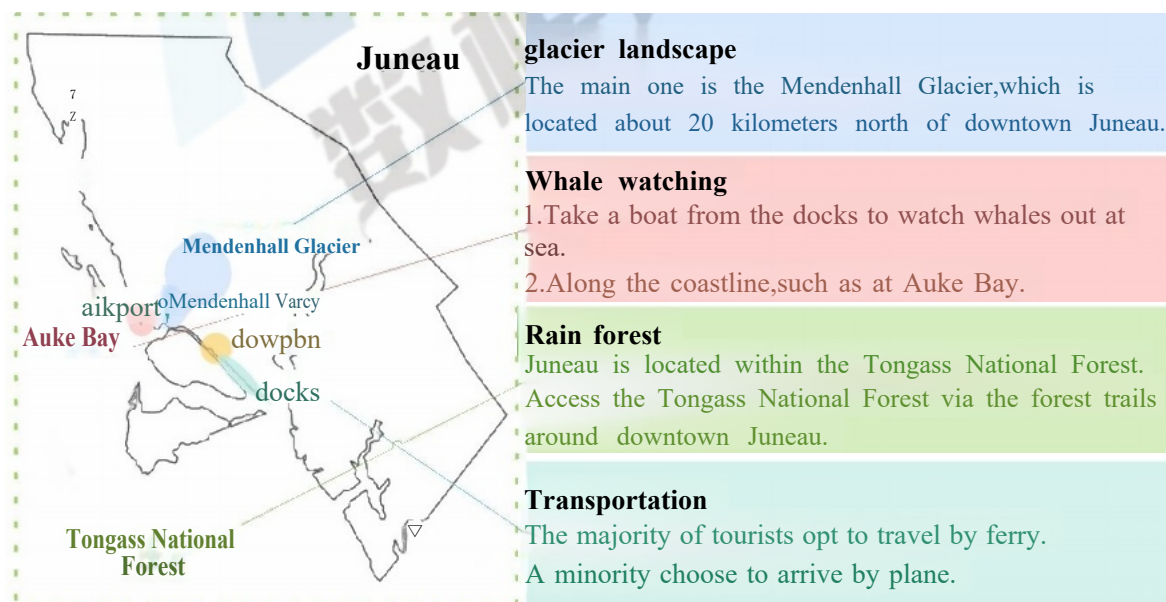


Figure 4: General Situation Map of Juneau

注：有些变量未在此处列出，将在各章节中详细讨论。

## 4 模型制备

### 4.1 数据概览

由于材料本身并未直接提供数据，我们需要在模型构建过程中确定具体收集哪些数据。经过问题分析，我们发现需要收集阿拉斯加朱诺市的相关信息，包括游客数量、观光消费、碳足迹、平均气温等数据。考虑到数据量庞大，我们没有罗列所有内容，而是选择通过可视化方式呈现数据以便展示。

### 4.2 数据收集

表2 数据与数据库网站	
数据库名称	描述
每年访客人数	<a href="https://www.traveljuneau.com/">https://www.traveljuneau.com/</a>
景点费用	<a href="https://www.budgetyourtrip.com/">https://www.budgetyourtrip.com/</a>
每年碳足迹	<a href="https://www.noaa.gov/">https://www.noaa.gov/</a>
年平均温度	<a href="https://www.noaa.gov/">https://www.noaa.gov/</a>

### 4.3 关于朱诺市旅游业的介绍

为了建立一个更合理的模型，我们首先基于收集的数据，分析了朱诺市旅游景点的分布情况及交通状况。

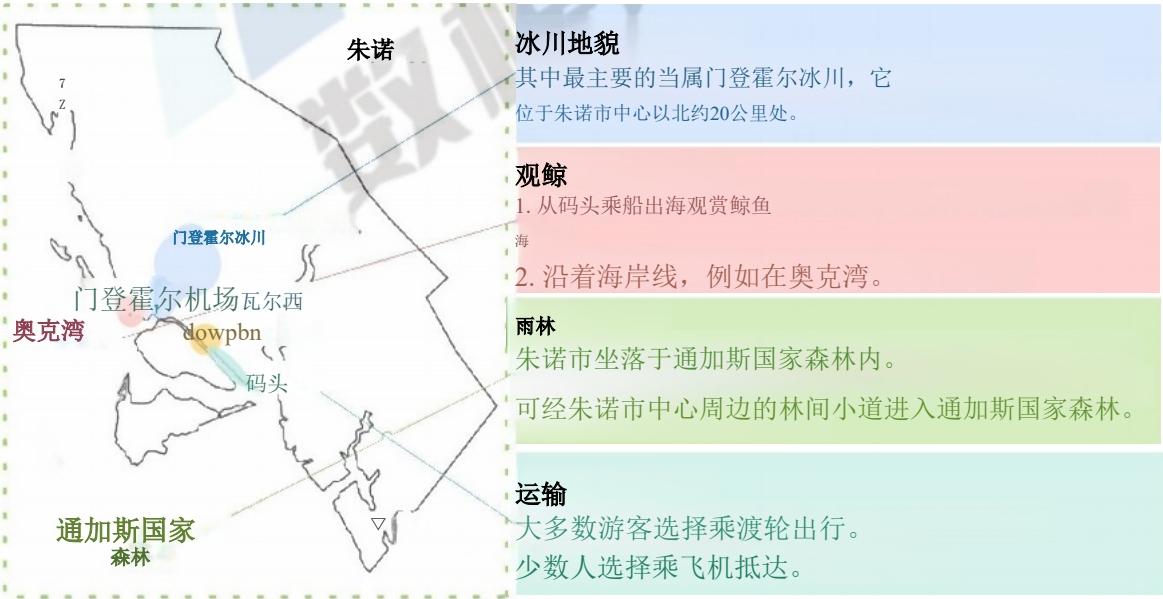


图4：朱诺市概况图

## 5 Sustainable Tourism Optimization Model

### 5.1 Multi-Objective Optimization Model

Multi-objective optimization model is a model that simultaneously optimizes multiple conflicting objective functions to achieve an optimal balance. In this question, the aim is to explore the optimal implementation plan for tourism stability measures under the goals of optimization (maximizing financial revenue, minimizing environmental damage, and maximizing residents' satisfaction) and constraints (limits on the number of tourists, increases in tourist fees and hotel taxes, and restrictions on alcohol consumption) so as to achieve sustainable development.

#### 5.1.1 Objective Function

Based on the given glossary, sustainable tourism focuses on economic, environmental and social indicators. Accordingly, we establish three quantifiable conflicting objectives—Maximum Revenue, Minimum Environmental Damage, and Maximum Resident Satisfaction—along with relevant decision variables for quantitative analysis. The function construction process is as follows:

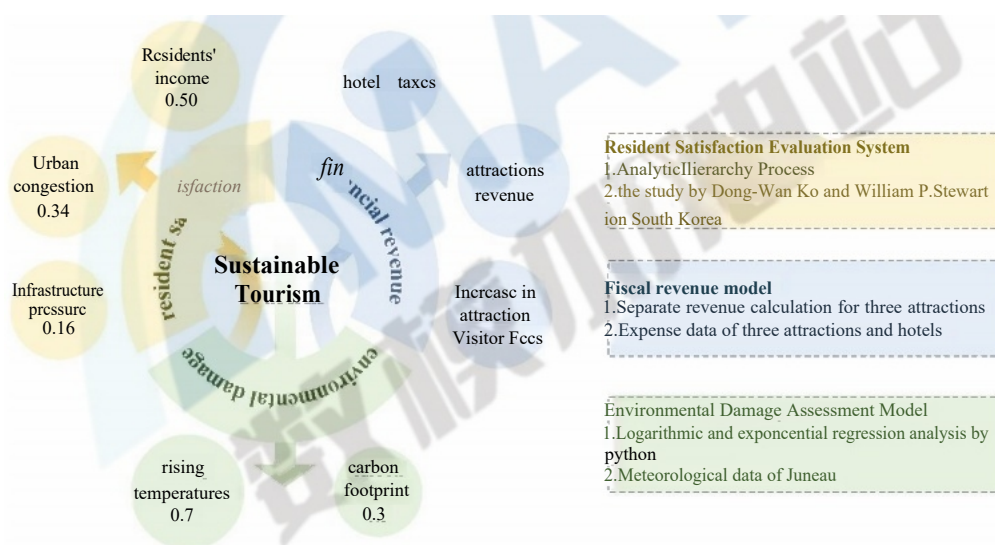


Figure5: Flowchart of multi-objective programming

#### • Maximum Financial Revenue

##### 1) Modelling ideas

Taking financial income as the optimization goal provides a material foundation for the sustainable development of Juneau. While promoting economic development, it offers financial support for environmental protection, infrastructure construction, and the development of community projects in Juneau.

##### 2) Supplementary assumptions and justifications

## 5 可持续旅游优化模型

### 5.1 多目标优化模型

多目标优化模型是一种能够同时优化多个相互冲突的目标函数以实现最优平衡的模型。本研究旨在探索旅游稳定措施的最优实施方案，该方案需在优化目标（实现财政收入最大化、环境损害最小化及居民满意度最大化）与约束条件（游客数量限制、旅游费用及酒店税上调、酒精消费管控）之间取得平衡，从而实现可持续发展。

#### 5.1.1 目标函数

根据给定的术语表，可持续旅游关注经济、环境和社会指标。因此，我们确立了三个可量化的冲突目标——最大收益、最小环境损害和最大居民满意度——以及相关的决策变量用于定量分析。函数构建过程如下：



#### ● 最大金融收益

##### 1) 建模想法

以财政收入为优化目标，为朱诺市的可持续发展提供了物质基础，在促进经济发展的同时，为朱诺市的环境保护、基础设施建设、社区项目开发等提供了财政支持。

##### 2) 补充假设与依据

**There are differences in consumption revenue among the three scenic spots, and the increases in tourist fees also vary.**

The attractions and features of different scenic spots vary, and their operation strategies such as ticket pricing and project fees also differ, resulting in different consumption revenues. To maximize benefits, there are also differences in the tourist fees increased when formulating stability policies for different scenic spots.

◇ **Hotels are concentrated in the urban area of Juneau.**

The urban area of Juneau has convenient transportation and complete infrastructure. However, the three major natural scenic spots have harsh environments, which are not conducive to living. Then, it is reasonable to assume that hotels are concentrated in the urban area, tourists' accommodation expenses are basically the same across different scenic areas, and hotel taxes are managed uniformly.

### 3) Model construction

As a tourist destination, Juneau's primary fiscal revenues stem from direct tourism earnings and taxes. Consequently, we've chosen these two revenue streams as metrics for gauging the total fiscal revenue. When it comes to taxes, we primarily focus on the hotel tax.

#### I. attractions revenues

Based on the previous assumptions, we calculate the revenues of the three scenic spots separately and then sum them up. The equation is given as (1):

$$income = \sum x_i \cdot t_i + x_0 \cdot \Delta t_i \quad i = 1, 2, 3 \quad (1)$$

"  $i$  represents the three scenic spots respectively, which  $i=1$  refers to the glacier scenic spot,  $i=2$  refers to the whale watching area, and  $i=3$  refers to the tropical rainforest.

