Problem Chosen	2025 MCM/ICM Summary Sheet	Team Control Number
B		2510625

An MCM Paper Made by Team 2510625

Summary

Here is the abstract of your paper.

对于问题 1，我们仔细分析了旅客人数，税收的变化，财政在基建方面的投入比例对于政府最后的收入，环境质量以及社会满意度所产生的影响后进行了线性规划，建立了混合优化模型并用种群迭代机制从局部最优解找到了全局的最优解。基于往年朱诺的居民满意度调查数据和相对应年的游客数量对社会满意度和游客人数进行了一个非线性的拟合，其可靠度为 0.7423。我们将社会满意度和环境质量通过乘以一个合适的系数进行了去量纲处理，方便衡量对目标函数的影响。根据我们的模型生成的结果显示在游客人数为 1552632，游客税率为 8%，废物管理投入占比为 0.128，水资源管理投入占比为 0.113，环境保护投入占比为 0.159 的时候，总收入为 295000000000 美元，CO_2 的排放量为 285684.21 吨，居民满意度为 65.84(100 为最大)，环境指数为 0.5014(1 为最大，越小越好)。敏感性分析上，我们分析了变量的局部敏感性和全局敏感性，具体结果如图 x 所示并得出人数是关键的变量。

Secondly, that is ...

Finally, that is ...

目录

1 Introduction

1.1 Problem Background

Here is the problem background. Three major problems are discussed in this paper, which are:

- **地理位置**：朱诺市是美国阿拉斯加州的首府，位于阿拉斯加东南部，拥有约 30,000 名居民。这座城市以其丰富的自然资源、独特的地理位置和迷人的自然景观而闻名，是许多游客前往阿拉斯加的首选目的地之一。朱诺市不仅是阿拉斯加的政治中心，也是一个重要的旅游枢纽，以其冰川、雨林和丰富的野生动物资源吸引着来自世界各地的游客。
- **旅游现状**：近年来，朱诺市的旅游业经历了迅猛的发展，尤其是在邮轮旅游方面。2023 年，朱诺市创下了接待 160 万邮轮游客的纪录，单日最多接待 7 艘大型邮轮，游客数量高达 20,000 人。[1] 这些游客为城市带来了可观的经济收益，约 3.75 亿美元。[2] 然而，这种快速发展的旅游业也带来了一系列问题，尤其是与过度旅游相关的挑战。
- **环境影响**：朱诺市的门登霍尔冰川是该市的主要旅游景点之一，但近年来由于气温上升，冰川正在快速消退。自 2007 年以来，冰川已经后退了相当于八个足球场的距离。这种环境变化不仅对自然景观造成了破坏，也引发了当地居民对旅游业可持续性的担忧。[3]

