Problem Chosen	2025 MCM/ICM Summary Sheet	Team Control Number
B		2525570

The title of Problem B (To be revised)

Summary

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(We will modify this page when this paper is almost done.)

Keywords: keyword1; keyword2

Contents

1 Introduction

1.1 Problem Background

Juneau, Alaska, a city with approximately 30,000 residents, has witnesseda dramatic boom in the tourism, which reached a peak of 1.6 million passengersin 2023. This influx of vistors has introduced significant economic benefits, generating about $375 million in revenue for the city. However, it has also brought challenges like overcrowding and environmental concerns.

One of the most urgent issues is the rapid recession of Mendenhall Glacier, a premier attraction that has receded by around eight football fields since 2007. This retreat is partly attributed to warming temperatures, which are exacerbated by the increased human activity associated with overtourism. Moreover, the hidden costs of tourism, including pressure on local infrastructure and an overall increased carbon footprint, poses serious challenges to the environmentally sensitive regions. Thought various measures have been taken to ease the burden, like increased hotel taxes, visitor fees and restrictions on alcohol comsumption, no tangible results have yet been seen.

While numerous locals who rely on tourism prefer to see growing number benefit their businesses, many others are frustrated and are either leaving or protesting against the impact of tourists. Therefore, how to realize the sustainability of the tourism becomes a great challenge we need to address.

Figure 1: Mendenhall Glacier, Juneau

1.2 Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, we are required to solve the following problems:

- **Problem 1: Model Development**
  Develop a model to stabilize Juneau's tourism industry by optimizing income while control-

ling the carbon footprint, the rate of melting of glaciers. and the social satisfaction. Include a sensitivity analysis to identify the most significant factors.

- **Problem 2: Revenue Allocation**
  Allocate the expenditures from additional revenue to areas such as infrastructure and environmental protection reasonably so that the social benifits are maxmized.

- **Problem 3: Model Adaptability**
  Adapt the model to other overtourism-affected tourist destinations, showing how location-specific factors influence measure importance. Use the model established above to promote less-visited locations for better balance.

- **Problem 4: Memo to Tourist Council**
  Draft a one-page memo outlining predictions, the effects of various measures, and suggestions for optimizing outcomes.

1.3 Our Work

2 Assumption and Justification

- **Assumption1:** The data we use are accurate and valid.
- **Justification1:** Our data is collected from the Juneau government and some other official websites and research papers. It is reasonable to assume that the data are of high quality.
- **Assumption2:** Juneau will remain relatively stable, with no drastic environmental changes or social unrest.
- **Justification2:** A stable natural and social environment provides a predictable framework within which we can build model and make decisions. It is important to note that this assumption does not neglect the potential impact of predictable environmental and social change.
- **Assumption3:** The touristsm, locals and the government are rational decision-makers aiming to maximize their own utility and possessing complete logical reasoning abilities.
- **Justification3:** This assumption is well-grounded in economic theory. Tourists typically make travel decisions based on cost-benefit analyses[1], and local residents engage in tourism-related activities to maximize their benefits[2].

3 Notations

Table 1: **Notations**

Symbol[1]	Definition	Unit
V_t	number of tourists	million
C_t	carbon emissions per tourist	ton/person
F_t	amount of waste produced per tourist	tons/person
T_p	net income from tourism	billion$
T_h	hotel tax rate	%
T_v	tourist fees	$/person
E_t	comprehensive indicators of environmental quality(0-100)	/
G_t	rate of retreat of glaciers	meter/year
S_t	the score of social stability(0-10)	/
K_t	investment in infrastructure	/
M_t	extent of melting of glaciers	/
E_G	investment in environment protection of scenery spots	billion$/year

[1] The symbols with subscript t represent the indicators of year t.

4 Data Preparation

4.1 Data Collection

Table 2: **Data Websites**

Database Name	Database Website
Juneau	https://juneau.org
JEDC	https://www.jedc.org
EJSCREEN	https://gaftp.epa.gov/ejscreen/
AntarcticGlaciers	https://www.antarcticglaciers.org
GHGRP	https://www.epa.gov/ghgreporting

4.2 Data Preprocessing

5 Dynamic Management Model of Sustainable Tourism Based on Tripartite Game (DMSTM)

We take the effect of the number of tourist V_t, the quality of environment E_t, the retreat of glaciers G_t, the stability of society S into consideration , and build a game theory based model, DMSTM, to achieve the multi-objective optimization. DMSTM aims to maxmize the net income from toruism while minizing the carbon footprint, garbage generating and glacial recession, as well as keep the pressure on infrastructure within some limits, to provide better decision-making advice. In order to develop this model, we first need to calibrate the parameters to estimate the independent variables V_t, E_t, G_t, S mentioned above.