"  $t$  and  $\Delta t$  are attraction revenue and Increase in attraction Visitor Fees, respectively.

Based on the data retrieved:

$$t_1=239, t_2=189, t_3=160$$

"  $x$  represents the number of daily visitors to the attraction.

#### II. hotel taxes

Given reasonable assumptions, we calculate the government revenue from hotel taxes using the total number of tourists, the average accommodation expenditure per capita, and the hotel tax rates before and after the implementation of the stability policy. The equation is given as (2):

$$hotel \quad revenue = x_0 \cdot k \cdot (r + \Delta r) \quad (2)$$

·  $x$  represents caps on the number of daily visitors, which is equivalent to the total number of tourists given the assumptions.

·  $k$  refers to the average accommodation expenditure per capita, valued at \$179.

三个景区的消费收入存在差异，旅游费的增幅也各不相同。

不同景区的景点特色各异，其运营策略如门票定价和项目收费也各不相同，导致消费收益差异显著。为实现效益最大化，在制定不同景区的稳定政策时，还需考虑游客费用的差异化调整。

#### ◇ 酒店集中于朱诺市城区。

朱诺市城区交通便利、基础设施完善，但三大自然景区环境恶劣，不利于居住，因此可以认为，酒店集中于城区，景区间的旅游住宿费用基本相同，酒店税实行统一管理。

### 3)模型构建

作为旅游胜地，朱诺市财政收入主要来源于旅游直接收入和税收。因此，我们选择这两项收入作为衡量财政总收入的指标。在税收方面，我们主要关注酒店税。

#### I. 景点收入

基于前述假设，我们分别计算了三个景点的收入，随后将它们相加。该方程表示为(1):

$$income = \sum x_i \cdot t_i + x_0 \cdot \Delta t_i \quad i = 1, 2, 3 \quad (1)$$

i分别代表三个风景名胜区，其中i=1对应冰川景区

t和Δt分别表示景点收入和景点门票收入的增加。

根据检索到的数据:

$$t_1=239, t_2=189, t_3=160$$

x表示该景点的日均游客量。

#### 二.酒店税

基于合理假设，我们通过计算游客总数、人均住宿支出及政策实施前后酒店税率，得出政府税收收入。具体公式如公式(2)所示:

$$酒店收入 = x_0 \cdot k \cdot (r + \Delta r) \quad (2)$$

·  $x_0$  represents 对每日游客数量的限制，根据假设，这相当于游客总数。

·  $k$ 表示人均住宿支出的平均值，其数值为179美元。

$r, \Delta r$  are Hotel Tax and Increase in Hotel Tax Rate, respectively,  $r$  has a value of 0.09.

Sum up the consumption revenue and hotel revenue to obtain the revenue function. Therefore, from (1), (2), we have Eq.(3):

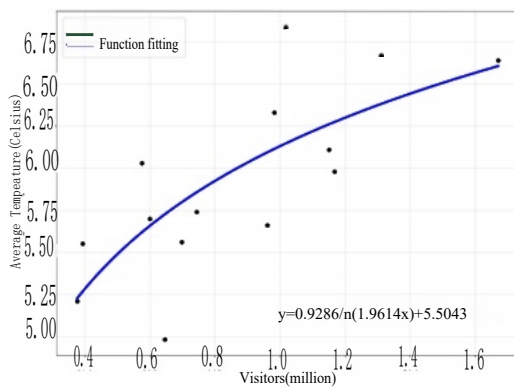
$$\max FR = \sum_{i=1}^3 x_i \cdot t_i + x_0 \cdot \Delta t + x_0 \cdot k \cdot (r + \Delta r) \quad (3)$$

- Minimum Environmental Damage

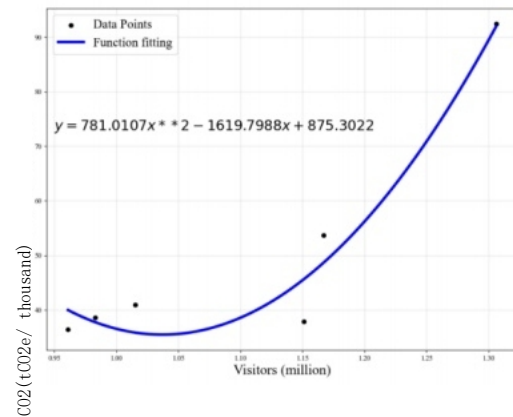
### 1) Modelling ideas

Juneau is renowned for its natural scenery. Reducing environmental damage is, on the one hand, aimed at protecting its core tourism resources. On the other hand, it also prevents short-term benefits gained from stability measures at the cost of environmental damage.

We retrieved the average temperature, abiotic carbon dioxide emissions, and the corresponding number of tourists in Juneau for some years. By conducting logarithmic and exponential regression analyses on these data points respectively. We carried out the fitting process with Python, and the results are presented in the following figure.



(a) Fitted function of average temperature



(b) Fitted function of carbon footprint

Figure 6: Function fitting results

To ensure the stability of the fitting model, we excluded data from the pandemic years (2020 and 2021) and some other outliers. Results show that the average temperature and the number of tourists follow a logarithmic distribution (a). After the number of tourists reaches a certain level, influenced by weather conditions and environmental regulation capabilities, the increase in average temperature tends to level off. However, based on the current number of tourists, the average temperature is rapidly rising. The relationship is shown in (4):

$$T = 0.9286 \ln(0.0019641x_0) + 5.5043 \quad (4)$$

$r$ 为酒店税， $\Delta r$ 为酒店税率的增加， $r$ 的值为0.09。

将消费收入与酒店收入相加，即可得到收入函数。因此，根据(1)、(2)，我们得到等式(3)：

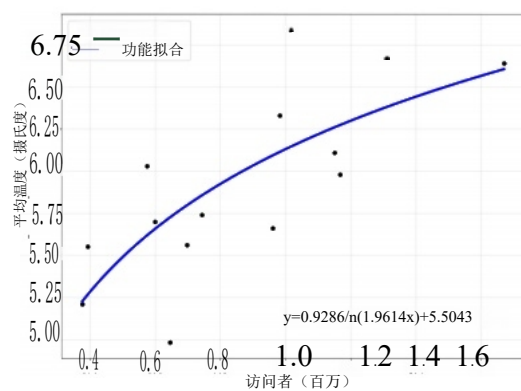
$$\max FR = \sum_{i=1}^3 x_i \cdot t_i + x_0 \cdot \Delta t + x_0 \cdot k \cdot (r + \Delta r) \quad (3)$$

## ● 最小环境损害

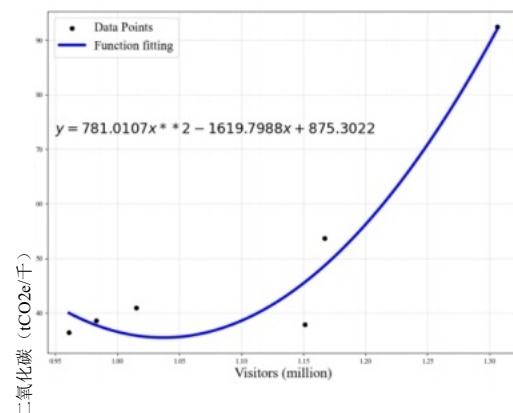
### 1) 建模想法

朱诺以其自然风光著称。减少环境破坏一方面旨在保护其核心旅游资源，另一方面也防止因稳定措施而获得的短期利益以环境破坏为代价。

我们获取了朱诺市数年间的平均气温、非生物二氧化碳排放量及相应游客数量数据。通过分别对这些数据点进行对数回归和指数回归分析，我们使用Python完成了拟合过程，结果如以下图所示。



(a) 平均温度拟合函数



(b) 碳足迹拟合函数

图6：函数拟合结果

为确保模型拟合的稳定性，我们剔除了2020年和2021年疫情年份的数据及其他异常值。研究结果表明，平均气温与游客数量呈现对数分布特征（图a）。当游客数量达到一定规模后，受天气条件和环境调控能力影响，平均气温增速趋于平稳。然而根据当前游客数量数据，平均气温却呈现快速攀升趋势。该关系式如公式(4)所示：

$$T = 0.9286 \ln(0.0019641x_0) + 5.5043 \quad (4)$$

The carbon footprint and the number of tourists exhibit an exponential distribution(b).The growth in the number of tourists directly impacts the transportation and accommodation industries.Meanwhile,it triggers a chain reaction and aggregation effect in the catering and manufacturing industries,leading to a rapid increase in the carbon footprint.The relationship is(5):

$$C=781.0107x_0^2-1619.7998x_0+875.3022 \quad (5)$$

### 3) Environmental Damage Function

Based on the above functional relationships,we establish a model for the degree of environmental damage.We normalize the temperature and carbon dioxide emissions by dividing them by their respective historical minimum values and then perform a weighted sum.

Since temperature is a direct factor in glacier melting and the greenhouse effect caused by carbon dioxide emissions is an indirect factor,we assign weights of 0.7 and 0.3 to the average temperature and carbon footprint respectively.The expression is as follows:

$$\min ED = \min \left[ w_1 \frac{T(x_0)}{T_{\min}} + w_2 \frac{C(x_0)}{C_{\min}} \right] \quad (6)$$

- $T_{\min}$  represents the minimum average annual temperature for Juneau,2014-2023,which is  $5.21^{\circ}\text{C}$ .
- $C_{\min}$  represents the minimum annual carbon footprint of Juneau,2014-2023,with a value of 3.64131.
- $w_1, w_2$  refer to the corresponding weights of temperature and carbon,which are 0.7,0.3, respectively.

### ● Maximum Resident Satisfaction

#### 1) Modelling ideas

To quantify the satisfaction of Juneau residents,we need to consider both the positive and negative impacts of tourism on their life experiences.The positive impacts mainly stem from the economic income generated in related industries driven by tourists.The negative impacts, however,primarily result from the overcrowding in the city due to the influx of tourists,as well as the pressure exerted on urban infrastructure such as clean water supply and waste disposal.

Therefore,we need to comprehensively consider the weighted factors of job creation,urban congestion,and infrastructure pressure to establish a quantifiable evaluation system for residents'satisfaction.

#### 2) Calculating Weights Based on the Analytic Hierarchy Process(AHP)

When we determine the weight of the three elements to construct the final objective,we apply the **Analytical Hierarchy Process** to avoid being overly subjective on weight selection.