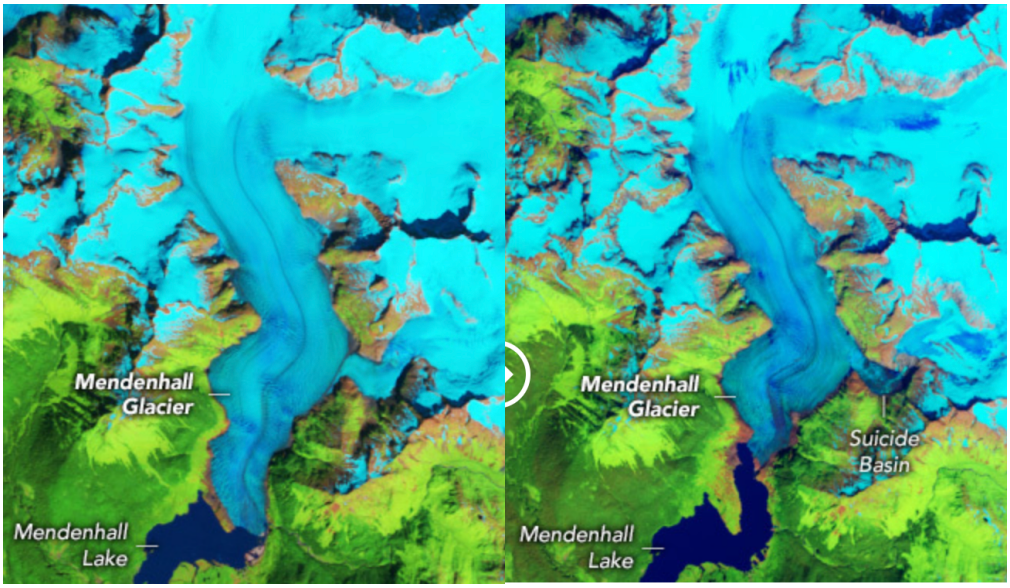


Figure 1: glacier

1.2 Problem Restatement and Analysis

- **Problem1:** 建立一个可持续旅游产业的模型，它应当满足最大化收入，最大化环境质量且最大化社会满意度并对其进行敏感性分析。
- **Problem2:** 建立一个模型去解决游客分流到其他人流量比较小的景点，这也是增加收入减少区域压力的措施。
- **Problem3:** 展示模型如何可以适应另一个受过度旅游影响的旅游目的地，应当去获取另一个城市的相关信息并用模型进行预测。
- **Problem4:** 展示模型随着具体措施会发生的变化以此来为决策者提供更好的建议，比如加酒店税、游客费用、每日游客数量上限以及限制酒精销售和消费等。
- **An article:** 为朱诺市旅游局写一封一页的备忘录，概述结果的预测、各种措施的影响以及对如何优化结果的建议。

1.3 Our work

To avoid complicated description , intuitively reflect our work process, the flow chart is show as the following figure:

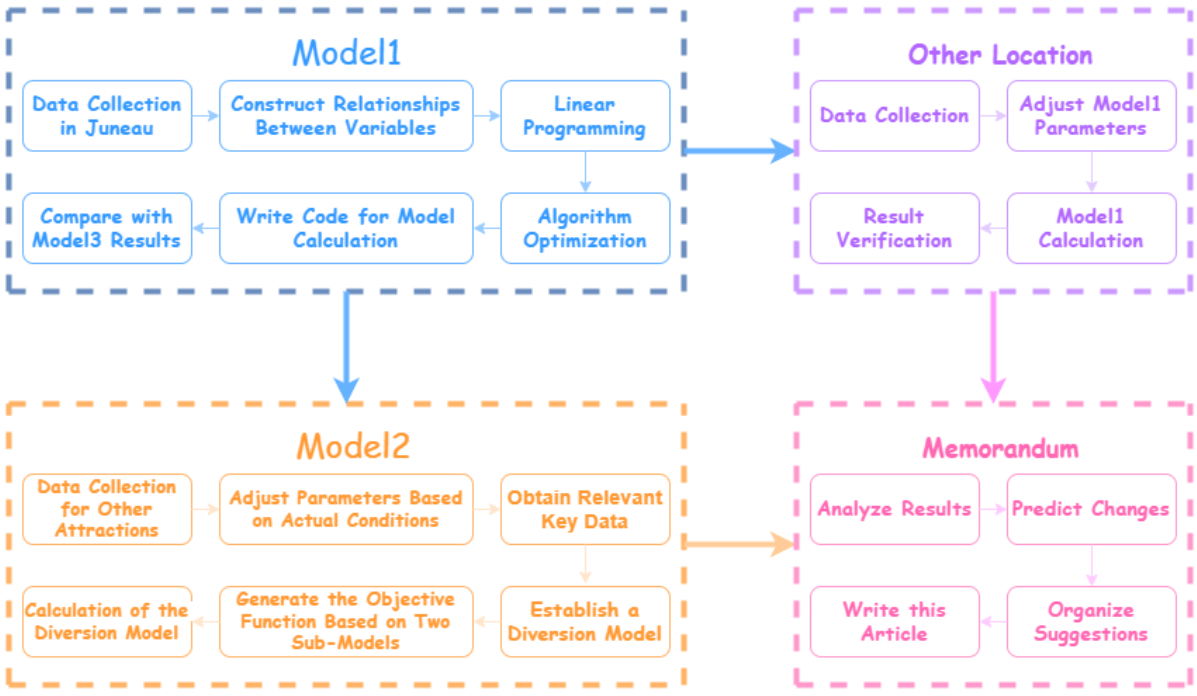


Figure 2: Pcocess map

2 Preparation of the Models

2.1 Assumptions

2.2 Notations

The primary notations used in this paper are listed in Table 1.

