Problem Chosen	2025 MCM/ICM Summary Sheet	Team Control Number
B		2503139

Income and Expenditure Game! Balance between income and sustainability

Summary

With the development of transportation technology and social demands, many regions have gradually transformed into tertiary industries. Among these service sectors, tourism is becoming one of the top choices. The area can benefit from its strong relationships with the catering, commerce, and retail industries. Tourism is also an excellent way to increase employment opportunities.

However, over-tourism has become a hot topic these days, especially for some worldwide resorts. Traveler overloading has influenced a lot on local resource distribution and even caused some problems. What we explore is to find the solution to it.

Firstly, we take tourist numbers and tax rates as the points for optimization, while infrastructure pressure, glacier melting, and resident satisfaction serve as constraints for Juneau tourism. We can measure relevant indicators using the NGSA-II Model and analytic hierarchy process. Also, it shows the effect of tax on other factors and the sensitivity between composite impact on sustainable development and tourist numbers.

Then, we promote our model to a new place Iceland which has similar environmental conditions with Juneau. According to some specific features of Iceland, we revised the previous model by adjusting the factors of water supplies and resident satisfaction to jobs created and traffic pressure. To promote attractions that have fewer tourists to develop a better balance, we construct a new function to evaluate the tourist attraction index to our model. After that, the NGSA-II Model helps to set approved tourist amounts and construction costs.

Finally, we wrote a memo to the tourist council of Juneau, analyzed the current situation and problems of Juneau tourism, and made predictions and analyses of the problems. Then we provided our solutions and the possible effects of the predicted measures in the future.

Overall, this research builds the systems devoted to making predictions and giving suggestions for the over-tourism places and attractions lacking tourists. It paves the way for further improvement of the tourism industry.

Keywords: NGSA-II Model; sustainable development; over-tourism.

Table of Contents

1 Introduction

1.1 Problem Background

Juneau, located in the southeast of Alaska, is the capital of the U.S. state of Alaska. It is unique among U.S.state capitals for having no roads connecting it to the rest of the state or to the contiguous United States. Due to the extremely rugged terrain, its transportation is just shipping and aviation.

Tourism in Juneau started developing in 1963 and grew at a fast speed (Schwartz, S., & Gellert, H., 1966)[1]. It gradually became a local pillar industry. However, due to the over-tourism issue, obvious social and environmental problems began to emerge and grew to a severe one (Timm, K., 2014).

The same is true for Iceland, which is far away in Europe. Iceland also meets the situation of over-tourism, owing to its high latitude, its location as an island, and its similar glacier condition compared to Juneau as well[3](Hall, D. K. et al., 2000).

Vatna Glacier **http://fam-tille.de/sparetime.html**

Mendenhall Glacier https://bpic.588ku.com/

1.2 Restatement of the Problem

Based on the background information and conditions outlined in the problem statement, we must address the following issues:

Problem 1: Build a model for the sustainability of Juneau tourism and describe factors for optimization and constraints, then illustrate how expenditures from extra revenue promote sustainability in return and consider the importance of factors through sensitivity analysis.

Problem 2: Show how the model above can be applied to another over-tourism place and regard the choice of places, then see how it can promote less-tourist attractions or locations.

Problem 3: Write a one-page memo to the tourist council of Juneau showing our predictions, measure effects, and suggestions for optimization according to our research above.

1.3 Our Work

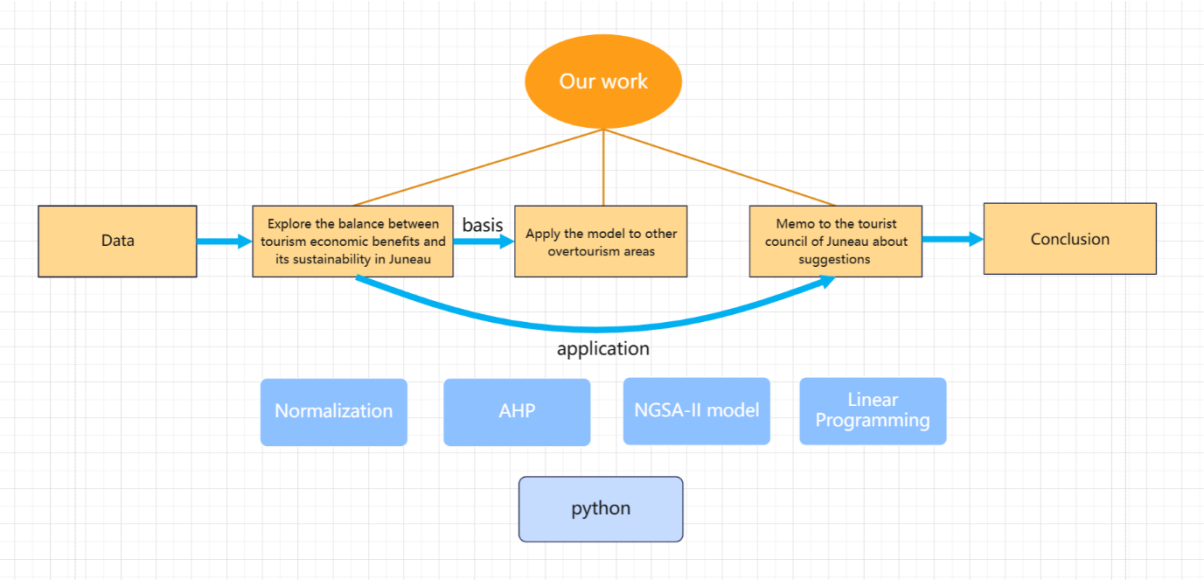


Figure 1: Our Work

2 Assumptions and Justifications

Considering there are some interference factors, we make some reasonable assumptions. Each assumption is followed by an explanation:

▼Assumption 1: All the data used are valid.