碳足迹与游客数量呈指数分布(b)。游客数量的增长直接影响交通运输和住宿行业，同时在餐饮和制造业引发连锁反应与集聚效应，导致碳足迹急剧上升。其关系式为(5)：

$$C=781.0107x_0.^2-1619.7998x_0+875.3022 \quad (5)$$

### 3) 环境损害函数

基于上述功能关系，我们建立了一个环境损害程度的模型。通过将温度和二氧化碳排放量分别除以其历史最小值进行标准化处理，随后进行加权求和。

由于温度是冰川消融的直接因素，而二氧化碳排放引起的温室效应是间接因素，我们分别赋予平均温度和碳足迹0.7和0.3的权重。其表达式如下：

$$\min ED = \min \left[ w_1 \frac{T(x_0)}{T_{\min}} + w_2 \frac{C(x_0)}{C_{\min}} \right] \quad (6)$$

■  $T_{\min}$ 为2014-2023年6月诺市的年平均最低气温，为5.21℃。

■  $C_{\min}$ 表示2014-2023年朱诺市的最小年碳足迹，其数值为3.64131。

■  $w_1$ ， $w_2$ refer 分别对应温度和碳的相应权重，分别为0.7,0.3。

## ● 居民满意度最高

### 1) 建模想法

要评估朱诺市民的满意度，需综合考量旅游业对生活体验的正反两面影响。积极效应主要来自游客带动的旅游相关产业创收，而负面影响则主要体现在游客激增导致的城市过度拥挤，以及清洁供水、垃圾处理等城市基础设施承受的压力。

因此，我们需要综合考虑就业创造、城市拥堵和基础设施压力等加权因素，建立一套可量化的居民满意度评估体系。

### 2) 基于层次分析法（AHP）的权重计算

当我们确定了构成最终目标的三个要素的权重时，我们应用分析层次过程来避免在权重选择上过于主观。

When using AHP, we need to compare the relative importance of three elements: residents' income, urban congestion, and infrastructure pressure, and establish a Pairwise Comparison Matrix.

When developing a structural equation model of residents' attitudes towards tourism development in Jeju Island, South Korea (a popular tourist destination) [6], Dong-Wan Ko and William P. Stewart used a 5-point Likert-type scale in a questionnaire survey, asking residents to rate urban indicators and obtained items-total correlation data. The statistics for residents' income, urban congestion, and infrastructure were 0.64, 0.44, and 0.20 respectively.

Since both Juneau and Jeju Island in South Korea are popular tourist destinations, we'll use this as a reference to determine the relative importance of the three elements and establish the pairwise comparison matrix for the criterion layer. The results are as follows:

Table 3 Comparison matrix of the standard level

Criteria	Resident Income	City Congestion	Infrastructure Pressure
Resident Income	1	1.45	3.2
City Congestion	0.69	1	2.2
Infrastructure Pressure	0.31	0.45	1

Normalize the matrix and calculate the weights of the three elements, which are 0.50, 0.34, and 0.16 respectively.

### 3) Environmental Damage Function

Based on the above weights, we need to establish relationships between the original decision variables and the three factors of residents' economic income, urban congestion, and infrastructure pressure, set up a scoring mechanism, and ultimately form a quantifiable evaluation system for residents' satisfaction.

According to data from the Juneau Tourism Bureau, in 2023, 38% of residents had a positive attitude towards tourism, 30% were neutral, and 25% were negative. Therefore, we can regard the residents' satisfaction in 2023 as the passing line. Thus, we normalize the indicators of job creation, urban congestion, and infrastructure pressure in 2023, and quantify the satisfaction in 2023 as **68 points (38+30)**.

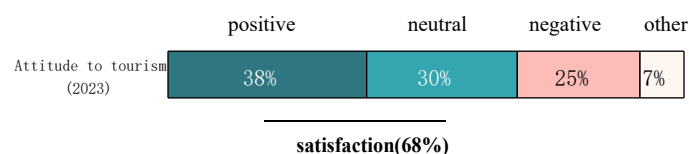


Figure 7: Residents' Attitudes towards Tourism in 2023

使用 AHP 时，我们需要比较三个要素的相对重要性：居民收入、城市拥堵和基础设施压力，并建立成对比较矩阵。

在开发韩国济州岛（一个热门旅游目的地）居民对旅游发展态度的结构方程模型时，Ko Dong-Wan 和 Stewart William P. 使用了5点李克特量表进行问卷调查，要求居民对城市指标进行评分，并获得了项目-总相关数据。居民收入、城市拥堵和基础设施的统计值分别为 0.64,0.44 和0.20。

鉴于美国朱诺市与韩国济州岛均为热门旅游胜地，我们将以此为基准，评估三个要素的相对重要性，并构建标准层的两两比较矩阵。具体结果如下：

表3 标准水平比较矩阵			
标准	居民收入	城市拥堵-基础设施 支票电托收	压力
居民收入	1	1.45	3.2
城市拥挤	0.69	1	2.2
基础设施压力	0.31	0.45	1

对矩阵进行归一化，计算出三个元素的权重，分别为 0.50,0.34 和0.16。

3)环境损害函数

基于上述权重，需建立原始决策变量与居民经济收入、城市拥堵、基础设施压力三者之间的关联关系，构建评分机制，最终形成可量化的居民满意度评估体系。

根据朱诺旅游局提供的数据，2023年有38%的居民对旅游业持积极态度，30%持中立态度，25%持消极态度。因此，我们可以将2023年居民满意度视为及格线。于是，我们对2023年的就业创造、城市拥堵和基础设施压力等指标进行标准化处理，并将2023年的满意度量化为**68分（38+30）**。

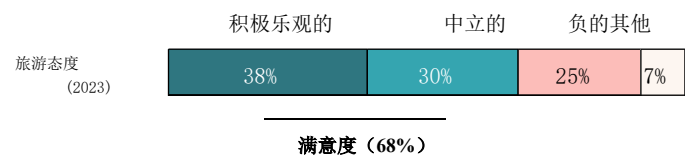


图7：2023年居民对旅游业的态度

Residents' income: Since the contribution of tourism can be attributed to the product of per-capita consumption and the number of tourists, we divide this value by the corresponding data in 2023.

Urban congestion: We measure urban congestion using the road area per tourist. The level of congestion in the city is associated with both the volume of tourists and the total road area.

Infrastructure pressure: It's mainly about waste disposal. EPA data shows Americans generate 2.2kg of waste per person daily. Some studies suggest tourists produce 20%-40% more waste than locals. So, we'll assume tourists generate 2.8 kg per day. We'll measure it by the ratio of total waste (locals and tourists) to the city's max waste-handling capacity.

Therefore, we present the following expression (4) for residents' satisfaction:

$$RS = w_3 \cdot \frac{(t_0 + \Delta t) \cdot x_0}{t_0 \cdot x_{2023}} + w_4 \cdot \frac{S \cdot x_{2023}}{S_{2023} \cdot x_0} + w_5 \cdot \frac{G_0 (2800000 \cdot x_{2023} + 2.2 \cdot P_j)}{G_{2023} (2800000 \cdot x_0 + 2.2 \cdot P_j)} \quad (7)$$

- $S_{2023}$  represents the road surface area of Juneau in 2023, which can be estimated at 300 square kilometers.
- $S$  represents the upcoming planned road surface area of Juneau.
- $G_{2023}$  represents the waste carrying capacity of Juneau in 2023, can be estimated at 10170
- $G$  represents the upcoming planned waste-carrying capacity of Juneau.
- $P_j$  represents the number of original residents in Juneau, which is approximately 31,700.

After simplification, the above formula is:

$$RS = \frac{(243 + \Delta t) \cdot x_0}{811.62} + \frac{S}{528.35x_0} + \frac{G}{26250000x_0 + 6538125} \quad (8)$$

### 5.1.2 Constraint

The constraint conditions of this model mainly consider the impact of Juneau's stable tourism measures on the independent variable, the number of tourists, and restrictions of environmental factors. The specific analysis is as follows:

#### ● Restrictions on the number of visitors

The regulation on the limit of the number of tourists stipulates the daily upper limit of the number of tourists received in Juneau. Subject to the constraint by (4):

$$x_1 + x_2 + x_3 \leq x_0 \quad (9)$$

However, considering the effectiveness of policy implementation and the complexity of the model, we made a reasonable assumption earlier: the daily number of tourists can always

居民收入：由于旅游业的贡献可归因于人均消费与游客数量的乘积，我们将该数值除以2023年的对应数据。

城市拥堵：我们通过人均道路面积来衡量城市拥堵程度。城市的拥堵水平与游客数量及道路总面积均存在关联。

基础设施压力：主要体现在垃圾处理方面。美国环保署数据显示，美国人每人每天产生2.2公斤垃圾。研究表明，游客产生的垃圾量比本地居民多20%-40%。因此我们假设游客日均垃圾量为2.8公斤，并通过计算总垃圾量（本地居民与游客）与城市最大垃圾处理能力的比值来评估压力。

因此，我们提出以下表达式(4)用于居民满意度：

$$RS = w_3 \cdot \frac{(t_0 + \Delta t) \cdot x_0}{t_0 \cdot x_{2023}} + w_4 \cdot \frac{S \cdot x_{2023}}{S_{2023} \cdot x_0} + w_5 \cdot \frac{G_0 (2800000 \cdot x_{2023} + 2.2 \cdot P_j)}{G_{2023} (2800000 \cdot x_0 + 2.2 \cdot P_j)} \quad (7)$$

■ S2023代表2023年朱诺市的路面面积，估算为300平方公里。

■ S代表朱诺市即将规划的道路路面面积。

■ G<sub>2023</sub> 代表2023年朱诺市的废物承载能力，估计为10170

■ G代表朱诺市即将规划的垃圾处理能力。

· P<sub>j</sub>：表示朱诺市原住民人口数量，约为31,700人。简化后，上述公式为：

$$RS = \frac{(243 + \Delta t) \cdot x_0}{811.62} + \frac{S}{528.35x_0} + \frac{G}{26250000x_0 + 6538125} \quad (8)$$

### 5.1.2 约束

本文模型的约束条件主要考虑了朱诺市稳定旅游措施对自变量——游客人数的影响以及环境因素的限制。具体分析如下：

#### ● 访客人数限制

游客人数限制规定了朱诺市6月每日接待游客的上限。受(4)项约束：

$$X_1 + X_2 + X_3 \leq X_0 \quad (9)$$

然而，考虑到政策实施的有效性及模型的复杂性，我们此前已作出合理假设：每日游客数量始终

reach the upper limit. Thus, this constraint is transformed into an equality relationship and used as a known condition. The equation is given as (5):

$$X_1 + X_2 + X_3 = X_0 \quad (10)$$

## ● Increase in visitor fees and hotel taxes

### 1) Modelling ideas

An increase in tourist fees leads to a decrease in the number of tourists in Juneau to some extent. To predict the impact, we construct a **tourist volume prediction model** based on the changes in the number of tourists over the past decade and Nguyen's research on tourism demand elasticity.

### 2) Supplementary assumptions and justifications

- ◇ \$196 represents a relatively rational market level in Juneau. i.e., the number of tourists has reached an equilibrium state at the current price level.

Based on the number of tourists in Juneau from 2014 to 2023 (from the Alaska Tourism Bureau) and the consumption data (from BudgetYourTrip.com), we've calculated that the average daily consumption per person is \$243. From an economic perspective, this price is the result of long-term interaction and adjustment among market participants.

### 3) Model construction

Based on Nguyen's research on the **tourism demand elasticity** in ASEAN [7], the local tourism demand (which can be regarded as the number of tourists here) is jointly determined by multiple factors including consumers' income, the consumption price in the tourist area itself, and the consumption price in alternative tourist areas. We applied the model proposed by Nguyen to the tourism industry in Juneau and obtained the following formula (6):

$$\ln x = \beta_0 + \beta_1 \ln Y + \beta_2 \ln t + \beta_3 \ln S + \varepsilon \quad (11)$$

- $x$  and  $Y$  represents the demand of domestic tourists and the income of tourists, respectively.