Table 1: Notations

Symbol	Definition
R_e	Total tourism income
N_t	Number of tourists
N_{tmax}	Maximum number of tourists allowed per day
τ_t	Tax rate
P_t	Average spending per tourist
E	Environmental quality index
CO_{2p}	Carbon emissions per person
C_{base}	Base carbon emission treatment capacity
C_{waste}	The amount of basic waste that the city can handle
C_{water}	The basic amount of water that the city can provide
$S_{residents}$	Residential satisfaction
S	Social satisfaction
P_{waste}	Cities' investment in waste management
P_{water}	Cities' investment in water management
P_e	Cities' investment in environment management
Z	Representation of target equation

3 Solution to Problem1

3.1 建立一个可持续旅游发展的模型

3.1.1 找到状态变量之间的关系

我们的目标函数应受收入，社会满意度和环境质量三者影响，若收入增加，则目标函数也应该增加，社会满意度同理，而环境质量越大负面影响也越大所以目标函数应减小，因此我们可以得到：

$$Target\ equation: Z = R_e + S - E \tag{1}$$

旅游的总收入应当和旅客的人数成简单的线性关系，因此我们可以很简单的得到公式2

$$R_e(N_t, P_t) = P_t N_t \tag{2}$$

环境质量方面，主要考虑三个因素的影响：二氧化碳排放量，水的消耗量以及废物的产生量，而这三个因素都与游客人数密切相关。通过朱诺市的对这三个因子的处理能力和人均消耗/产生量，可以计算出朱诺市可以承载的人数 $C_{base}, C_{waste}, C_{water}$，我们将实际的人数和承载人数相比，通过比例衡量体系压力。最后使用 Analytic Hierarchy Process(ATP) 方法结合各因子的重要性因素得到了公式 3：

$$E = k_1(CO_{2p}N_t - C_{base}) + k_2\frac{N_t}{C_{waste}} + k_3\frac{N_t}{C_{water}} \tag{3}$$

社会满意度方面，我们收集了朱诺市 1998，2002，2006，2022，2023 五年的社会满意度调查 [4]，并摒除其无影响和不知道的无效评价，将剩下的评价依据李斯特量表分成了五级，并进行了量化以使结果保持在 1 以内。同时我们查找了这五年的游客人数 **[?]** 来和社会满意度进行了数据拟合并得到了如下结果：