▲Justification 1: The data are collected from the latest journals and reliable websites. There is no manual errors during data collection.

▼Assumption 2: Ignore the influence of emergencies.

▲Justification 2: Emergencies such as COVID-19 or extreme weather would lead to unpredictable results, not under regularity.

3 Notations

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

Table 1: Notations used in this paper

Symbol	Description	Unit
F_1	profit of tourism	USD
T	average tourists amount visiting Juneau	unit
E	the average cost of a Juneau tour	USD
W	daily cost of drinking water supplies management in Juneau	USD
F_2	estimation of composite impact in Juneau	-
A	hotel tax rate in Juneau	-
R	resident satisfaction in Juneau	-
S	daily waste production amount in Juneau	-
I	total rate of glaciers melting in Juneau	km^2a^{-1}
C	daily carbon footprint in Juneau	-
J	job creation of tourism in Iceland	unit
P	Traffic stress on flight in Iceland	-
PL	attraction ratings in Iceland	-
CO	construction cost of attractions in Iceland	USD
FE	tourist expense of attractions in Iceland	USD
w_i	weight	-
F_3	estimation of composite impact in Iceland	-
F_4	Tourist attraction appeal index in Iceland	-

4 Data Description

The data we use here is mainly related to Juneau and Iceland situations, such as tourist amount, resident satisfaction and annual flight times . The data sources are listed in Table 2.

Table 2: Data Sources

Data Source	Website	Data Type
Google Scholar	https://scholar.google.com/	Academic Paper
CEIC Database	https://www.ceicdata.com/en	Statistics
Icelandic Tourist Board	https://www.ferdamalastofa.is/	Statistics
City and Borough of Juneau	https://juneau.org/	Statistics
Travel Juneau	https://www.traveljuneau.com/	Statistics

5 Estimation focusing on the relation between composite impact and tourist numbers

5.1 The Establishment of Model 1

As mentioned before, we want to build a model to display the plan for sustainable tourism in Juneau. However, mutual constraints exist between profit and social and environmental issues resulting from tourism. Finding the balance of profit and problems follows the NGSA-II model. This model often acts as an optimizing model for multiple objectives. Overall, we can find the best strategy for Juneau tourism by iterating over the data.

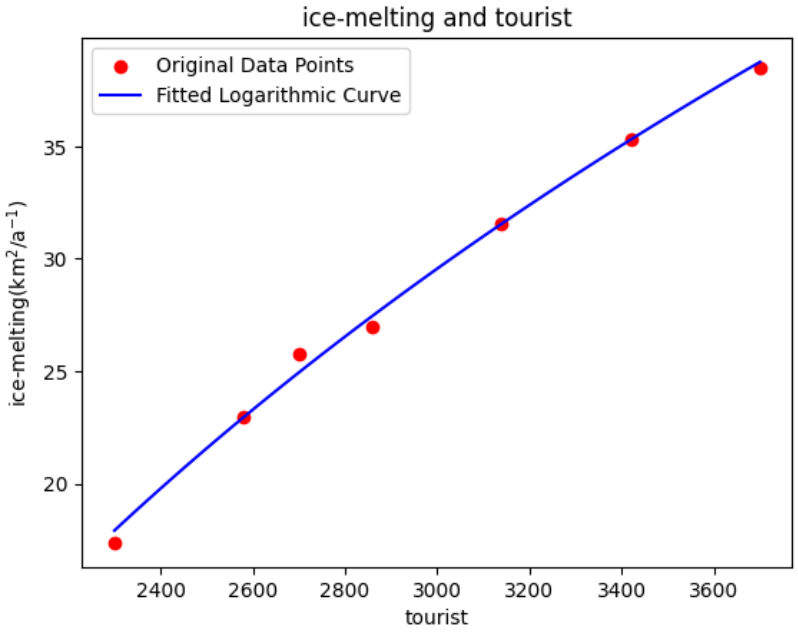
The first objective function represents tourism profit:

$$F_1 = T \times E$$

The second objective function represents the social and environmental consumption caused by tourism. It includes drinking water supplies, waste management, increased carbon footprint in tourist destinations, glacier melting, and residential satisfaction. The first three are included in the pressure on local infrastructure and are linearly correlated with the number of tourists. Regarding glacier melting and residential satisfaction, we searched for relevant data[1] from recent years and found that these two functions fit the number of tourists:

[Figure 4.1] illustrates the relationship between glacier melting rate and tourist numbers in Juneau:

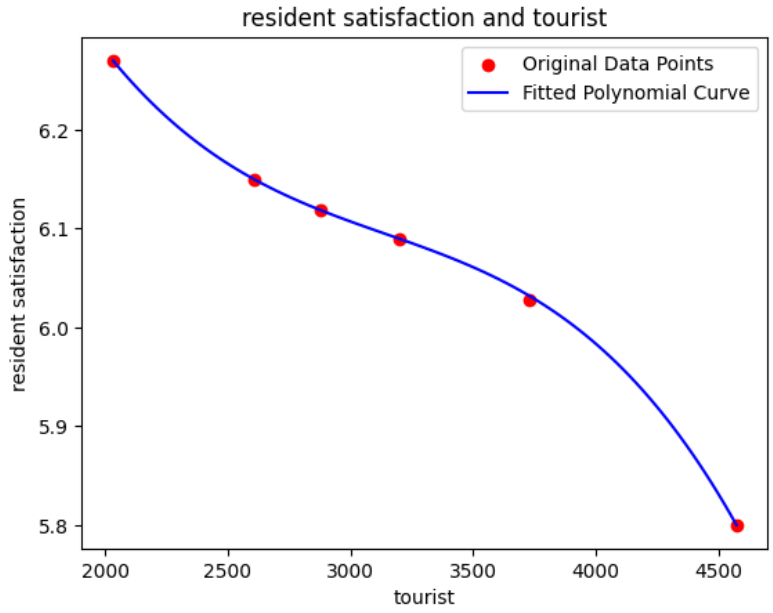
$$I = 5.4584 \times e^{0.0005T}$$



[Figure 4.1] Relationship between ice-melting rate and tourist number in Juneau

[Figure 4.2] illustrates the relationship between local resident satisfaction and tourist number in Juneau:

$$R = (-57.85) \times (T \times 10^{-4})^3 + 54.51 \times (T \times 10^{-4})^2 - 17.99 \times (T \times 10^{-4}) + 8.16$$



[Figure 4.2] Relationship between local resident satisfaction and tourist number in Juneau

Considering the different importance of the factors related to social and environmental issues, we conduct the analytic hierarchy process to estimate the weight coefficient of each factor. In this process, we compare the importance of paired indicators and construct a judgment matrix to show the weight of factors. For elements in the matrix, a_{ij} represents the importance of the i-th indicator relative to the j-th indicator.

The following table shows the importance comparison of drinking water supply, water management and carbon footprint in Juneau (w_{11}, w_{12} and w_{13}):

	drinking water supply	waste management	carbon footprint
drinking water supply	1	1/2	1/6
waste management	2	1	1/4
carbon footprint	6	4	1

Then we transformed the table into judgment matrix:

$$\begin{bmatrix} 1 & 1/2 & 1/6 \\ 2 & 1 & 1/4 \\ 6 & 4 & 1 \end{bmatrix}$$

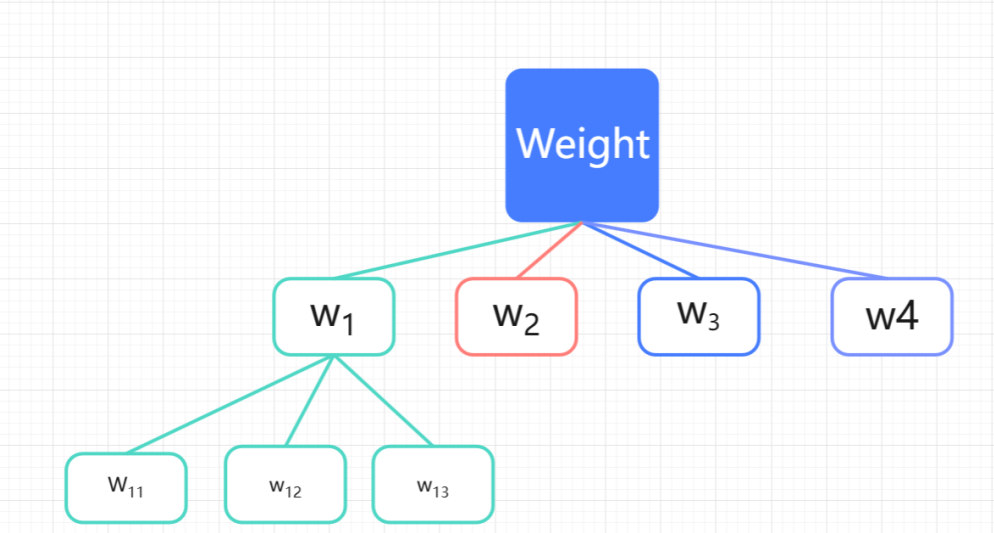
The following table shows the comparison of importance between infrastructure pressure, resident satisfaction, tax rate, and glacier melting rate in pairs in Juneau (w_1, w_2, w_3, and w_4):

	infrastructure pressure	resident satisfaction	tax rate	glacier melting rate
infrastructure pressure	1	1/3	4	1/3
resident satisfaction	3	1	2	1/2
tax rate	1/4	1/2	1	1/3
glacier melting rate	3	2	3	1

Then we transformed the table into judgment matrix:

$$\begin{bmatrix} 1 & 1/3 & 4 & 1/3 \\ 3 & 1 & 2 & 1/2 \\ 1/4 & 1/2 & 1 & 1/3 \\ 3 & 2 & 3 & 1 \end{bmatrix}$$

The mind mapping below shows the weight relationship of the factors in Juneau:



After we get the weights w, we first check the consistency of the matrix to ensure that the matrix we construct is not too different from the consistent matrix, and then we can use normalization to control the value of all items between 0 and 1 so that we can get the final function displaying the index of social and environmental issues. For each factor, we get a minimum or maximum restriction by searching for recent policies or data to get into the normalization process. Especially for the hotel tax rate, we select 15% for the maximum restriction for Juneau[2]

The second objective function represents the social and environmental issues (When F_2 converges to 0, it represents the best condition):

$$F_2 = w_1 \times (w_{11} \times \frac{R}{Rmax} + w_{12} \times \frac{A \times T}{Amax} - w_{13} \times \frac{S \times T}{Smax}) - w4 \times \frac{W \times T}{Wmax} - w5 \times \frac{C \times T}{Cmax} - w6 \times \frac{I}{Imax}$$

We further consider the constraints of each factor:

• The number of tourists is restricted to equal to or under 16,000 per day[4].

• Drinking water supplies, waste management, and increased carbon footprint in tourist destinations are linearly related to tourist numbers so it is also restricted to what we mentioned above.