- $t$  is Tourism service prices, while  $S$  is the price of substitute tourism destinations

- $\beta_0, \beta_1, \beta_2$  and  $\beta_3$  are parameters to be estimated.

"  $\varepsilon$  represents the error term.

### 4) Calculate parameters

For this model, due to the lack of per capita income data of Juneau tourists, we will not consider the impact of tourists' income on Juneau's tourism industry for the time being.

Cruise ships are a major means of transport for travelers going to Juneau. They have stable passenger sources and offer unique services. Also, considering the weak correlation between Alaska's tourist numbers and per-capita consumption in the past four years, Juneau's tourism

达到上限。因此，该约束条件被转化为等式关系，并作为已知条件使用。方程表示为(5):

$$X_1 + X_2 + X_3 = X_0 \quad (10)$$

## ● 游客费用和酒店税增加

### 1) 建模想法

旅游费的增加在一定程度上导致了朱诺市6月份游客数量的减少，为了预测其影响，我们根据过去10年游客数量的变化情况以及Nguyen关于旅游需求弹性的研究，构建了一个游客量预测模型。

### 2) 补充假设与依据

- ◇ 196美元是 Juneau.i.e. 的相对合理的市场水平，是旅游人数 $s$ 在当前价格水平下，TS 已达到均衡状态。

根据2014年至2023年6月间朱诺市的游客数量（数据来源：阿拉斯加旅游局）和消费数据（数据来源：BudgetYourTrip.com），我们计算出每人每天的平均消费为243美元。从经济角度来看，这个价格是市场参与者长期互动和调整的结果。

### 3) 模型构建

基于阮氏对东盟地区旅游需求弹性的研究[7]，当地旅游需求（可视为游客数量）由消费者收入、旅游区消费价格及替代旅游区消费价格等多重因素共同决定。

我们将阮氏提出的模型应用于朱诺市旅游业，最终得出如下公式(6):

$$\ln x = \beta_0 + \beta_1 \ln Y + \beta_2 \ln t + \beta_3 \ln S + \varepsilon \quad (11)$$

- $x$  and  $Y$  分别代表国内游客需求和游客收入。
- $t$  为旅游服务价格， $S$  为替代旅游目的地价格
- $\beta_0, \beta_1, \beta_2, \beta_3$  待估计的参数。

$\varepsilon$  代表误差项。

### 4) 计算参数

对于该模型，由于缺乏朱诺游客的人均收入数据，我们暂时不考虑游客收入对朱诺旅游业的影响。

邮轮是前往朱诺的主要交通方式，不仅客源稳定，还提供特色服务。此外，鉴于过去四年阿拉斯加游客数量与人均消费水平的相关性较弱，朱诺的旅游业

demand elasticity is less influenced by its consumption price. Since there is a negative correlation between the number of tourists and local consumption,  $\beta_2$  should be negative.

In addition, we need to consider the self-paid prices in alternative tourist cities to Juneau. Common alternatives are Ketchikan and Anchorage in Alaska, with average daily per-person consumption prices of \$259 and \$266, respectively. Juneau accounts for about 13%-15% of Alaska's tourism.

So, we tentatively assume that the absolute values of  $\beta_2$  and  $\beta_3$  are the same. Let  $S$  be the average of the self-consumption prices of the other two alternative cities, which is \$262.5.

$$S = \$262.5 \quad (12)$$

Based on the research by Nguyen[7], the absolute value ratio between  $\beta$  and  $\beta_2$  is approximately 2.3, and the absolute value ratio between  $\beta_2$  and  $\beta_3$  is approximately 100.

$$\beta_2 = \beta_3 = 100 \quad (13)$$

Then, by substituting the number of tourists in Juneau in 2023 (1.67 million) and the average daily per-person consumption price of \$243, we can establish the relationship between Juneau's tourism demand and the planned self-consumption in Juneau:

$$\ln x = -0.721 \ln t + 4.43 \quad (14)$$

Further, associate it with the decision variables of this model, that is (15):

$$\ln x = -0.721 \ln (243 + \Delta t + 173 \Delta r) + 4.43 \quad (15)$$

- Environmental constraints

Environmental constraints are considered from three aspects: temperature, carbon footprint, and urban carrying capacity.

Temperature constraints: The temperature in the scenic area should not be too high. Its value should be less than the average of historical extreme values, which is 6.03°C.

$$T(x_0) < \frac{T_{\max} + T_{\min}}{2} \quad (16)$$

> Carbon footprint constraints: The carbon footprint should not be too high. Its value should be less than the average of historical extreme values, which is 6.44 tCO<sub>2</sub>e/k.

$$C(x_0) < \frac{C_{\max} + C_{\min}}{2} \quad (17)$$

> urban carrying capacity: The amount of garbage processed should not exceed the urban carrying capacity.

$$\frac{(2800000x_0 + 2.2P_j)}{G} < 1 \quad (18)$$

需求弹性受其消费价格的影响较小。由于游客数量与当地消费之间存在负相关关系， $\beta_2$  应为负值。

另外，我们还需要考虑与朱诺相比，其他旅游城市自费消费价格的差异，常见的旅游城市有阿拉斯加的基奇坎和安克雷奇，人均消费价格分别为259美元和266美元，而阿拉斯加的旅游收入中，朱诺占13%~15%。

因此，我们暂时假设  $\beta_2$  and  $\beta_3$  are 的绝对值相同。设 S 为另外两个替代城市的自消费价格的平均值，即262.5美元。

$$S=\$262.5 \quad (12)$$

根据Nguyen[7]的研究， $\beta$  与  $\beta_{2is}$  的绝对值比约为2.3， $\beta_2$  and  $\beta_{3is}$  的绝对值比约为100。

$$\beta_2 = \beta_3 = 100 \quad (13)$$

通过代入2023年朱诺市167万游客数量及人均日消费243美元的计算数据，我们得以建立朱诺市旅游需求与规划内自消费之间的关联关系。

$$\ln x = -0.721 \ln t + 4.43 \quad (14)$$

此外，将其与该模型的决策变量（即公式（15））相关联：

$$\ln x = -0.721 \ln (243 + \Delta t + 173 \Delta r) + 4.43 \quad (15)$$

#### ● 环境制约

从温度、碳足迹和城市承载力三个方面考虑环境约束。

温度限制：景区内温度不宜过高，其数值应低于历史极端值的平均值（6.03°C）。

$$T(x_0) < \frac{T_{\max} + T_{\min}}{2} \quad (16)$$

> 碳足迹限制：碳足迹不应过高，其数值应小于历史极端值的平均值，即6.44tCO<sub>2</sub>e / k。

$$C(x_0) < \frac{C_{\max} + C_{\min}}{2} \quad (17)$$

城市承载力：处理的垃圾量不应超过城市承载力。

$$\frac{(2800000x_0 + 2.2P_j)}{G} < 1 \quad (18)$$

## 5.2 NSGA-II for Multi-objective Optimization

The model employs Non-dominated Sorting Genetic Algorithms (NSGAII) for multi-objective optimization, seeking the optimal balance among **financial revenue**, **environmental damage**, and **residents' satisfaction**. NSGA-II is an improved multi-objective genetic algorithm. It deals with multi-objective optimization problems by stratifying population individuals through a non-dominated sorting mechanism. The algorithm flow chart can be viewed in Figure 8.

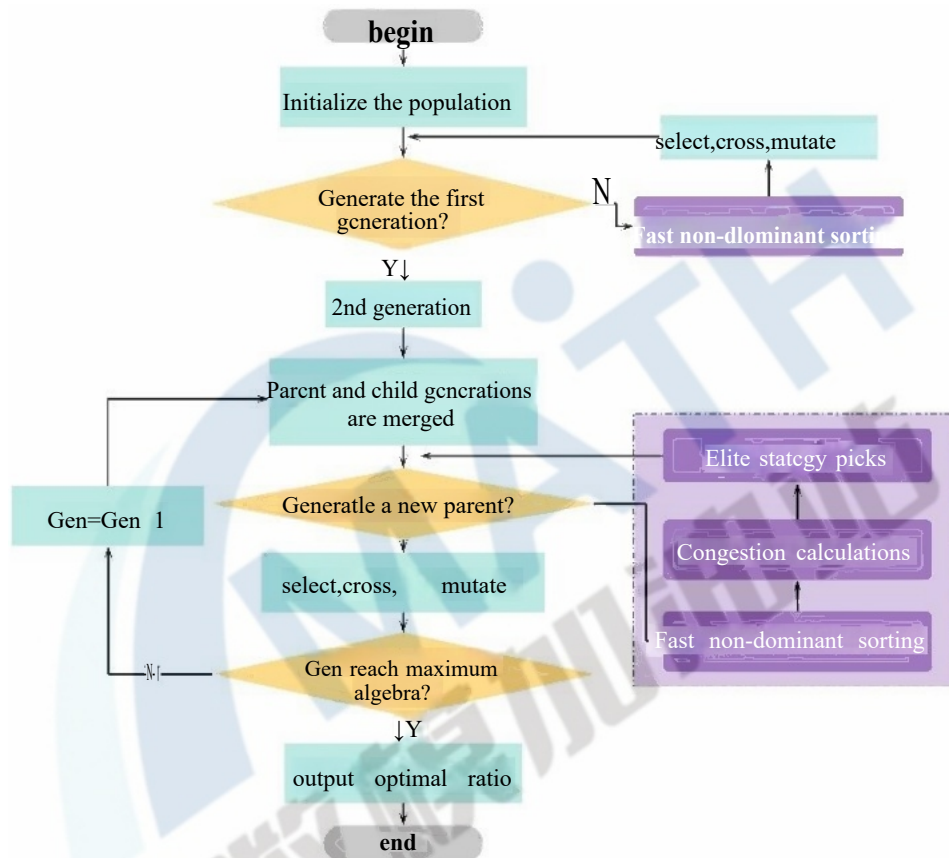


Figure 8: NSGAII Algorithm Flowchart

After solving with Python, a Pareto front containing 255 solutions was obtained.