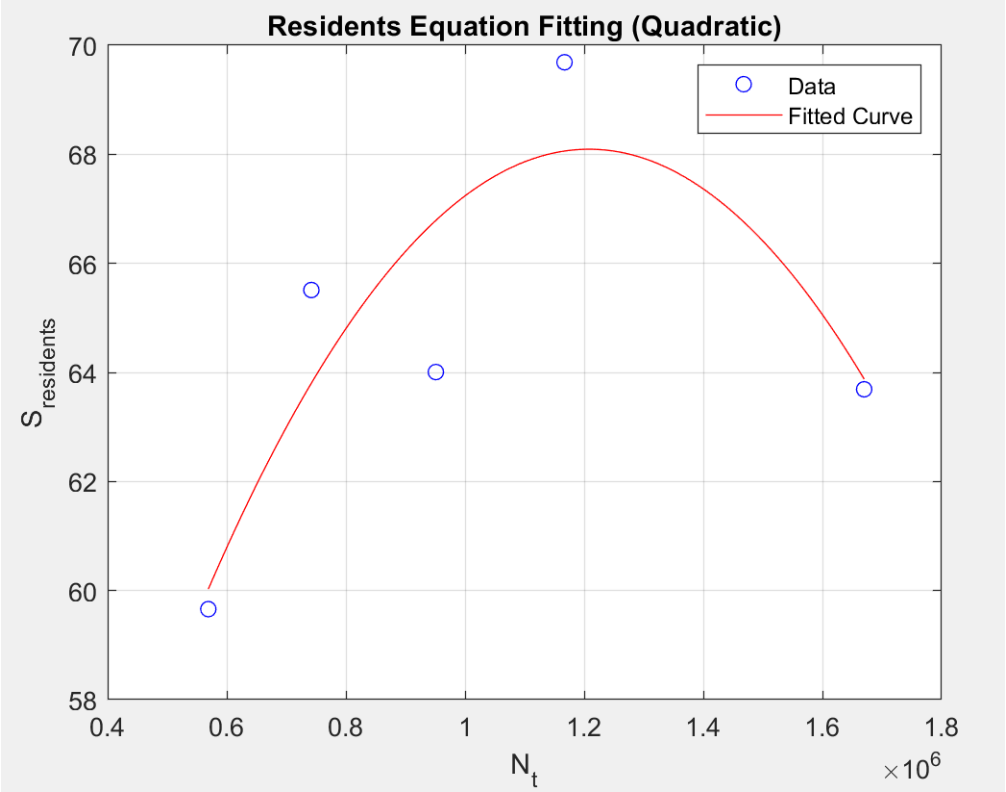


Figure 3: satisfaction

其中，$a_1 = -1.9753\text{e}{-11}, a_2 = 4.772\text{e}{-5}, b = 39.2660, R^2 = 0.7423$。最后，为了消除量纲带来的影响以来衡量社会满意度对目标函数的影响，我们给数据加上了一个合适的系数 $k4$。得到的公式 4 如下：

$$\begin{cases} S_{residents} = a_1 N_t^2 + a_2 N_t + b_1 \\ S = k_4 S_{residents} \end{cases} \tag{4}$$

$$\begin{cases} \frac{\mathrm{d}C_{waste}}{\mathrm{d}t} = \alpha_1 P_{waste} \\ \frac{\mathrm{d}C_{water}}{\mathrm{d}t} = \alpha_2 P_{water} \\ \frac{\mathrm{d}C_{base}}{\mathrm{d}t} = \alpha_3 P_e \end{cases} \tag{5}$$

基建的额外投入方面，由于税率变化后的数据不够用于进行拟合以及考虑到税收对游客数量和消费意愿的抑制效应以及对消费的增长效应，结合实际已有的数据，认为在一定范围内波动时游客消费不受影响，简化为常数考虑。最后结合基建投入在政府实际分配中

的比值，限定上限进行约束后得到公式 6 如下：

$$\begin{cases} P_{waste} = k_5 \tau_t R_e \\ P_{water} = k_6 \tau_t R_e \\ P_e = k_7 \tau_t R_e \\ k_5 + k_6 + k_7 \leqslant 0.4 \end{cases} \tag{6}$$

3.1.2 找到约束条件

在经济方面，很显然我们有 R_e 必须要大于等于 0。为了限制税率的值，我们根据 xxx 得出税率应小于等于 8%。因此有公式 7：

$$Financial: \begin{cases} R_e \geqslant 0 \\ \tau_t \leqslant 8\% \end{cases} \tag{7}$$

游客人数方面，我们依据朱诺市的政策 [**?**] 得出了每天的游客的人数限制。公式 8 如下:

$$Tourism: 0 \leqslant N_t \leqslant N_{tmax} \tag{8}$$

环境方面，以 NASA 的冰川融化数据 [5] 为基础，通过度日因子法来进行量化计算，最后通过二氧化碳影响温度进而影响速度的因素来限定了二氧化碳的最大排放量。而在水资源最大承载量和废物处理最大承载量上面，考虑到旺季人数占全年的比例以及对于基建的压力，升大设置 1.2 倍日平均承载量作为上限来限制人数。公式 9 如下：

$$Environmental: \begin{cases} N_t \cdot CO_{2p} \leqslant CO_{2max} \\ 0.012 N_t \leqslant \frac{1.2}{365} C_{waste} \\ 0.012 N_t \leqslant \frac{1.2}{365} C_{water} \end{cases} \tag{9}$$

社会满意度方面，经过合适的量化后，我们将 60 作为及格线。故公式 10 如下：

$$Societal: \ S_{residents} \geqslant 60 \tag{10}$$

3.1.3 Multi-start Optimization Algorithm

Since our model has five decision variables, namely N_t, τ_t, k_5, k_6 and k_7, which interact with each other and have varying degree of influence on the objective function. In order to achieve relatively optimal conditions for each decision variable locally and at the

same time strive for the global objective to be optimal, such as maximizing tourism revenue, minimizing environmental impact, and maximizing resident satisfaction, etc., we use a multi-start optimization strategy to optimize the various influencing factors of the objective function. The pseudocode is as follows:

Algorithm 1 Multi-start Optimization Algorithm

Input: n_starts, $Nmax$
Output: $best\_result$
/* Initialize variables */
$best\_result \leftarrow null$
$best\_objective \leftarrow \infty$
/* Generate starting points for each parameter */
$Nt\_starts \leftarrow linspace(100000,\ 0.8 \times Nmax,\ n\_starts)$
$\tau\_starts \leftarrow linspace(0.02,\ 0.07,\ n\_starts)$
$k\_starts \leftarrow linspace(0.05,\ 0.15,\ n\_starts)$
Define optimization bounds
/* Perform optimization from multiple starting points */
for $i \leftarrow 0$ **to** $n\_starts - 1$ **do**
    /* Construct initial point */
    $x0 \leftarrow [Nt\_starts[i],\ \tau\_starts[i],\ k\_starts[i],\ k\_starts[i]]$
    /* Minimize objective function */
    $result \leftarrow$ **minimize_function**
    /* Update best result if better solution found */
    if $result.success$ **and** $result.objective < best\_objective$ **then**
        $best\_objective \leftarrow result.objective$
        $best\_result \leftarrow deepcopy(result)$
    end if
end for
return $best\_result$

The solution and output of the model: The model maximizes economic, environmental, and social benefits through multi-start optimization of five decision variables. In the initialization phase, the algorithm first sets up an empty optimal solution container and an infinite initial optimal objective value as the benchmark. Then, the algorithm generates multiple sets of different starting points within reasonable value ranges to ensure that the algorithm can explore a larger solution space. During the optimiza-

tion loop phase, the algorithm performs a complete optimization attempt for each set of starting points. Each attempt uses the **Sequential Least Squares Quadratic Programming** (SLSQP) method to find the solution that optimizes the objective function, considering all constraints, such as visitor number limits, tax rate range, investment ratio restrictions, etc.). If an optimization attempt is successful and the resulting objective function value is better than the currently recorded optimal value, the optimal solution and objective value are updated. This process repeats until all starting points have been tested, and the globally optimal result is retained.

3.1.4 计算结果

CO_{2max} 的计算过程，C_{waste} 和 C_{water} 的计算过程。

旅游总收入上，根据以往的数据，我们给旅客平均消费值赋值为 x。经过我们的计算可以得到游客每年人数应为 x 人，P_e 为 x，结合以往的数据来看，这个数据是相对合理的。

居民满意度上，将旅客人数带进拟合方程后可以得到居民满意度为 x，符合我们的预期范围。

环境质量上，经过我们的 ATP 法得出 $k1 = X, k2 = X, k3 = X$，将旅游人数和 CO_{2max}，C_{waste},C_{water}, N_t 带入方程后得出结果为 x，符合我们的预期范围。

3.2 Sensitivity Analysis

Since we have used a multi-start optimization strategy, we use **Sobol Analysis** to simultaneously analyze the local sensitivity and global sensitivity of the input variables N_t, τ_t, k_5, k_6 and k_7. The pseudocode is as follows:

The results are shown in the figure below:

Algorithm 2 Sensitivity Analysis

Input: $n\_samples$
Output: Si (result of Sobol Analysis)
/* Define problem structure */
Initialize problem dictionary:
    number of variables, variable names, variable bounds
/* Generate samples */
$param\_values = saltelli.sample(problem,\ n\_samples)$
/* Evaluate model for all samples */
Initialize empty array Y
for each parameter set X in $param\_values$ **do**
    Calculate objective function value for X
    Add result to array Y
end for
/* Normalize results */
$Y = (Y - minimum\ of\ Y)/(maximum\ of\ Y - minimum\ of\ Y)$
/* Perform Sobol Analysis */
$Si = sobol.analyze(problem,\ Y)$
Print results
Visualize results
return Si

