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An Exploration of Tourism Development Based on Undominated Sorting Genetic Algorithm II and Multi-Objective Optimization

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Abstract: This study was conducted using the Non-dominated Sorting Genetic Algorithm II (NSGA-II) and a multi-objective optimization model, aiming to cope with the development of sustainable tourism as well as to provide a reference for other tourism areas. Firstly, the TriOptima sustainable triple equilibrium model was constructed, with economic income, environmental protection and social satisfaction as multiple objectives, and the number of tourists, the proportion of environmental protection investment and the proportion of community investment were introduced as decision variables to constrain the multiple aspects and build an optimization framework. Then, the NSGA-II is used to solve the Pareto optimal solution set. Secondly, the model can be extended to other tourism zones, and in case of over-tourism, the model can be adjusted, and new objectives can be added according to their geographic characteristics and environmental challenges, so that the tourism optimization scheme can be proposed to achieve the best balance of multiple benefits.

Keywords: Sustainable Tourism Development, Undominated Sorting Genetic Algorithm II, Multi-objective Optimization.

1. Introduction

To cope with the over-tourism situation[1], this paper comprehensively uses the Non-dominated Sorting Genetic Algorithm II (NSGA-II) and the multi-objective optimization model to carry out the research[2]. The multi-objective optimization model can systematically incorporate economic, environmental and social objectives into the same framework for optimization, and comprehensively consider multiple factors in sustainable tourism development[3], which breaks through the limitations of the traditional single-objective analysis. NSGA-II algorithm, on the other hand, has the powerful ability to deal with the complex multi-objective optimization, which efficiently explores the trade-offs between the objectives through the fast non-dominated sorting and the elite retention strategy. Relationships.

In this paper, we first construct a multi-objective optimization model with economic, environmental, and social objectives as the core[4], incorporate constraints such as investment budget, carbon emission, and number of tourists, and solve the model with NSGA-II to explore the trade-offs among objectives and obtain the Pareto-optimal solution[5]. The model is then extended to other regions affected by over-tourism. Through the scientific use of algorithms and models, this paper provides scientific decision support for sustainable tourism development in the region, effectively balancing economic, environmental and social benefits[6].

2. Tourism Sustainability Analysis

2.1. TriOptima-S3E Modeling

In this section, the TriOptima sustainable triple equilibrium model will be constructed, which resolves natural conflicts between economic, environmental and social goals. The model quantifies the equilibrium between the three through a multi-objective optimization framework and uses a multi-objective genetic algorithm to generate a Pareto-optimal solution set that supports dynamic trade-offs and scientific decision-making, avoiding unsustainable outcomes caused by traditional models that ignore multi-dimensional interactions.

1). Decision Variable

To model this problem, the following decision variables are introduced:

N : Number of tourists

r : Tax rate per tourist

α : Proportion of environmental investment (as a percentage of tourism revenue)

β : Proportion of community investment (percentage of tourism revenue)

2). Objective Functions

Subsequently, the objective function will be discussed in terms of economic, environmental and social objectives.

(1) Economic Objectives

The economic objective is centered on maximizing the revenues that can be derived from tourism, consisting mainly of tourism consumption revenues and tourism tax revenues, but also influenced by additional investment plans. The objective function can be expressed as:

$$Maximize\ f_1 = (c \cdot N + r \cdot N) \cdot (1 - \alpha - \beta) \quad (1)$$

Where c is the per capita consumption, tourism consumption income and tax revenue are linearly related to the number of tourists.

(2) Environmental objectives

The core of the environmental objective is to reduce the negative impacts of tourism activities on the environment, which mainly includes reducing the reduction of glacier area and the increase of carbon emissions due to the excessive influx of tourists. Among them, carbon emissions can be expressed as:

$$C = C_0 + b \cdot N \cdot (1 - k_1 \alpha) \quad (2)$$

The annual decline in glacier area can be expressed as:

$$\Delta G = \Delta G_0 \cdot (1 - k_2 \alpha) \quad (3)$$

Where b is the carbon emission coefficient and k_1 is the k_2 environmental investment disincentive coefficient.

Therefore, the objective function of the environmental goal is:

$$Minimize\ f_2 = \lambda_1 \cdot C + \lambda_2 \cdot \Delta G \quad (4)$$

Where λ_1 is λ_2 normalized weights.

(3) Social objective

The core of the social objective is to maximize resident satisfaction and reduce the decline in residents' quality of life caused by tourism. Therefore, the objective function of the social objective can be expressed as:

$$Maximize\ f_3 = \gamma_0 + \gamma_1 \cdot N + \gamma_2 \cdot \beta \cdot (c \cdot N + r \cdot N) \quad (5)$$

Where γ_0, γ_1 and γ_2 are the coefficients of residents' satisfaction.