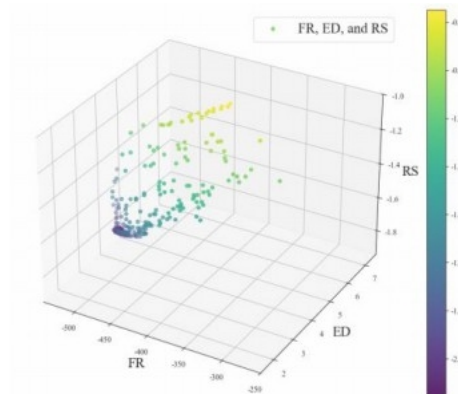


Figure 9: Pareto Front

## 5.2 NGSa -二阶多目标优化

该模型采用非支配排序遗传算法（NGSAII）进行多目标优化，旨在寻求财政收入、环境损害与居民满意度之间的最佳平衡。NSGA-II是一种改进型多目标遗传算法，通过非支配排序机制对种群个体进行分层处理，从而解决多目标优化问题。算法流程图详见图8。

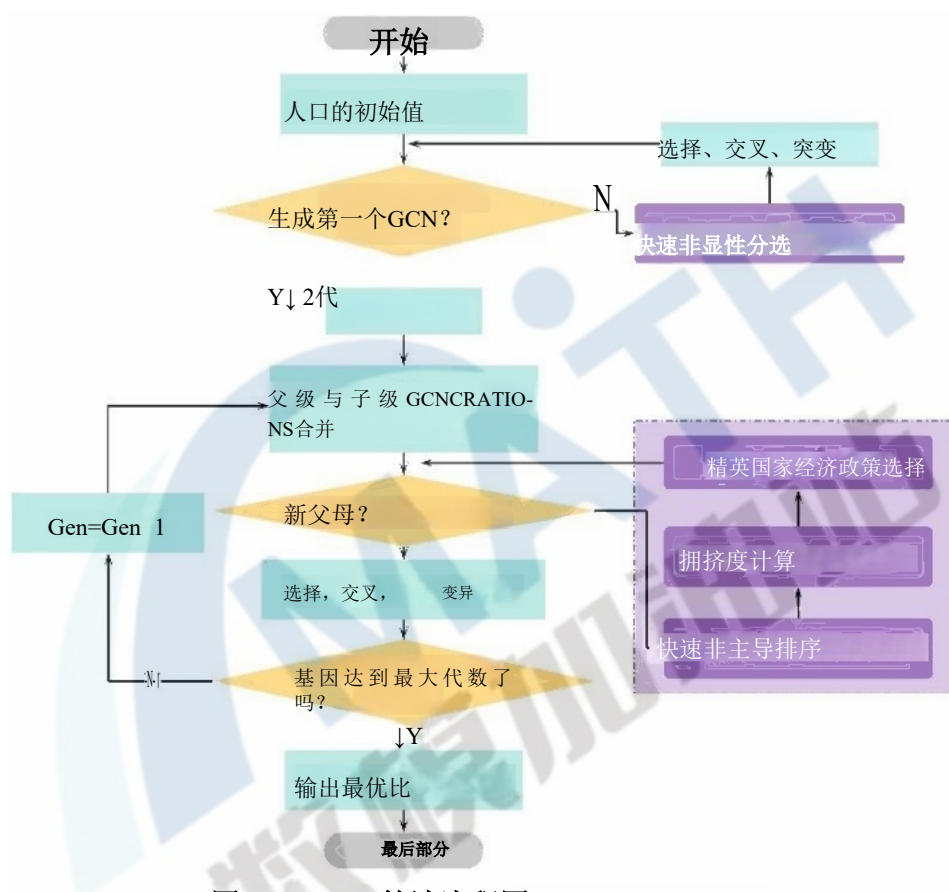


图8：NGSAII算法流程图

用Python求解得到255个解的Pareto前沿。

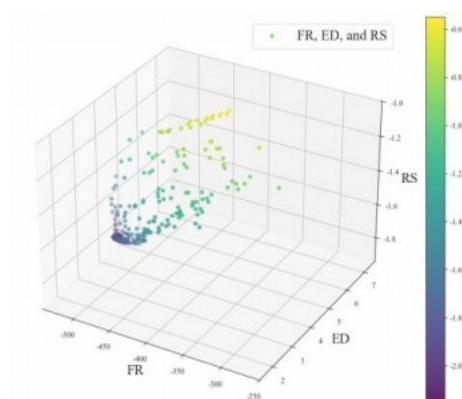


图9：帕累托前沿

We selected three solutions with distinct characteristics, and the values of their corresponding objective functions are shown in the following table.

Tabel 4 Solutions with distinct eigenvalues

Group	TR	ED	RS
1	-584.7340389	6.535613545	-2.11708582
2	-376.3766352	1.828567732	-1.238253427
3	-464.2609648	2.819160665	-1.526391146

Analysis based on the above results:

The first group despite offering relatively high economic income and resident satisfaction, cause significant environmental damage, which is inconsistent with the goal of sustainable tourism development. Therefore, it is excluded.

The second group results in minimal environmental damage. However, the limited number of tourists leads to low economic returns from tourism and subsequently reduced resident satisfaction. Hence, it is also discarded.

Conversely, the third group not only causes less environmental damage but also achieves relatively high economic returns and resident satisfaction. It is worthy of consideration for the final plan. To better illustrate the role of the decision variables, we identified four solutions with characteristics similar to those of the third group. The corresponding data for these solutions are shown in the table below.

Tabel 5 optimal solution

Group	$x_1$	$x_2$	$x_3$	$x_0$	$\Delta t$	$\Delta r$	S	G
1	1.2481	0.1063	0.1291	1.4836	72.4388	0.0962	491.45	2760835
2	1.0386	0.1821	0.2311	1.4520	72.9	0.0773	498.75	2959685
3	1.0984	0.1149	0.1787	1.3920	72.2892	0.0715	500	2871410
4	1.1231	0.1009	0.1623	1.3864	72.5652	0.0757	498.38	2881902

## 5.3 Expenditure-Feedback Model for Additional Revenue

### 5.3.1 Expenditure plan

According to the decision variables of the optimal solution we chose, the road area S and infrastructure capacity G are close to the upper bounds of the initial variables set in NSGA-II. This shows that increasing S and G is crucial for overall benefits. Since enhancing S and G needs government spending, it's closely linked to the extra revenue the government gains via regulatory measures in this model.

In this model, the additional revenue obtained by the government mainly depends on the increases in fees and taxes. The specific relationship is as follows:

$$\Delta FR = x_0(\Delta t + k\Delta r) \quad (19)$$

我们选取了三种具有不同特性的溶液，其对应目标函数的数值如下表所示。

表4 具有不同特征值的解决方案

组	TR	ED	RS
1	-584.7340389	6.535613545	-2.11708582
2	-376.3766352	1.828567732	-1.238253427
3	-464.2609648	2.819160665	-1.526391146

基于上述结果的分析：

第一类旅游区虽然经济收入和居民满意度较高，但对环境造成了严重的破坏，不符合可持续旅游发展的目标，因此被排除在外。

第二类旅游方式对环境损害最小，但由于游客数量有限，旅游经济收益较低，进而导致居民满意度下降，因此也被弃用。

与之相反，第三组方案不仅对环境破坏较小，还能带来较高的经济效益和居民满意度，值得纳入最终规划。为更直观地展示决策变量的作用，我们筛选出四个与第三组特征相似的解决方案，相关数据详见下表。

表5 最优解

组	x1	x2	x3	x0	△t	△r	S	G
1	1.2481	0.1063	0.1291	1.4836	72.4388	0.0962	491.45	2760835
2	1.0386	0.1821	0.2311	1.4520	72.9	0.0773	498.75	2959685
3	1.0984	0.1149	0.1787	1.3920	72.2892	0.0715	500	2871410
4	1.1231	0.1009	0.1623	1.3864	72.5652	0.0757	498.38	2881902

5.3 追加收入支出反馈模型

5.3.1 支出计划

根据我们选择的最优解的决策变量，道路面积S和基础设施容量G接近 NSGAI 中初始变量集的上限。这表明增加S和G对于整体效益至关重要。由于提升S和G需要政府支出，因此这与政府通过监管措施获得的额外收入密切相关。

在该模型中，政府额外收入主要来源于费用和税收的增加，具体关系如下：

$$\Delta FR = x_0 (\Delta t + k \Delta r)$$

(19)

The benefits of Sand G are mainly reflected in the resident satisfaction(RS).Let the cost of building one square kilometer of road surface be and the cost of increasing the infrastructure capacity by one unit be.We use the ratio of their correlation coefficients with the resident satisfaction (RS)to determine the expenditure weights for them.After calculation,the expenditure ratio  $w$  of S to G is 6.5.

Therefore,the total expenditure on S and G in that year can be expressed as:

$$\text{Cost}_t = a_1(S - S_{t-1}) + a_2(G - G_{t-1}) \quad (20)$$

Undoubtedly,this expenditure plan is formulated from the perspective of resident satisfaction.If there is still a surplus in the additional revenue,the government should invest it in environmental protection projects to mitigate a series of issues such as glacier melting.This way,the parameters related to environmental damage can be reduced,and the impact of the number of tourists on environmental damage can be lessened

### 5.3.2 Feedback effect

Since the specific expenditure on S and G directly affects the resident satisfaction in that year,we need to weigh the previous year's revenue against the current year's expenditure.

- ◇ When  $\Delta FR_{t-1} > \text{Cost}_t$ ,that is,when the additional revenue from the previous year can cover the expenditure of the following year to meet the requirements of resident satisfaction,the model can achieve the expected results in terms of resident satisfaction,i.e.:

$$RS = w_3 \frac{(t_0 + \Delta t)x_0}{t_0 \cdot x_{2023}} + w_4 \frac{S_t \cdot x_{2023}}{S_{2023} \cdot x_0} + w_5 \frac{G_t(2800000x_{2023} + 2.2P_j)}{G_{2023}(2800000x_0 + 2.2P_j)} \quad (21)$$

- ◇ When  $\Delta FR_{t-1} < \text{Cost}_t$ ,due to the insufficient revenue in the previous year,the values of G and S can only be allocated in a weighted manner based on the maximum value of the additional revenue,i.e.:

$$RS = w_3 \frac{(t_0 + \Delta t)x_0}{t_0 \cdot x_{2023}} + w_4 \frac{x_{2023}}{S_{2023} \cdot x_0} \cdot \left[ \frac{w \cdot \Delta FR_{t-1}}{(1+w)a_1} + S_{t-1} \right] + w_5 \frac{(2800000x_{2023} + 2.2P_j)}{G_{2023}(2800000x_0 + 2.2P_j)} \cdot \left[ \frac{\Delta FR_{t-1}}{(1+w)a_2} + G_{t-1} \right] \quad (22)$$

## 6 Sensitivity Analysis

For each optimal solution,we used the local perturbation method to detect variable sensitivity.We varied one decision variable within the perturbation range of(-10%,+10%)while keeping other decision variables constant and observed the impact on the objective function. The final results were presented in a heat map,where the color intensity or temperature variation indicates the magnitude of the correlation coefficient.The closer the absolute value is to 1,the stronger the correlation.