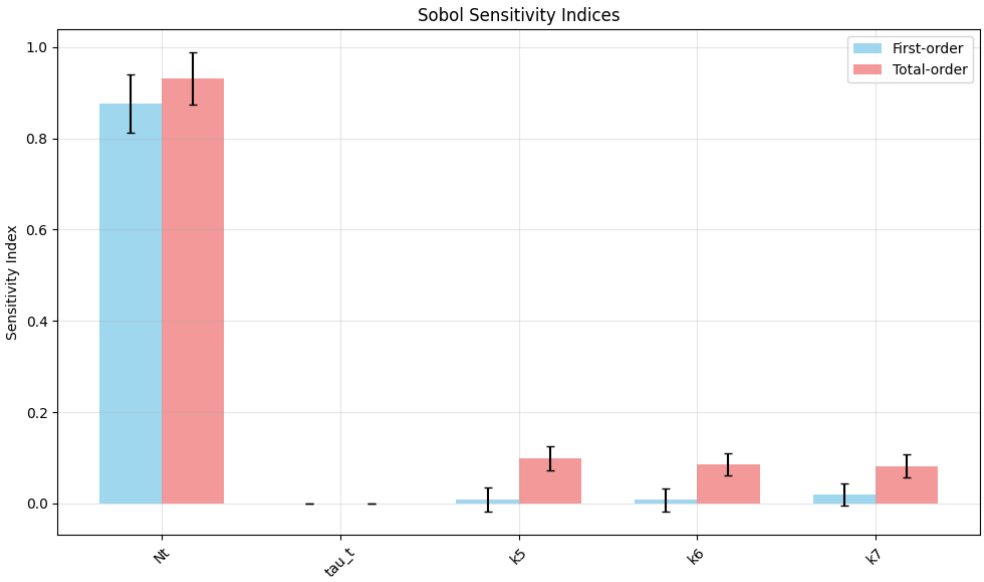


Figure 4: Sensitive Analysis

From the figure, it is clear that the number of tourists is the most critical variable, with its local and global sensitivities reaching 0.877 and 0.932, respectively, far greater than the other input variables. This also aligns with the objective fact that, as a tourist city, Juneau's income is heavily influenced by the number of tourists.

4 Solution to Problem2

4.1 建立分流模型

4.2 Commetary on Model 2

The instance of long and wide tables are shown in Table 2.

Table 2: Basic Information about Three Main Continents (scratched from Wikipedia)

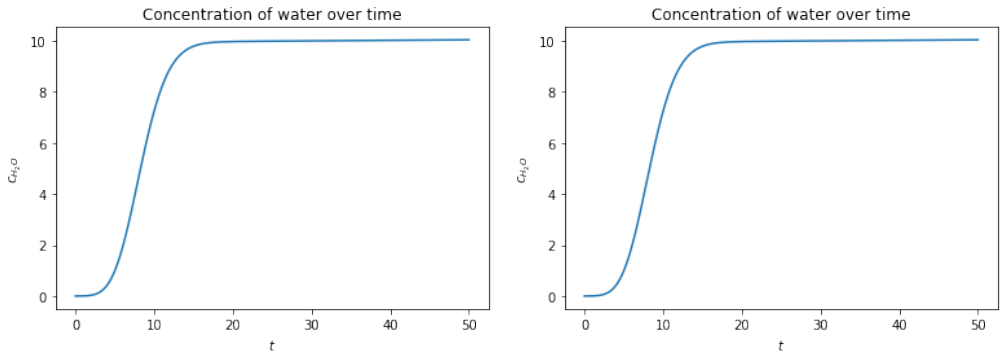
Continent	Description	Information

Africa	Africa Continent is surrounded by the Mediterranean Sea to the north, the Isthmus of Suez and the Red Sea to the northeast, the Indian Ocean to the southeast and the Atlantic Ocean to the west.	At about 30.3 million km^2 including adjacent islands, it covers 6% of Earth's total surface area and 20% of its land area. With 1.3 billion people as of 2018, it accounts for about 16% of the world's human population.
Asia	Asia is Earth's largest and most populous continent which located primarily in the Eastern and Northern Hemispheres. It shares the continental landmass of Eurasia with the continent of Europe and the continental landmass of Afro-Eurasia with both Europe and Africa.	Asia covers an area of 44,579,000 square kilometres, about 30% of Earth's total land area and 8.7% of the Earth's total surface area. Its 4.5 billion people (as of June 2019) constitute roughly 60% of the world's population.
Europe	Europe is a continent located entirely in the Northern Hemisphere and mostly in the Eastern Hemisphere. It comprises the westernmost part of Eurasia and is bordered by the Arctic Ocean to the north, the Atlantic Ocean to the west, the Mediterranean Sea to the south, and Asia to the east.	Europe covers about 10,180,000 km^2, or 2% of the Earth's surface (6.8% of land area), making it the second smallest continent. Europe had a total population of about 741 million (about 11% of the world population) as of 2018.

Figure 5 gives an example of subfigures. Figure 5a is on the left, and Figure 5b is on the right.