• Resident satisfaction is restricted to equal to or above half of the estimation of the local satisfaction criterion[5].

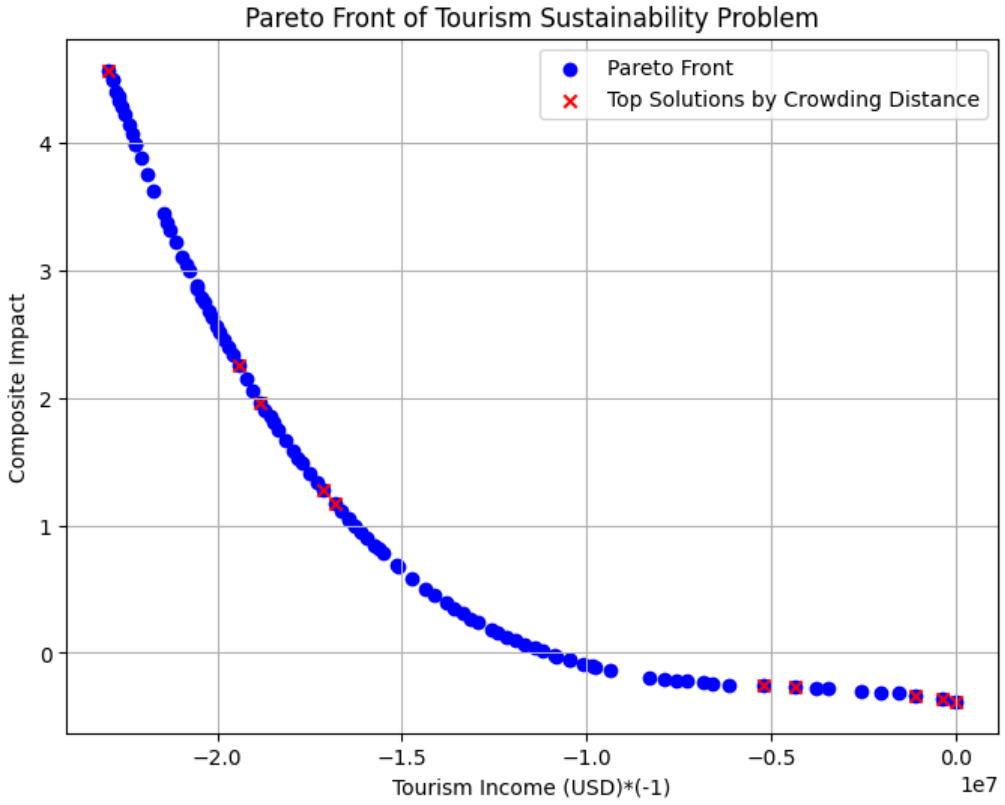
• The tax rate is restricted to up to 15 percent[6].

After combining the two functions into the NGSA-II model, we can get the Pareto Front which shows the relation between composite impact and tourist income. All the points on this curve are nondominated solutions, meaning the most characteristic points of this curve. We apply the crowding distance to further screen the points by estimating the density of a certain range near a specific point and finding the best tourist numbers and corresponding tax rates for

Juneau tourism.

5.2 The Solution of Model 1

By converting the models above into the Python code, the results of the solutions are shown in [Figure 4.1] signing in red cross.



[Figure 4.3] Pareto Front of Tourism Sustainability Problem

In consideration of sustainability, we do our best to protect the environment as well as promote tourism to gain profit. Further considering the density distribution, we select two solutions speaking for off-season and peak season respectively.

For the off-season, we select 3635 as the maximum daily tourist number and 0.1457 as the tax rate. For the peak season, we select 13549 as the maximum daily tourist number and 0.1448 as the tax rate. These two choices are selected from the ten best suitable conditions, considering both tourism profit and composite impact, which estimates the region's sustainability.

It is also obvious that if we control the income in a certain middle range, we can ensure the composite impact not to be so high, which proves that the income can do good to the sustainability of local tourism.

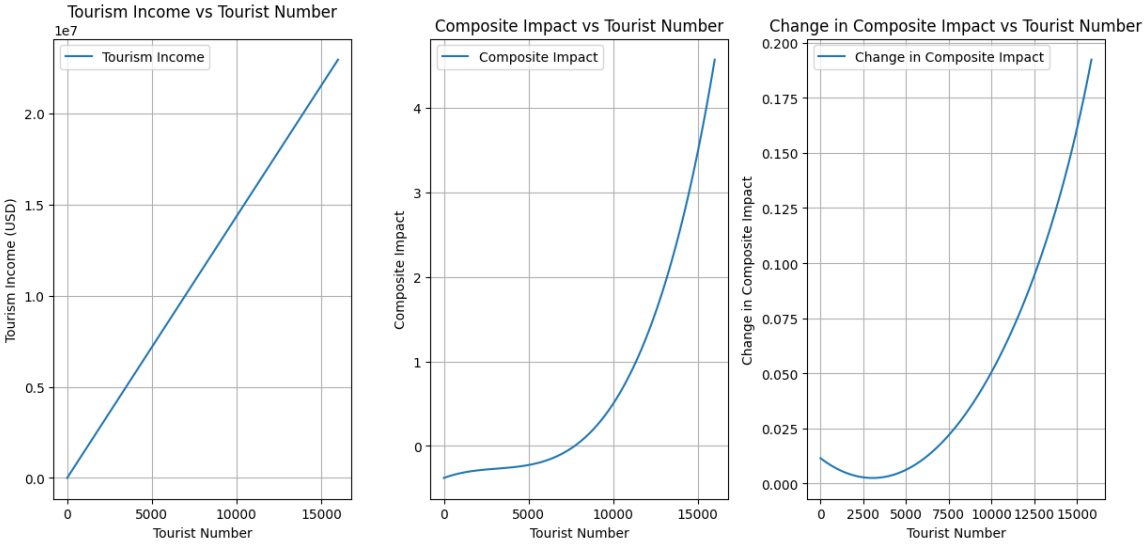
5.3 Sensitivity Analysis

Our model's predictions hinge significantly on key parameters such as tourist number (T) and composite impact (F_2). Through sensitivity analysis, we have uncovered the following insights:

Tourist number (T): It verifies from 0 to 16,000, when increasing to around 3,000, the

change of composite impact comes to around 0. After that, the changing rate of the composite impact continuously grew until the tourist number reached its maximum. The fluctuation is around 1.25% in low tourist numbers and about 15% in high tourist numbers.