砂石场的效益主要体现在居民满意度（RS）上，设每平方千米路面的建设成本为C，每单位基础设施容量的增加成本为C'，用砂石场和砂石场与居民满意度的相关系数的比值确定砂石场的支出权重，经计算得出砂石场与砂石场的支出比为6.5。

因此，该年度S和G的总支出可表示为：

$$\text{成本}_t = a_1 (S_t - S_{t-1}) + a_2 (G_t - G_{t-1}) \quad (20)$$

该支出方案的制定无疑以居民满意度为核心考量。若新增财政收入仍有结余，政府应将资金投入环境保护项目，以缓解冰川消融等系列环境问题。此举既能降低环境损害相关指标，又能有效减少游客数量对生态环境造成的负面影响。

### 5.3.2 反馈效应

由于S和G的具体支出直接影响当年居民满意度，我们需要将上一年度的收入与当年的支出进行权衡。

◇ 当 $\Delta FR_{t-1} > \text{Cost}$ 时，即前一年的额外收入能够满足下一年度的支出，以满足居民

满意度的要求时，该模型能够实现预期的居民满意度结果，即：

$$RS = w_3 \frac{(t_0 + \Delta t)x_0}{t_0 \cdot x_{2023}} + w_4 \frac{S_t \cdot x_{2023}}{S_{2023} \cdot x_0} + w_5 \frac{G_t(2800000x_{2023} + 2.2P_j)}{G_{2023}(2800000x_0 + 2.2P_j)} \quad (21)$$

◇ 当 $\Delta FR_{t-1} < \text{Cost}$ 时，由于前一年收入不足，其数值

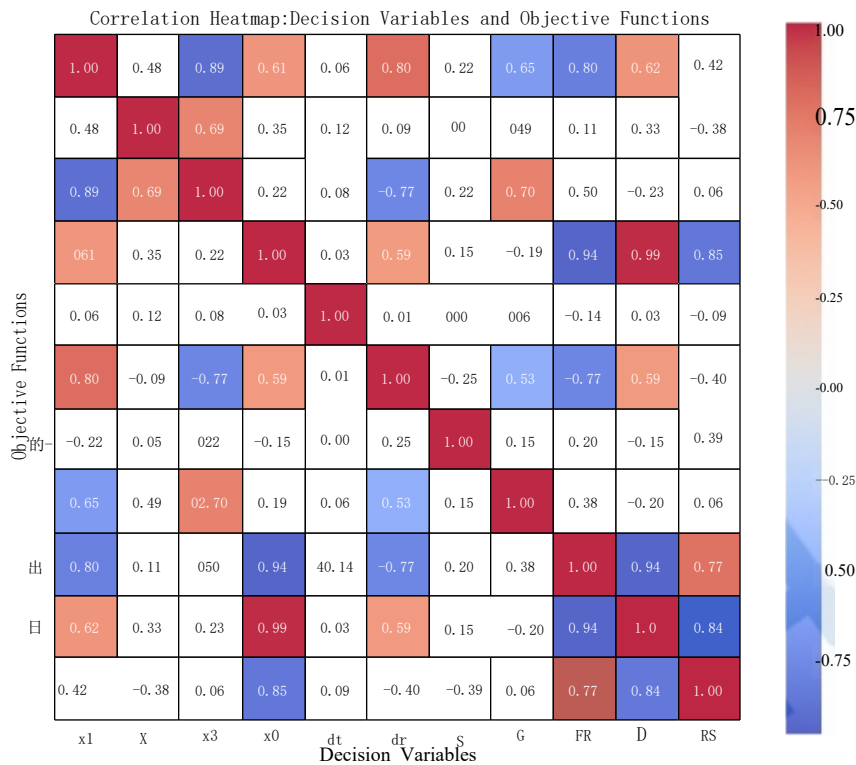
G和S的分配只能基于附加收入的最大值进行加权分配，即：

$$RS = w_3 \frac{(t_0 + \Delta t)x_0}{t_0 \cdot x_{2023}} + w_4 \frac{x_{2023}}{S_{2023} \cdot x_0} \cdot \left[ \frac{w \cdot \Delta FR_{t-1}}{(1+w)a_1} + S_{t-1} \right] + w_5 \frac{(2800000x_{2023} + 2.2P_j)}{G_{2023}(2800000x_0 + 2.2P_j)} \cdot \left[ \frac{\Delta FR_{t-1}}{(1+w)a_2} + G_{t-1} \right] \quad (22)$$

## 6 敏感性分析

针对每个最优解，我们采用局部扰动法检测变量敏感性。在保持其他决策变量恒定的前提下，将某一决策变量在（-10%，+10%）的扰动范围内进行调整，并观察其对目标函数的影响。最终结果以热图形式呈现，其中颜色强度或温度变化值表示相关系数的大小。绝对值越接近

1、相关性越强。



**Figure 10:Correlation Heatmap:Devisiion Variables and Objective Functions**

From the heat map,we can see that:

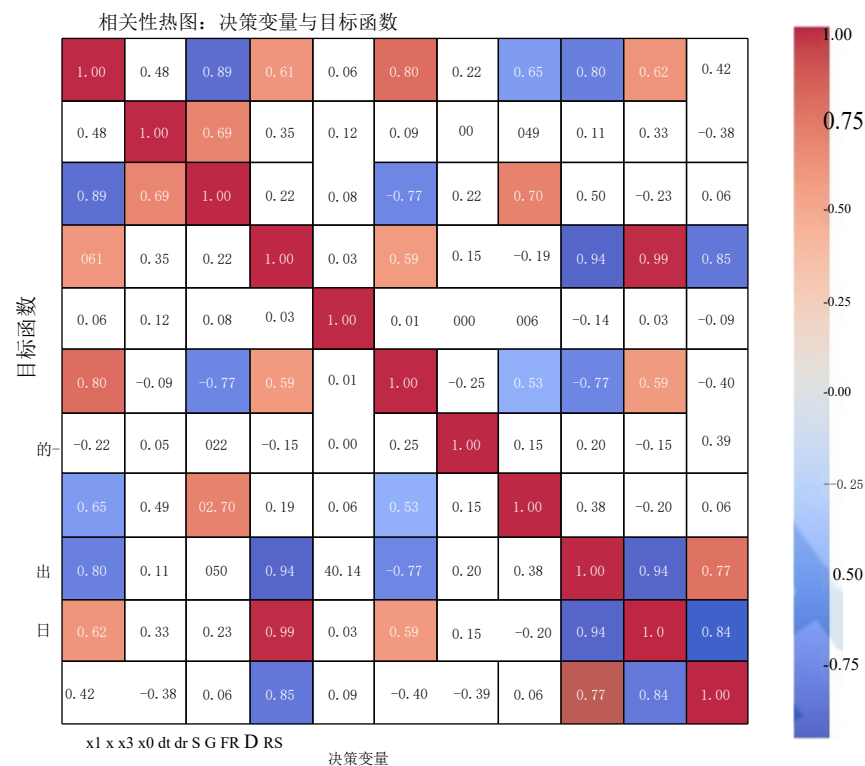
The absolute values of the correlation coefficients between  $x_0$  and FR,ED,RS are 1.00, 0.75,and 0.97 respectively.Its impact on the three objective functions is higher than all other decision-making variables.Therefore,in the Juneau sustainable tourism development model,restricting the total number of daily tourists is the most important factor.

The absolute values of the correlation coefficients of the increase in fees with fiscal revenue,environmental damage,and resident satisfaction are 0.68,0.35,and 0.66 respectively, which are much larger than those of hotel tax(0.03,0.02,0.25).

Among  $x_1, x_2$ ,and  $x_3, x_3$  has the greatest impact on the three objective functions. This clearly shows that diverting tourists to relatively less -popular attractions like the rainforest plays an important role in the overall sustainable development of tourism.Next is the number of tourists visiting the glacier.This indicates that the long-established popular attractions still have a significant influence on the overall tourism benefits and can bring considerable economic income to the community.

The construction of urban roads and infrastructure also has different impacts on overall sustainable development.Expanding roads which relieves congestion will yield greater benefits than improving infrastructure such as increasing the maximum daily waste disposal capacity of the city.This provides significant reference for the government's fiscal expenditure decisions.

Based on the above sensitivity analysis,the most influential factor on tourism is the restriction on the total number of daily tourists.When considering measures from the perspective



**图10：相关性热图：划分变量与目标函数**

从热图中可以看出：

$x_0$ 和 FR、ED 和 RS 之间的相关系数绝对值分别为 1.00、0.75 和 0.97。它对这三个目标函数的影响高于所有其他决策变量。因此，在朱诺可持续旅游发展模型中，限制每日游客总数是最重要的因素。

费用增加与财政收入、环境破坏、居民满意度的相关系数绝对值分别为 0.68,0.35 和0.66，远大于酒店税（0.03,0.02,0.25）。

在x1、x2和x3中，x3对三个目标函数的影响最大。这清楚表明，将游客引向雨林等相对冷门的景点，对旅游业整体可持续发展具有重要作用。其次是冰川游客数量。这说明历史悠久的热门景点仍对整体旅游收益产生显著影响，能为当地社区带来可观的经济收入。

城市道路和基础设施建设对城市可持续发展的影响也各不相同，缓解交通拥堵的扩路工程比提高城市垃圾日处理能力等基础设施建设带来的效益要大，这为政府的财政支出决策提供了重要参考。

根据上述敏感性分析，对旅游业影响最大的因素是每日游客总量的限制。在考虑措施时，从

of tourist consumption, adjusting fees brings better benefits than changing hotel tax. When considering measures based on the distribution of tourist numbers, it is necessary to divert tourists from the popular glacier attraction to relatively less-visited but community-beneficial attractions like the rainforest through promotion and welfare policies.

## 7 Expansion of the Model

### 7.1 Expansion Model for the Maldives

To test the generalizability of the model, we applied it to another tourist destination, the Maldives. The Maldives is a country highly dependent on tourism. However, in recent years, with the increase in the number of tourists, high carbon emissions and global warming have led to several environmental problems such as sea-level rise and coral reef degradation, which have seriously affected the sustainable development of the tourism industry in the Maldives.

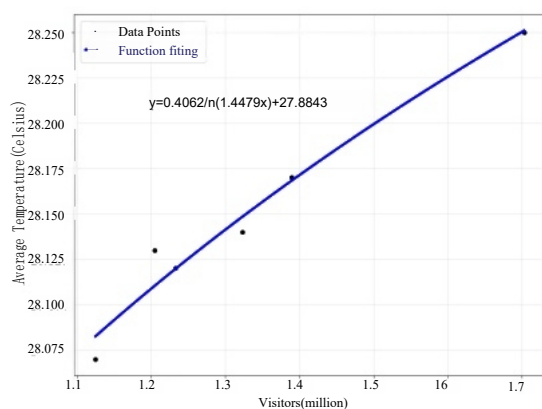
#### 1) Modelling ideas

Similar to Juneau, we mainly divided it into three scenic spots: the most popular North Malé Atoll, and the relatively less-visited Male and Haa Alifu Atoll.

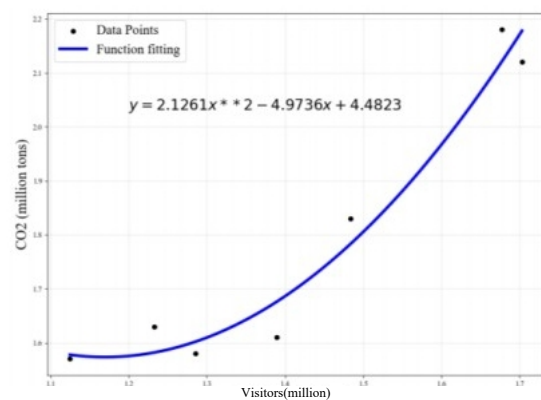
The overall application of the model is similar to that in Juneau. But in terms of decision variables, considering that the Maldives is a small island-nation, the impact of the road area on residents' satisfaction is ignored, and the degree of congestion caused by tourists is directly measured by the number of tourists.