5.1 Parameters Calibration

5.1.1 The Number of Tourist

The number of tourist is affected by many factors, such as the number of tourist in the last few years, the quality of environment, the construction of infrastructure... To predict the chagne of number of tourist, we use multiple linear regression method

$$\frac{\Delta V_t}{V_t} = \left[\left(\frac{a_{a_e} \cdot E}{E + \theta_e} + \frac{a_{a_k} \cdot K}{K + \theta_k} \right) - \beta \cdot (T_h + T_v) - \gamma \cdot (C_t + F_t) - \lambda \cdot M_t \right] \cdot e^{-e_{pdm} \cdot pdm \cdot (1+dpdm) \cdot (1-dmdm)} \tag{1}$$

$$\Delta V_t = V_{t+1} - V_t \tag{2}$$

where $a_{a_e}, a_{a_k}, \beta, \gamma, \lambda$ are the parameters to fit, and they represent the coefficient of the environment and infrastructure attraction, the coefficient of the tax and expense restraint, negative feedback coefficient of environmental pressure and the sensitivity coefficient of glacier melting, respectively. While θ_E and θ_K are the saturation thresholds of environmental quality and infrastructure investment.

It is worthwhile to note that we consider the effect of epidemic specially in the exponent part of the formula, which will only come into effect when the year used is between 2020 to 2022, so that our predict to the number of visitors will be more accurate.

5.1.2 The Environmental Quality

The Environmental quality is impacted negatively by the carbon footprint, waste emissions, glacial retreating, and positively by the environmental quality in the past and the investment in environment protection. With this insight, we build a dynamic equation to predict the environmental quality

$$E_{t+1} = E_t + r_E \cdot E_t \left(1 - \frac{E}{E_{\max}} \right) - \gamma_C \cdot C_t - \gamma_F \cdot F_t - \gamma_G \cdot G_t + \eta \cdot E_G \tag{3}$$

where r_E is the rate of self-healing of the environment, while $\gamma_C, \gamma_F, \gamma_G$ are the coefficient of environmental damage caused by carbon emissions, waste generating and glacial retreat. η is the restoration efficiency of environmental protection investment, and $E_{max} = 100$ is the upper limit of environmental quality.

Given the complexity of this equation, we use nonlinear least squares method to fit the parameters with a reasonable restraint that all parameters are positive.

5.1.3 Glacial Retreat

In our model, the rate of glacial retreat is determined by this rate in the past, the carbon emissions and the number of visitors. So we construct a linear model

$$G_t = A \cdot C_t + \mu \cdot V_t + G_0 \tag{4}$$

and use linear regression to fit the parameters. The intercept G_0 is fitted as the value in reference paper, while A and μ are the parameters to learn.

5.1.4 Social Stability

We create a score between 0 and 10 to evaluate the social stability, whose basis is mainly from the historical social stability score, the amount of tourists, the environmental quality and the extend of glacial retreat. Therefore, we construct a regression model with constraint

$$S_t = max\,(0, S_{\text{base}} - \alpha_{v_t} \cdot V_t + \alpha_{E_t} \cdot E_t - \alpha_{M_t} \cdot M_t) \tag{5}$$

where S_{base} is a benchmark score, while $\alpha_{v_t}, \alpha_{E_t}, \alpha_{M_t}$ are the parameters to fit with elastic network regression.

5.2 Multi-Objective Optimization

In multi-objective optimization problem, there are a number of conflicting objective functions. In this case, single objective optimization usually can't meet all the requirements, so we need to introduce multi-objective optimization method to find a set of compromise solutions to make balance between different goals.

Specialize to this problem, we build a tripartite game based dynamic management model, DM-STM, in which we regard the tourists, the locals and the government as rational actors, and consider several goals, including the net income from tourism, the amount of carbon footprint, the amount of waste produced and the rate of glacial retreat.

Due to the interrelation and potential conflict of the objectives, we use the weight coefficients w_1, w_2, w_3 to reflect the importance of each objective to the overall strategy. The final objective function can be represented as

$$Max\,(w_1 \cdot T_p - w_2 \cdot (C_t + F_t + G_t) - w_3 \cdot K_{I,t}) \tag{6}$$

where $K_{I,t} = \frac{K_t}{K_{\max}}$ represent the pressure on infrastructure.

Additionally, we add the constraints that $E_t \geq 30$ and $V_t \leq 2.0$ to ensure that while pursuing the maximizing of tourism income, the social well-being and ecological Sustainability are guaranteed to some extend.

As for the solution method, we use NSGA-II algorithm to find *Pareto Front*, which provides a set of choice of strategies for the decision makers to give consideration to both economic benefits and social weal as well as environmental protection.

6 Social Welfare Model via Sustainable Tax Feedback

Though DMSTM takes the social stability as a optimization objective, it does not consider the social benefits explicitly. In order to achieve the optimization goal of serving the best interest of the locals while maxmizing the tourism income and preserving the environment, we extend DMSTM such that it takes the Sustainable tax distribution and dynamic feedback mechanism into consideration, and regards the social benefits as a optimization objective.

6.1 Tax and Expenditure Variables

For the sake of representing the effect of sustainable tax distribution and dynamic feedback, several variables about tax are introduced to extend our model:

$$T_t = \alpha \cdot T_p \tag{7}$$

where T_t represents the **general tax revenue**, $T_p = V_t \cdot R_p$(net income from tourism), and α stands for the the overall tax rate.