Composite impact (F_2): It increases quickly at high tourist numbers and grows at a slow speed when the tourist number is low.



[Figure 4.4] The relationship between the changing of composite impact and tourist number

6 Rollout of the model in another region

6.1 The Establishment of Model 1

We applied the model above to Iceland, another country that is affected by over-tourism and has similar ecological and environmental characteristics, with more glaciers.

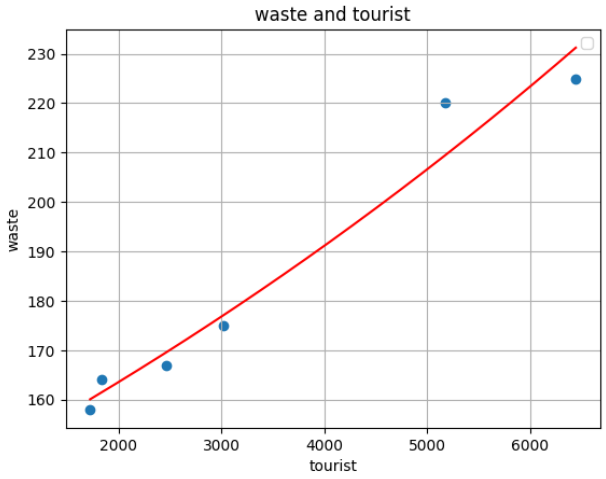
$$F_1 = T \times E$$

Different from Juneau, Iceland has abundant freshwater resources, so water supply is not a problem there. Also, according to an official survey, resident satisfaction remains at a high level. Thus there is no need to consider it as a factor. By research, we know that the most relative factors to the sustainability of Iceland include waste management, carbon footprint, traffic pressure, jobs created, glacier melting, and tax rate.

We modify the composite impact function for Iceland:

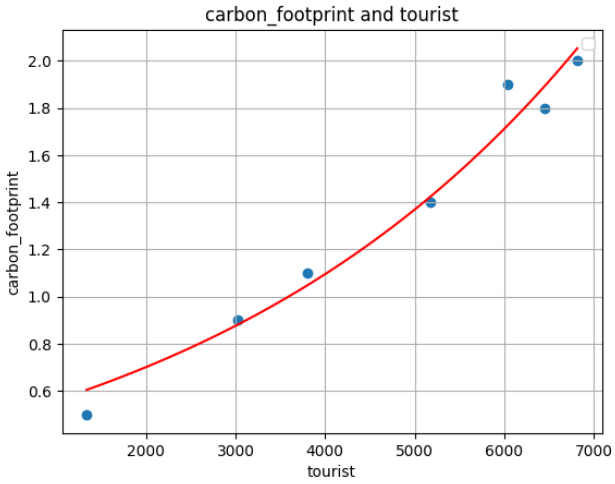
$$F_3 = w_1 \times \frac{S_i}{S_{max}} + w_2 \times \frac{C_i}{C_{max}} + w_3 \times \frac{TP_i}{TP_{max}} - w_4 \times \frac{J_i}{J_{max}} + w_5 \times \frac{I_i}{I_{max}} - w_6 \times \frac{A_i}{A_{max}}$$

[Figure 6.1] illustrates the relationship between waste(10kt) and tourist numbers in Iceland:



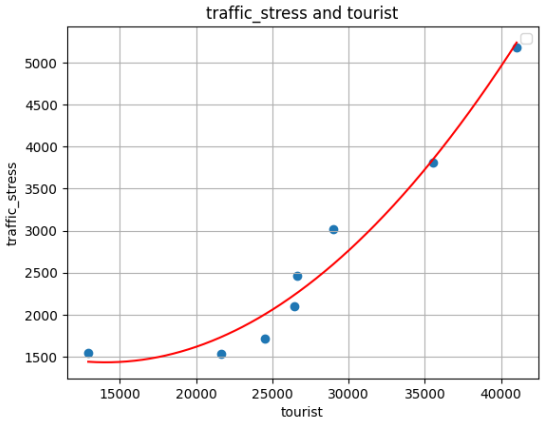
$$S = 139.39e^{8\times10^{-5}T}$$

[Figure 6.2] illustrates the relationship between carbon footprint(10kt) and tourist numbers in Iceland:



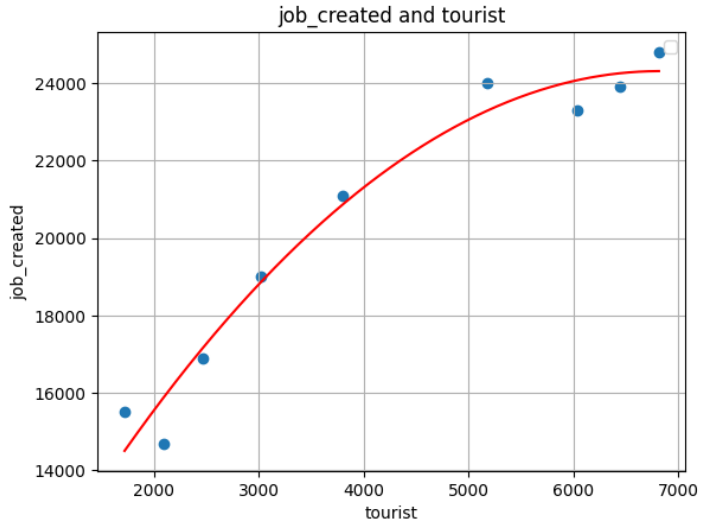
$$C = 0.3986 \times e^{0.0002T}$$

[Figure 6.3] illustrates the relationship between traffic stress(number of the flight times , thousand times) and tourist numbers in Iceland:



$$P = 5 \times 10^{-6}T^2 - 0.1473T + 2468.6$$

[Figure 6.4] illustrates the relationship between job created and tourist numbers in Iceland:



$$J = -0.0004T^2 + 5.1323T + 6785.8$$

	waste management	carbon footprint	traffic pressure	Jobs created	environmental impact	tax rate
waste management	1	1/2	2	3	1/2	3
carbon footprint	2	1	3	4	1	4
traffic pressure	1/2	1/3	1	2	1/3	2
residential satisfaction	1/3	1/4	1/2	1	1/4	1
environmental impact	2	1	3	4	1	4
tax	1/3	1/4	1/2	1	1/4	1

Just like what we did in the last model, the table below is the importance comparison form. We consider different weights from this matrix:

$$\begin{bmatrix} 1 & 1/2 & 2 & 3 & 1/2 & 3 \\ 2 & 1 & 3 & 4 & 1 & 4 \\ 1/2 & 1/3 & 1 & 2 & 1/3 & 2 \\ 1/3 & 1/4 & 1/2 & 1 & 1/4 & 1 \\ 2 & 1 & 3 & 4 & 1 & 4 \\ 1/3 & 1/4 & 1/2 & 1 & 1/4 & 1 \end{bmatrix}$$

We chose three Iceland attractions as examples, which are Golden Circle, Blue Lagoon, Helgufoss. Golden Circle and Blue Lagoon both hot spots and Helgufoss is relatively unpopular.

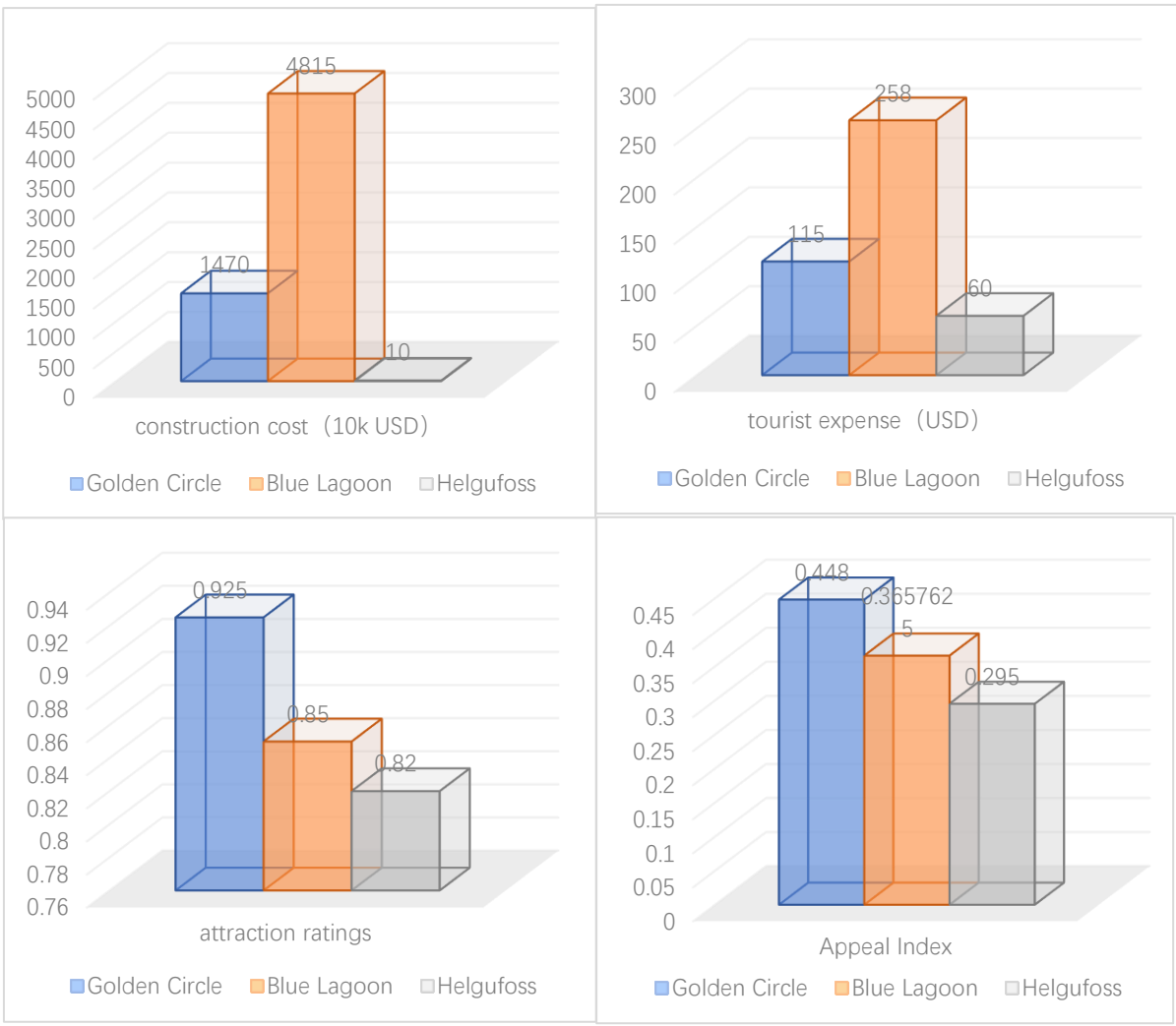
To promote the location with fewer tourists, we build a new model to evaluate the Tourist Attraction Appeal Index:

$$F_4 = a \times PL_i + \mathrm{b} \times \frac{CO_i}{CO_{max}} + c \times \frac{FE_i}{FE_{max}}$$

After analyzing expert research and tourist feedbacks in Iceland, we set the weights as 0.4, 0.3 and 0.3 respectively.

6.2 The solution of the model

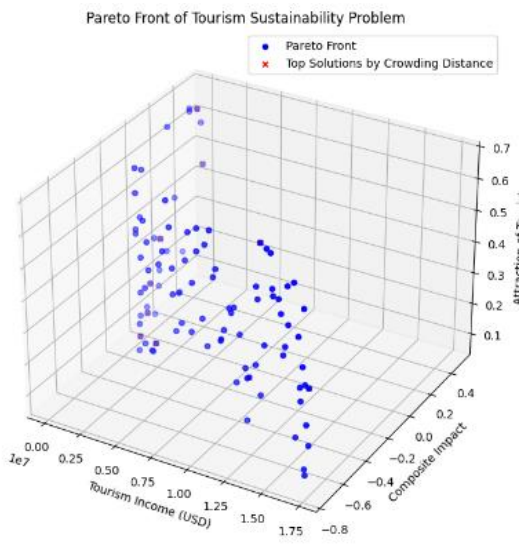
[Figure 6.1] shows the previous construction cost, tourist expense and attraction ratings of these attractions. Then by using g_3 we can calculate the appeal index respectively.



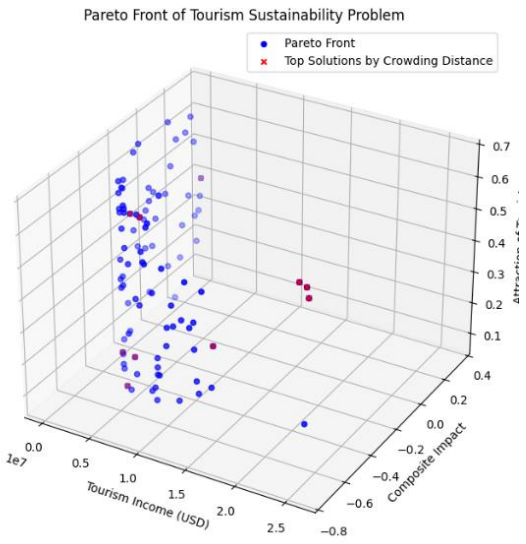
[Figure 6.5] previous data for these attractions

We assume these three attractions have the same tax. To divert tourists to the unpopular attractions, we need to increase the construction cost to improve the travel experience, and lower the basic tourism costs such as ticket prices and traffic fees. On the other hand, we can control the daily tourist amount and improve the basic tourism cost of the hot attractions.

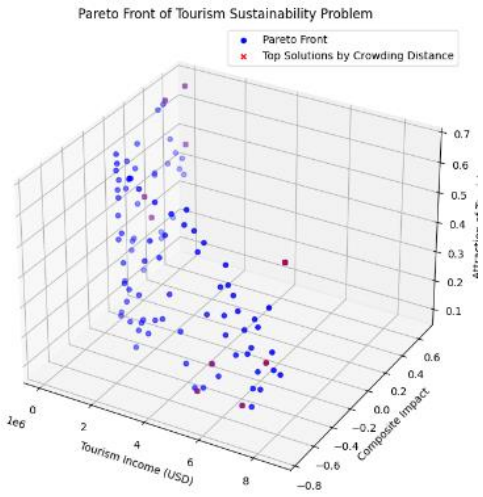
Next, we can combine the three functions into the NGSA-II model, and get the Pareto Front which shows the relation between composite impact, tourist income and Tourist Attraction Appeal. [Figure 6.6]