#### 2) Model construction

First, we collected the number of tourist arrivals, corresponding carbon dioxide emissions, and average annual temperature in the Maldives over the past decade. The following figure shows the results of the regression analysis:



(a) Fitted function of average temperature



(b) Fitted function of carbon footprint

Figure 11: Function fitting results

Meanwhile, we collected the following data of the Maldives: the average daily consumption per tourist is \$351, the average price per person in hotels is approximately \$115.6, the

在旅游消费方面，调整费用比改变酒店税更能带来效益。在制定基于游客数量分布的措施时，有必要通过推广和福利政策，引导游客从热门的冰川景点转向相对冷门但对社区有益的景点，如雨林。

## 7 模型的扩展

### 7.1 马尔代夫的扩张模式

为验证模型的普适性，我们将其应用于另一个旅游目的地——马尔代夫。该国高度依赖旅游业发展，但近年来游客数量激增导致碳排放量攀升，进而引发海平面上升、珊瑚礁退化等环境问题，严重制约了旅游业的可持续发展。

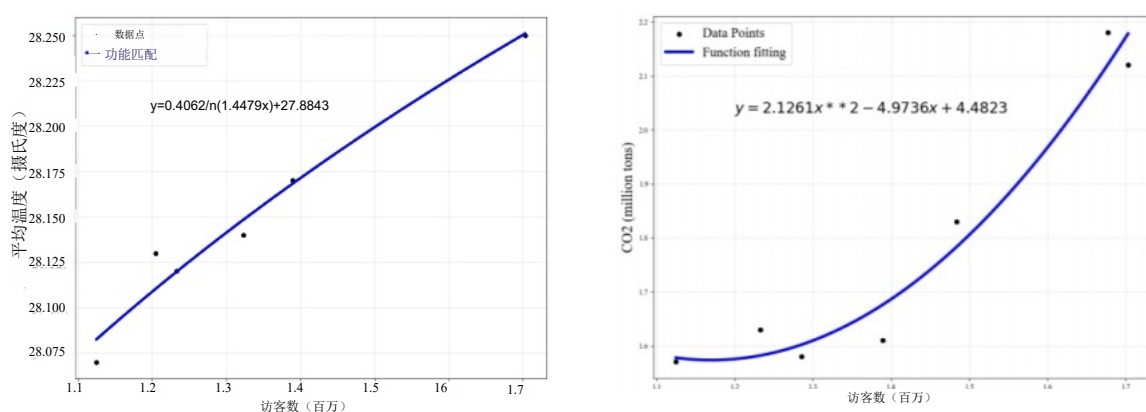
#### 1) 建模想法

与朱诺相似，我们主要将其划分为三个景区：最受欢迎的北马累环礁，以及相对游客较少的马累环礁和哈阿利富环礁。

该模型的整体应用与朱诺地区相似。但就决策变量而言，考虑到马尔代夫是一个小岛国，道路区域对居民满意度的影响被忽略，游客造成的拥堵程度则直接通过游客数量来衡量。

#### 2) 模型构建

首先，我们收集了过去十年间马尔代夫的游客到访人数、相应二氧化碳排放量及年平均气温数据。下图展示了回归分析的结果：



(a) 平均温度拟合函数 (b) 碳足迹拟合函数

图11：函数拟合结果

同时，我们收集了以下马尔代夫的数据：人均日消费351 touristtois 美元，人均酒店价格k约为115.6美元，

hotel tax rate  $r$  is 12%,the population of the original residents  $P_0$  is about 521,400,the average daily garbage production per capita of the original residents is about 2.8kg,the average daily garbage production per capita of tourists is about 3.5 kg,the maximum garbage carrying capacity  $G_{2023}$  is estimated to be 9,612,420 kg/day,and the estimated per capita consumption in the three scenic spots is \$800,\$250,and \$300 respectively.

Substituting these data,we obtain the expression for residents'satisfaction as(23):

$$RS = \frac{(351 + \Delta t)x_0}{1319.06} + \frac{0.6389}{x_0} + \frac{G}{26250000x_0 + 10753875} \quad (23)$$

For the degree of environmental damage,considering that carbon dioxide emissions play a major role in coral reefs,we set the weight of carbon dioxide emissions at 0.7 and the average annual temperature at 0.3.Its expression is(24):

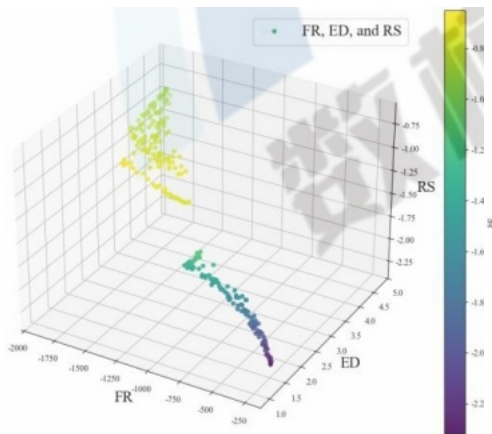
$$ED = 0.3 \frac{0.4062 \ln(14479x_0) + 27.8843}{28.07} + 0.7 \frac{2.1261x_0^2 - 4.9736x_0 + 4.4823}{1.57} \quad (24)$$

For the government's fiscal revenue,its expression is(25):

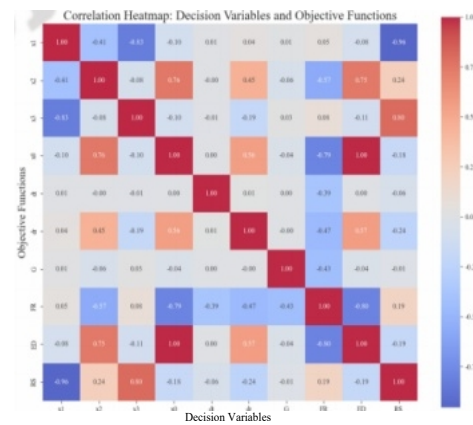
$$FR = 800x_1 + 200x_2 + 300x_3 + x_0 \cdot \Delta t + 115.6x_0 \cdot (0.12 + \Delta r) \quad (25)$$

### 3) Result and Analysis

In response,we stillused the NSGA-II method to solve the multi-objective programming problem.Eventually,similar to solving the problem in Juneau,we obtained three optimal solutions and conducted a sensitivity analysis.The scatter plot distribution(a)and the sensitivity heat map(b)are shown as follows.



(a)Pareto Front



(a)Correlation heatmap

Figure 12:Result chart

From the sensitivity heat map,we can see that limiting the maximum number of daily tourists remains the most sensitive among all decision variables.Its absolute values of correlation coefficients relative to FR(Fiscal Revenue),ED(Environmental Damage),and RS(Residents'Satisfaction)are 0.84,1.00,and 0.80 respectively.Similar to Juneau,in the Maldives,

酒店税率为12%，原住民人口P；约为521400人，原住民人均日垃圾产生量约为2.8kg，游客人均日垃圾产生量约为3.5kg，垃圾最大承载量  $G_{2023}$  估计为9612420kg/天，三个景区人均消费估计分别为800美元、250美元和300美元。

代入这些数据后，我们得到居民满意度的表达式（23）：

$$RS = \frac{(351 + \Delta t)x_0}{1319.06} + \frac{0.6389}{x_0} + \frac{G}{26250000x_0 + 10753875} \quad (23)$$

针对环境损害程度的评估，考虑到二氧化碳排放对珊瑚礁具有重大影响，我们将二氧化碳排放权重设定为0.7，年平均温度权重设定为0.3。其表达式为（24）：

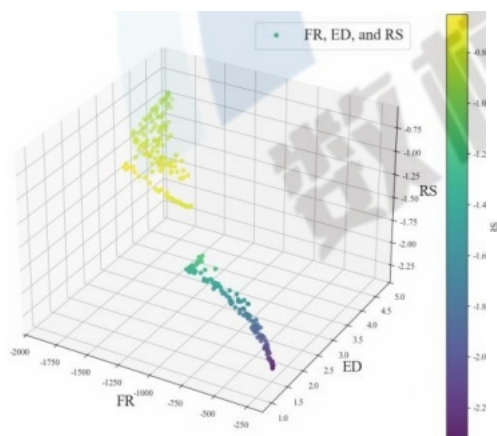
$$ED = 0.3 \frac{0.4062 \ln(14479x_0) + 27.8843}{28.07} + 0.7 \frac{2.1261x_0^2 - 4.9736x_0 + 4.4823}{1.57} \quad (24) \text{ 政府财政}$$

收入的表述为（25）：

$$FR = 800x_1 + 200x_2 + 300x_3 + x_0 \cdot \Delta t + 115.6x_4 \cdot (0.12 + \Delta r) \quad (25)$$

### 3) 结果与分析

作为回应，我们仍然使用 NSGA -II方法来解多目标规划问题。最终，类似于解决朱诺问题的方法，我们得到了三个最优解，并进行了敏感性分析。散点图分布(a)和敏感性热图(b)如下所示。



(a) 帕累托前沿

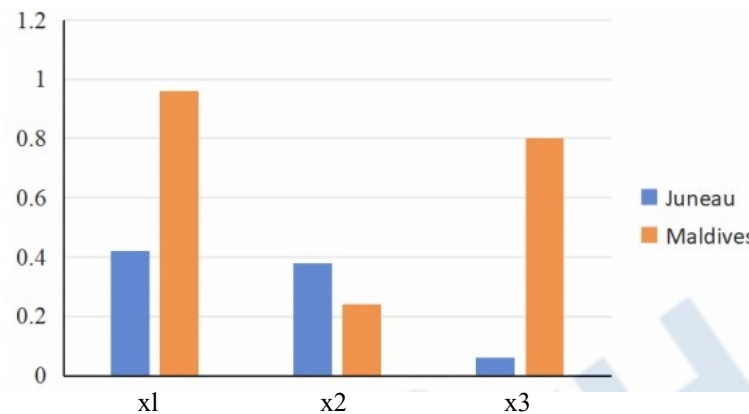


(a) 相关性热图图12：结果图表

从敏感性热图中可以看出，限制每日游客的最大数量仍然是所有决策变量中最敏感的。其与财政收入（FR）、环境损害（ED）和居民满意度（RS）的相关系数绝对值分别为 0.84, 1.00 和 0.80。与朱诺类似，在马尔代夫，

restricting the total tourist flow is still one of the most important measures for maintaining sustainable tourism development. Likewise, in terms of increasing tourist consumption, controlling the hotel tax brings more benefits than increasing tourist fees.

In addition, as shown in the figure, we also found that the correlation between residents' satisfaction and the number of tourists is higher in the Maldives compared to Juneau.



**Figure 13: the correlation between residents' satisfaction and the number of tourists**

This is determined by the characteristics of the Maldives itself. The average consumption per tourist in the Maldives is \$351, which is higher than the \$243 in Juneau. Moreover, as the Maldives is highly dependent on the tourism industry, many residents' incomes mainly come from it. Therefore, residents' satisfaction is more sensitive to the income brought by the number of tourists.