3.Constraints

(1) Limit the number of visitors

Considering the limited carrying capacity of Juno, it is necessary to set an upper limit for the number of visitors:

$$N \leq N_{max} \quad (6)$$

(2) Investment ratio constraint

Considering that investing a large amount of revenue in environmental or community projects may lead to a shortage of other necessary funds, we set a limit on the amount of revenue to be used for environmental and community investments, i.e:

$$\alpha + \beta \leq I_{max} \quad (7)$$

(3) Carbon Emission Limits

Juno's natural landscape is extremely attractive, but it is also susceptible to carbon emissions from tourism activities, so it is necessary to set limits on carbon emissions:

$$C \leq C_{max} \quad (8)$$

2.2. TriOptima-S3E Model Solution

The three core objectives of tourism management in Juneau - economic, environmental and social - are naturally in conflict with each other. The optimization of multiple conflicting objectives in the TriOptima-S3E model can be solved using the Non-dominated Sorting Genetic Algorithm II (NSGA-II).

The basic idea of this algorithm is to evolve the population through a combination of selection, crossover, and mutation through the mechanisms of non-dominated sorting and crowding distance to solve the multi-objective optimization problem and obtain the Pareto-optimal solution set.

The NSGA-II is used for solving the problem and the parameters are set as shown in table 1 below.

Table.1 NSGA-II Parameter Table

Type	Value
Population size	100
Number of iterations	200
Crossover probability	0.7
Mutation probability	0.2

2.3. Analysis of TriOptima-S3E Model Results

1). Visualization and Analysis

After data collection and model construction, NSGA-II is used to solve the TriOptima-S3E model and obtain the Pareto-optimal solution set between economic, environmental and social objectives. The visualization of the solution results is shown in Figure 1 below.

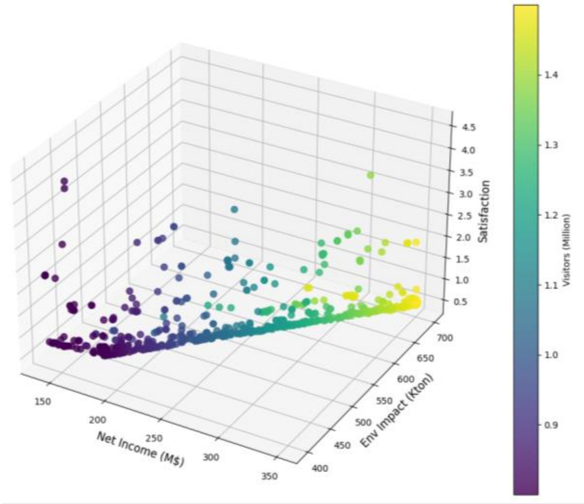

Figure 1. Pareto deconvolution chart

The Pareto solution set graph visualizes the distribution of the three objective dimensions. As can be seen in Figure 1, the solution set is uniformly distributed along the Pareto front, indicating that the algorithm can search well for multiple solutions that satisfy the demand. High-income programs are mainly concentrated on the right side and are usually accompanied by many tourists. High environmental programs are mainly concentrated in the lower left-hand side and require either a reduction in the number of tourists or an increase in environmental investment. High-satisfaction programs require a balance between visitor numbers and community investment.

2).Pareto optimal solution set analysis

Furthermore, there is an apparent conflict between the three objectives. Next, several typical solutions from the Pareto frontiers solution set are selected to demonstrate the parameter combinations and the objectives they achieve under different strategies.

Table.2. Optimal Pareto Solution Set for Economic Objectives

Number	N	α	β	r	f_1	f_2	f_3
1	1.48	0.05	0.10	0.5	246.7	748	0.68
2	1.45	0.08	0.12	0.6	239.2	712	0.71
3	1.42	0.12	0.15	0.7	231.5	685	0.75

It is easy to observe through table 2 that there is a negative correlation between the tax rate and the number of tourists. High tax rates may inhibit tourist growth and lead to a decrease in total tourism revenue. In addition, it can be observed that low environmental investment leads to high environmental stress and higher resident satisfaction due to lower tourist density.

Table.3 Optimal Pareto Solution Sets for Environmental Objectives

Number	N	α	β	r	f_1	f_2	f_3
1	0.82	0.30	0.20	2.5	98.4	402	0.89
2	0.85	0.28	0.18	2.3	105.2	418	0.86
3	0.88	0.25	0.15	2.0	112.7	435	0.83

As can be seen in table 3, carbon emissions and glacier decay significantly decrease as environmental investments approach their upper limits. In addition, resident satisfaction increases due to low tourism density and high community investment.

Table.4 Optimal Pareto Solution Sets for Social Goals

Number	N	α	β	r	f_1	f_2	f_3
1	0.95	0.25	0.20	1.8	135.6	508	0.92
2	1.02	0.22	0.18	1.5	148.3	545	0.89
3	1.10	0.18	0.15	1.2	162.9	588	0.85

As can be seen in table 4, increasing community inputs has a significant impact on increasing resident satisfaction. When the number of tourists is moderate, both environmental and social objectives are maintained at a good level.