Golden Circle



Blue Lagoon



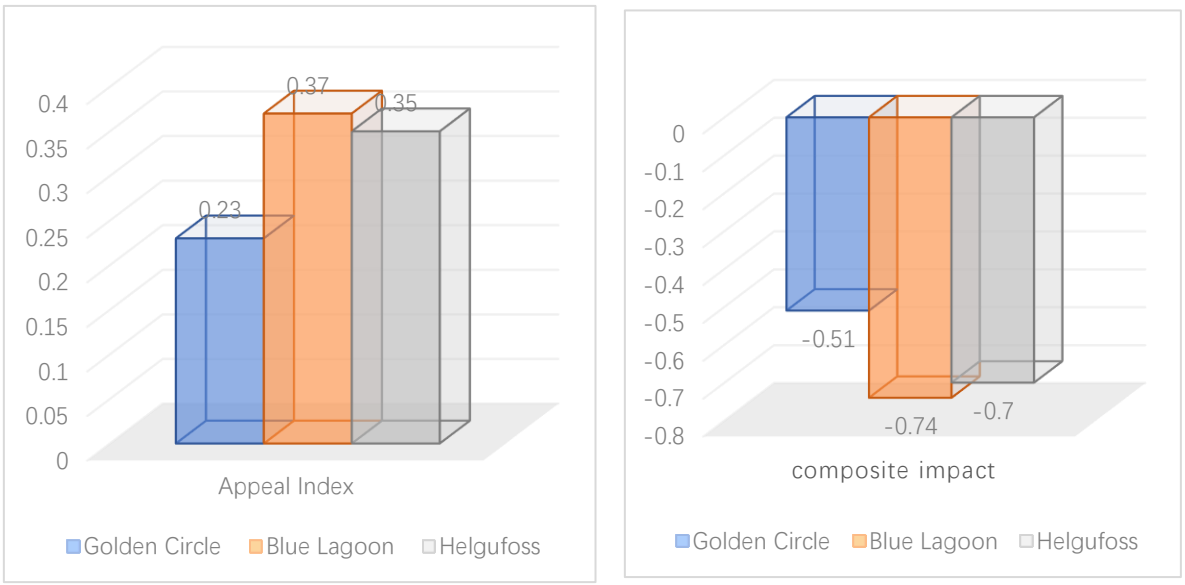
Helgufoss

[Figure 6.6] Pareto Front of the selected three attractions in Iceland

Let's assume that the three areas have a total of about 20,000 tourists a day，wo picked approved tourists amount, approved construction cost（10k USD）, approved cost for traveler（USD）, composite impact and Appeal Index from Pareto Front of selected three attractions. [Figure 6.7] shows the proper actions that should be taken.

location	approved tourists amount	approved construction cost (10k USD)	approved cost for traveler (USD)
Golden Circle	6668	681	341
Blue Lagoon	9644	7890	440
Helgufoss	4560	420	449

[Figure 6.7] approved data of the selected three attractions in Iceland
3 attractions



[Figure 6.8] effect of the approved actions

[Figure 6.8] shows that the effect of the given actions to promote the appeal index of the relative cold attraction, Helgufoss. The index increases from 0.29 to 0.35 and its composite impact is -0.7 which means it keeps a good sustainability.

7 Memo to the tourist council of Juneau concerning the suggestions on Juneau tourism

To: The Tourist Council of Juneau
From: Team 2503139
Date: January 27, 2025
Subject: Recommendations for Sustainable Tourism Development in Juneau

Dear Members of the Tourist Council,

The rapid growth of tourism in Juneau has brought significant economic benefits, but it has also led to serious environmental and social challenges. This memo outlines the current issues, predicts future problems, and provides actionable recommendations for sustainable tourism development based on our analysis and modeling.

I. Predicted Issues

If no measures are taken, our model predicts the following:

- Tourist numbers will continue to grow, peaking within 5–10 years before declining.
- The glacial melting rate will increase exponentially, causing irreversible environmental damage.
- Resident satisfaction will further decline, potentially leading to population outmigration.

II. Recommendations

To address these challenges and ensure sustainable tourism development, we recommend the following measures:

1. Limit Tourist Numbers: implement a daily cap on tourist numbers, with an optimal limit of 3635 visitors per day and a maximum of 13549 during peak periods, which will help alleviate overcrowding and reduce pressure on infrastructure and natural resources.
2. Increase Tax Rates: raise the tourism tax rate to approximately 14.57%. The additional revenue can be used to fund environmental protection, infrastructure improvements, and community welfare programs.
3. Enhance Environmental Protection and Allocate Tourism Revenue Wisely: increase investments in ecological conservation, such as glacier preservation. Use tourism income to improve infrastructure, such as transportation systems and public facilities, and also enhance local residents' welfare by funding healthcare, education, and community development programs.
4. Promote Diversified Attractions: increase promotion of lesser-known attractions, such as whale watching and rainforest tours, to redirect tourist traffic from overcrowded sites like the Mendenhall Glacier. This will help distribute visitor numbers more evenly and support the development of other attractions

III. Conclusion

Juneau's tourism industry is at a critical juncture. By implementing these measures, the city can achieve sustainable tourism development, balancing economic growth with environmental preservation and community well-being. We believe these steps will foster harmony between humans, society, the economy, and the environment, ensuring a brighter future for Juneau.

Thank you for your time and consideration. We look forward to your response.

Sincerely,
Team 2503139

8 Model Evaluation and Further Discussion

8.1 Strengths

★ We quantify the factors by linear regression to ensure the accuracy of our estimation of problems caused by tourists.

★ Python was used to visualize the dynamic changes over time and generations intuitively with graphs.

★ A composite index was used to systematically evaluate the effect of social and environmental issues caused by tourists to the sustainability of tourism.

8.2 Weaknesses

★ Many influencing factors unable to be quantifiable such as social equity and cultural diversity were not considered

★ Due to the lack of number of tourists by air, we consider cruise tourist number as the total number of tourists.

★ Model parameters were assumed without solid empirical support.

8.3 Further Discussion

The model could be improved by:

★ Introducing more influences among factors such as the influence from tax to tour expense.

★ Taking detailed resident reactions to the overall revenue into consideration

★ Calibrating parameters with field investigation data to enhance reliability

9 Conclusion

Through the establishment of four quantitative functions, the NSGA-II model, and the Analytic Hierarchy Process (AHP), our research demonstrates that by implementing a daily tourist cap and adjusting tourism tax rates in Juneau, the dual objectives of maximizing tourism profitability and environmental sustainability can be achieved. Furthermore, by adapting the parameters of this model, it has been successfully applied to the region of Iceland, providing tailored measures for underutilized tourist sites. This study offers valuable insights for scientists to further explore sustainable tourism strategies and provides policymakers with a framework to develop policies aligned with sustainable development principles.

References

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