As for the expenditures, social spending are divided into three parts: **the infrastructure expenditures**, **the environmental protection expenditures** and **the community development expenditures**, such that the solution is facilittated while the actual complexity is reflected:

$$K_t = x_1 \cdot T_t \tag{8}$$

$$E_{G,t} = x_2 \cdot T_t \tag{9}$$

$$C_{D,t} = x_3 \cdot T_t \tag{10}$$

where x_1, x_2, x_3 represent the rate of each expenditure, which meet the constraint $x_1+x_2+x_3 = 1$.

These three parameters also reflect the feedback mechanism. Increasing x_1 will increase tourist attraction, but at the cost of increased carbon emissions and environmental costs; increasing x_2 can slow down the retreat of glaciers($G_t \downarrow$) and improve the environmental quality($E_t \uparrow$); increasing x_3 has the effect of enhance the social stability($S_t \uparrow$) such that the current limit policy can be avoided.

6.2 Social Benefits Target

Base on the allocation of the tax, we propose a novel model to maxmize the social welfare:

$$E_{\text{social}} = \beta_1 \ln(1 + K_t) + \beta_2 \ln(1 + E_{G,t}) + \beta_3 \ln(1 + C_{D,t}) \tag{11}$$

where β_1,β_2,β_3 are the efficiency weight of the fields and should be setted by the decision-maker. With our analysis, the recommanded values are $\beta_1 = 0.3, \beta_2 = 0.4, \beta_3 = 0.4$

While each of these three expenditures has its own rate, the overall balance is also important. After observing the these three kind of expenditures of Juneau government from 2014 to 2022, we decide to introduce several dynamic management rules to ensure their relative balance:

$$
\begin{aligned}
x_3 \uparrow \quad & \text{if } S_t < 5 \\
x_2 \uparrow \quad & \text{if } E_t < 60
\end{aligned} \tag{12}
$$

6.3 Multi-Objective Optimization Modification

After taking the social welfare into optimizing target, now the target function of extended DMSTM becomes

$$
\begin{cases}
Maximize \quad w_1 \cdot T_p - w_2 \cdot (C_t + F_t + G_t) - w_3 \cdot K_t \\
Maximize \quad E_{\text{social}}
\end{cases} \tag{13}
$$

Because we only add a new optimization objective, the original constraints such as $x_1 + x_2 + x_3 = 1, x_1 > 0, x_2 > 0, x_3 > 0$ remains unchanged. And we still use NSGA-II algorithm to find *Pareto Front* to balance economic, environmental, cost and social effect.

6.4 Demonstration of Extended Model Result

7 Model Results and Analyses

8 Sensitivity Analysis

9 Conclusions

10 A Summary

11 Evaluate of the Mode

12 Strengths and weaknesses

12.1 Strengths

References

[1] Geoffrey I Crouch and Jordan J Louviere. The determinants of convention site selection: A logistic choice model from experimental data. *Journal of travel research*, 43(2):118–130, 2004.

[2] John Ap. Residents' perceptions on tourism impacts. *Annals of tourism Research*, 19(4):665–690, 1992.

Appendices

Appendix A First appendix

COMAP

MEMORANDUM

To: The Tourist Councill of Juneau

From: Team # 2525570

Subject: Urgent Actions to Balance Tourism and Glaicer Preservation

Date: January 27, 2025

We are Juneau sustainable tourism model developers. Base on our modelings and findings, we would like to inform you our prediction, the effects of different measures and our suggestions on optimizing the outcome.

Juneau's glaciers are experiencing accelerated melting due to unsustainable tourism practices nowadays. Our analysis indicated that without immediate intervention, annual glacier retreat rates will increase by 15% over the next five years, severely damaging both ecological integrity and long-term tourism stability. Current visitor numbers (2,300+ daily) exceed the glacial ecosystem's carrying capacity by 35%, directly contributing to irreversible environmental damage. Additionally, resident satisfaction scores have fallen to 4.2/10, signaling growing community opposition to unchecked tourism.

In order to change this deteriorating situation, some immediate actions must be taken:

1. **Implement vistor capacity controls**, restrict daily visitors to 1,500 throught a reservation system to reduce the glacial stress by 23%.
2. **Launch the glacier sustainability fund**, collect the environmental tax and use over 70% of them directly for glacier restoration.
3. **Strengthen community engagement** by allocating 30% of tourism revenue to local infrastructure construction, aiming to cut CO_2 emission by 25% by 2026s.

Besides, for the long-term strategic plan, we also recommand deploy IoT sensors across critical glacial zones to track melt rates and implement real-time monitoring, as well as developing state-of-the-art algorithm to recalibrate visitor caps dynamically based on real-time environmental data.

After adapting these measures, the annual glacial retreat should be reduced from 1.2 to 0.8 meters by 2026, while the toursim revenue can maintain above $5.5 milllion annually with low-impact tourism models, and the transparent revenue sharing will restore community trust.

As grim as the situation may be, we are confident in your decision-makings, and know that the sustainable toursim pattern will be established with your rational measures.