5 Solution to Problem3

为了展示模型是如何适应另一个受过度旅游影响的，我们经过数据的查找和收集决定选择位于中国四川省的九寨沟风景区来进行分析。



(a) Image on the left (b) Image on the right

Figure 5: Two images

因为每个地方的基础设施压力，人均消费等都大不相同，我们需要经过数据调研修改相应的参数后才能使用当前的模型进行预测。

通过对官网数据的收集 [6]，我们可以得出九寨沟县每年的收入和九寨沟风景区之间的关系。但是由于官方网站缺乏相应的满意度调查等信息，我们根据社会上的普遍评价对这些值进行了简单的估计，通过修改相应的限制条件，如水资源的人均消耗量，废物的人均产生量，水资源和废物处理的承载能力，游客人均消费水平，我们可以将模型适用于九寨沟的情况。根据我们模型跑出来的结果显示，xxx。这些数据和往年相比具有合理性，符合实际的基本预期。

Memorandum

To: 朱诺市政府
From: Team 2510625
Date: January 27th, 2025
Subject: 关于政府在旅游业上的一些建议

随着旅游市场的不断发展，朱诺市作为阿拉斯加的首府，拥有丰富的自然景观和独特的文化魅力，吸引了大量游客前来观光旅游。为了更好地了解旅游市场的发展趋势，评估各种措施对旅游市场的影响，并提出优化建议，我们进行了深入的市场调研和数据分析。

首先是关于旅游市场的预测，根据我们的市场调研和数据分析，预计未来几年朱诺市的旅游市场将呈现以下趋势：**游客数量增长：**随着全球经济的复苏和人们生活水平的提高，预计未来几年朱诺市的游客数量将呈现稳步增长的趋势。特别是来自亚洲和欧洲的游客数量将有较大幅度的增加。**旅游季节变化：**虽然夏季仍然是朱诺市的旅游旺季，但随着冬季旅游项目的不断丰富，如狗拉雪橇、冰钓等，冬季旅游市场也将逐渐升温。

二是各种措施的影响，为了促进朱诺市旅游市场的发展，我们分析了一系列措施，这些措施对旅游市场产生了以下影响：**适量提高税率：**适量提高税率短时间不会对旅游人数产生较大的影响，而税率的提高可以增加旅游业带来的收入，额外收入增加后可以对基建投入更多的金钱以来提高水资源和废物处理承载能力。**限制每日的游客人数：**限制每日的人数有助于缓解基础设施压力，提高居民满意度，同时如果限制的人数控制在一个比奥较好的值也能确保每日的收入保持在一个比较高的水平。

最后是一些优化的建议：**加强旅游基础设施建设：**继续加大对旅游基础设施的投入，进一步改善住宿、餐饮、交通等方面的条件。特别是要加大对偏远地区的旅游基础设施建设，提高旅游的可达性和便利性。有利于游客参观更多的景点，分散个别热门景点的压力。**提升旅游服务质量：**加强对旅游从业人员的培训，提高旅游服务的质量和水平。特别是要加强对导游、酒店服务人员等的培训，提高他们的专业素质和服务意识。这样可以提升朱诺市的旅游风评，增加游客前来的意愿。**加强市场营销推广：**继续在国内外主要旅游市场进行市场营销推广，提高朱诺市的知名度和美誉度。可以通过举办旅游推介会、参加旅游展会等方式，向更多的游客宣传朱诺市的旅游资源和旅游产品以来吸引更多游客和刺激游客消费，提高游客平均消费水平。

参考文献

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[4] *A simple, easy LaTeX template for MCM/ICM: EasyMCM*. (2018). Retrieved December 1, 2019, from https://www.cnblogs.com/xjtu-blacksmith/p/easymcm.html

[5] https://earthobservatory.nasa.gov/images/151682/alaskas-mendenhall-glacier

[6] https://www.jiuzhai.com/news/number-of-tourists/

Appendix A: Further on LaTeX

To clarify the importance of using LaTeX in MCM or ICM, several points need to be covered, which are ...

To be more specific, ...

All in all, ...

Anyway, nobody **really** needs such appendix ...

Appendix B: Program Codes

Here are the program codes we used in our research.

test.m

```
% MATLAB code example
for i = 1:10
    disp("hello, world!");
end
```

test.cpp

```
// C++ code example
#include <iostream>
using namespace std;

int main() {
    for (int i = 0; i < 10; i++)
        cout << "hello, world" << endl;
    return 0;
}
```