Model Promotion in Areas with Low Tourist Numbers

## 7.2 Expansion Model in low-tourist-volume areas

Unlike cities like Juneau, to promote the sustainable development of tourism in areas with a small number of tourists, the focus should be on developing the economic income effect, appropriately reducing the weight of ecological benefits, attracting more tourists, and making more reasonable expenditure plans.

First, according to the model proposed by Nguyen, the increase in fees and taxes in a region can affect tourism demand, i.e., the number of tourists. When applying our model to areas with fewer tourists, the correlation coefficients between fee/tax increases and the three objective functions will rise notably, with greater sensitivity. Thus, such areas can draw more tourists and yield more benefits by cutting prices. Secondly, an important conclusion drawn from this model is that diverting some tourists from popular scenic spots to less-visited ones plays a crucial role in the sustainable development of the overall tourism industry. Therefore, for regions with fewer tourists, they can attract tourists from other more popular areas through publicity, negotiation, or welfare policies.

In addition, unlike Juneau, which spends on infrastructure, road construction, and ecological projects, cities with fewer tourists should focus spending on external promotion and the development of tourism projects to boost economic income.

限制游客总量仍然是保持旅游业可持续发展的重要措施之一，同样地，从增加旅游消费的角度来看，控制酒店税比增加旅游消费税带来的效益更大。

此外，如图所示，我们还发现马尔代夫居民满意度与游客数量之间的相关性高于朱诺。

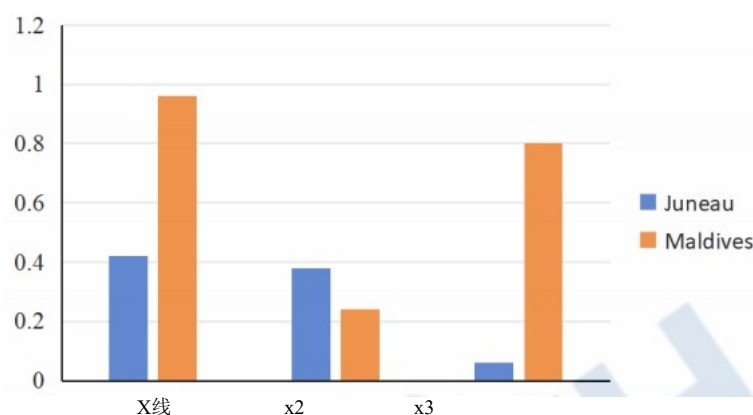


图13：居民满意度与游客数量的相关性

这取决于马尔代夫自身的特征。马尔代夫每位游客的平均消费为351美元，高于朱诺的243美元。此外，由于马尔代夫高度依赖旅游业，许多居民的收入主要来自旅游业。因此，居民满意度对游客数量带来的收入更为敏感。

低游客量地区旅游产品推广模式研究

## 7.2 低客流量地区旅游开发模式研究

与朱诺等城市不同，对于游客稀少的地区，要推动旅游业可持续发展，重点应放在提升经济效益上，适当降低生态效益的比重，吸引更多游客，并制定更合理的支出计划。

首先，根据Nguyen提出的模型，一个地区费用和税收的增加会影响旅游业 demand, i.e., 即游客数量。当我们把我们的模型应用到游客较少的地区时，费用/税收增加与三个目标函数之间的相关系数将显著上升，敏感性更大。因此，这些地区既能吸引更多游客，又能通过降价策略获得更大收益。其次，该模型得出一个重要结论：将部分游客从热门景点分流至冷门景点，对旅游业整体可持续发展具有关键作用。对于游客较少的地区，可通过宣传推广、政策协商或福利措施，吸引来自热门景区的游客。

此外，与朱诺市将资金投入基础设施、道路建设和生态项目不同，游客较少的城市应将资金重点用于对外宣传和旅游项目开发，以促进经济收入增长。

## 8 Model Evaluation

### 8.1 Strengths

- Strength 1: The TSMP model comprehensively considers multiple aspects of sustainable tourism.  
The model takes fiscal revenue, residents' satisfaction, and environmental damage as optimization objectives, and uses multiple indicators such as urban congestion degree, residents' income, and carbon footprint for measurement. It comprehensively considers the coordinated development of the economy, society, and environment emphasized by sustainable tourism, and balances the needs of multiple stakeholders including tourists, residents, the government, and so on.
- Strength 2: Quantified by multiple methods, our multi-objective optimization model is scientific and reasonable.  
Regression analysis is carried out using Python in the assessment of environmental damage. In the assessment of residents' satisfaction, the Analytic Hierarchy Process and analogical inference method are used to determine the weights. In the analysis of the constraints from the growth of tourist fees and taxes, the tourism consumption model is adopted.
- Strength 3: NSGA-II demonstrates remarkable superiority in solving multi-objective optimization problems.  
NSGA-II uses a fast non-dominant ranking method to divide the population into multiple non-dominant layers, preferentially retaining solutions at the Pareto front, which guarantees the quality of understanding. In addition, NSGA-II uses crowding distance to measure the density of solutions in the target space, and prefers uniformly distributed solutions, which well maintains the diversity of the Pareto solution set and avoids the concentration of solutions in a local region of the target space.
- Strength 4: Our model boasts great stability and scalability.  
After practical verification, our model can be applied to tourist attractions in different countries and regions, and can be predicted and inferred under many different conditions. In addition, on the basis of the original NSGA2 algorithm, we have added a constraint penalty mechanism, which can make the prediction results of the model more accurate by adding multiple constraints and customizing the penalty mechanism.

### 8.2 Weaknesses

- Weakness 1: We can incorporate more indicators such as alcohol consumption and housing pressure into the optimization model if we have more comprehensive data.
- Weakness 2: Due to the large amount of statistical data being measured on an annual basis, we have ignored seasonal factors.
- Weakness 3: The correlations and interactions among different scenic spots were not considered, such as the existence of joint ticketing.

## 8 模型评价

### 8.1 优点

- 优势1: TSMP模型综合考虑了可持续旅游的多个方面。

该模型以财政收入、居民满意度和环境损害为优化目标，采用城市拥堵程度、居民收入、碳足迹等指标进行量化评估。模型全面考量了可持续旅游所强调的经济、社会与环境协调发展，同时兼顾游客、居民、政府等多方利益相关者的诉求。

- 优势2: 经多种方法验证，我们的多目标优化模型具有科学性和合理性。

在环境损害评估中采用Python语言进行回归分析，在居民满意度评估中采用层次分析法和类比推理法确定权重，在旅游消费模型中分析旅游税费增长的约束。

- 优势3: NSGA -II在解决多目标优化问题方面表现出显著的优越性。

NSGA -II 使用快速非支配排序方法将种群划分为多个非支配层，优先保留帕累托前沿的解，这保证了理解的质量。此外，NSGA -I 使用拥挤距离来测量目标空间中解的密度，并优先考虑均匀分布的解，这很好地保持了帕累托解集的多样性，避免了解在目标空间的局部区域集中。

- 优势4: 我们的模型具有极高的稳定性和可扩展性。

经过实际验证，该模型可应用于不同国家和地区的旅游景点，并且在多种不同的条件下进行预测和推断，在原有NGSA2算法的基础上，增加了约束惩罚机制，通过增加多约束和定制惩罚机制，使模型的预测结果更加准确。

### 8.2 虚弱

- 缺陷1: 若能获取更全面的数据，我们可将更多指标（如酒精消费量与住房压力）纳入优化模型。
- 缺陷2: 由于每年测量的统计数据量庞大，我们忽略了季节性因素。
- 3、景区之间关联性、互动性考虑不周，如联票制度的设置。

## Memo

*To: the Tourist Council of Juneau*

*From: Team 2517929*

*Data: 2025.1.27*

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Dear officials,

We are very honored to provide suggestions on measures for the development of sustainable tourism in Juneau. To address the series of issues arising from the continuously growing number of tourists, we developed an optimization model for sustainable tourism and designed a feasible tourism sustainable management plan for Juneau, also called TSMP, based on the model's results, to maintain their status as a tourist destination.



### √ Tourism Sustainable Management Plan

#### 1. Limit the Total Number of Visitors to Tourist Attractions

We hope that the authorities can limit the total number of tourists to tourist attractions to about 1.43 million per year, so as to facilitate the long-term stable development of local tourism.

#### 2. Optimize the Tourist Experience of Different Attractions

We hope to optimize the experience of tourists in other tourist attractions and divert tourists, so as to reduce the bearing pressure of Mendenhall Glacier and achieve sustainable development in the future.

#### 3. Increase Hotel Taxes Appropriately

We tend to recommend that the authorities appropriately increase hotel taxes and put more excess income into infrastructure construction and environmental protection investment.

#### 4. More Fiscal Revenue into Infrastructure Construction and Environmental Protection

We suggest that the government spend more revenue on infrastructure such as road expansion, and should also spend more on environmental protection projects.

### √ Optimization suggestions

Due to the lack of data and time constraints, there are inevitably some flaws in our plan. To enhance the effectiveness of the measure implementation, optimizations can be carried out in the following aspects:

- ◇ Annual statistics of the number of tourists and tourism income
- ◇ Resident satisfaction survey at least once a year
- ◇ Collect opinions on infrastructure construction at least once a year
- ◇ The effect of fiscal expenditure at least once a year

It is believed that from the Tourism Business Management Plan (TBMP) to the Tourism Sustainability Management Plan (TSMP), the tourism industry in Juneau will never fade away and will create more well-being for the people.

## 备忘录

致：朱诺市旅游委员会

发件人：Team 2517929

Data:2025.1.27

尊敬的官员们：

我们非常荣幸能就朱诺可持续旅游发展措施提出建议。为了应对游客数量持续增长带来的一系列问题，我们开发了一个可持续旅游优化模型，并基于该模型的结果，为朱诺设计了一个可行的可持续旅游管理计划，即 TSMP，以维持其作为旅游胜地的地位。

目的地

朱诺市旅游可持续发展管理规划



## √旅游可持续管理计划

### 1.限制旅游景点的游客总量

希望有关部门能将每年到景区旅游的游客总数控制在143万人次左右，以利于当地旅游业的长期稳定发展。

### 2.优化不同景点的旅游体验

我们希望优化其他旅游景点的游客体验并分流游客，从而减轻门登霍尔冰川的承载压力，实现未来可持续发展。

### 3、适当提高酒店税

我们建议当局适当提高酒店税，将更多超额收入用于基础设施建设和环境保护投资。

### 4.加大财政收入投入基础设施建设与环境保护

建议政府增加财政收入，用于道路扩建等基础设施建设，同时增加环境保护项目的投入√建议优化

由于数据不足及时间限制，本方案不可避免存在某些缺陷。为提升措施实施效果，可在以下方面进行优化：

- ◇ 旅游人数和旅游收入年度统计
- ◇ 每年至少进行一次住院医师满意度调查
- ◇ 每年至少收集一次基础设施建设的意见
- ◇ 财政支出每年至少一次的效果

人们相信，从旅游业务管理计划（TBMP）到旅游可持续性管理计划（TSMP），朱诺的旅游业永远不会消失，并将为人们创造更多的幸福。

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