In addition, to find the optimal equilibrium in the conflict of objectives, avoid the unsustainability of the decision-making solution, and maximize the long-term comprehensive benefits, it is necessary to find the optimal equilibrium solution from the three natural conflicts of economic, environmental, and social objectives. The scoring of the equilibrium solution is based on the Euclidean distance from the solution to the ideal solution and converted to a percentage system. The score calculation can be expressed as:

$$Score = \left(1 - \frac{distance}{max\_distance}\right) \times 100 \tag{9}$$

Table.5 Balanced Solution Set

Number	N	α	β	r	f_1	f_2	f_3	Score
1	1.18	0.15	0.12	1.0	189.4	605	0.82	0.21
2	1.12	0.18	0.14	1.1	175.2	582	0.84	0.24
3	1.25	0.12	0.10	0.9	203.7	638	0.78	0.28

In table 5, all objectives are close to the center of the Pareto Front with no apparent weaknesses. At this point, with moderate visitor numbers and tax rates, and an even distribution of environmental and community investments, all objectives are at a good level.

2.4. Sensitivity Analysis of the TriOptima-S3E Model

To assess the impact of changes in key parameters in the model on the optimization results and to inform strategy development, a sensitivity analysis of the model is required to assess the sensitivity of the model outputs to various inputs. The main factors analyzed include: the number of tourists N, the proportion of environmental investment α, the proportion of community investment β, and so on. Some of these analyses and visualizations are shown in Figure 2.

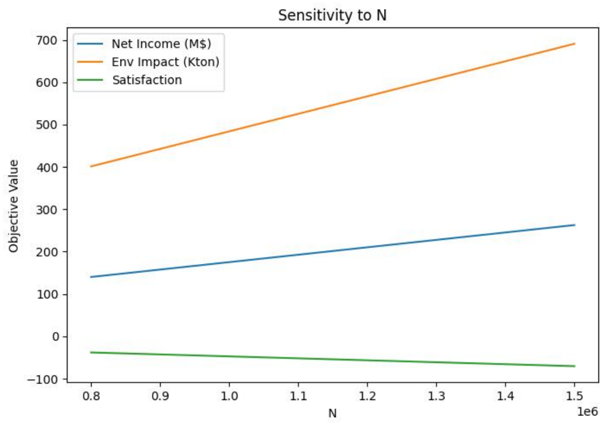

Figure 2. For the number of tourists N

The final analysis shows that total tourism revenue f_1 increases linearly with the number of tourists N, environmental objective f_2 increases significantly with the number of tourists N, and social objective f_3 decreases slowly with the number of tourists N. Therefore, it can be argued that the number of tourists N is a central factor influencing the environmental objectives, f_2 and an important factor contributing to the growth of total revenue f_1.

3. TriOptima-S3E for Other Destinations

3.1. Promotion Case Selection and Analysis

Maldives was selected as the destination for model promotion. The main reasons for choosing Maldives are as follows:

(1) Similarity of geographic features: as an archipelago country, Maldives is also blessed with natural landscape and fragile ecosystems, like the glacier landscape of Juno, both of which require special environmental protection

(2) Tourism dependence: The Maldivian economy is highly dependent on tourism, with tourism revenue accounting for a significant portion of GDP.

(3) Environmental Vulnerability: As a low altitude archipelago, the Maldives is particularly vulnerable to climate change and environmental damage

(4) Carrying capacity: the islands are limited in size and there is a clear physical limit on the number of tourists that can visit.

In addition, the Maldives faces three main situations. Among them, the economy is mainly the Maldives' over-dependence on tourism, the environment is mainly facing the destruction of coral reef ecosystems and the increase of marine pollution, etc., and the society is reflected in the decrease of residents' satisfaction and the increase of pressure on the infrastructures.

3.2. Adaptation of the TriOptima-S3E model

1). Adjustment of Decision Variables

To adapt to the characteristics of the Maldives, the decision variables should reflect its unique tourism management needs by partially changing the meaning of the original variables:

Proportion of environmental investment α : Shift in investment focus to marine ecological conservation.

2). Objective Function Adjustment

Due to the different natural environment of the Maldives, the environmental objective function needs to be modified:

$$Minimize\ f_2 = \lambda_1 \cdot C + \lambda_2 \cdot \Delta K + \lambda_3 \cdot W \tag{10}$$

Where ΔK represents the annual decline in coral reefs, which is converted from the decline in original glacial area.

Its form can be expressed as:

$$\Delta K = \Delta K_0 \cdot (1 - k_2\alpha) \quad (11)$$

In addition, a new sub-objective W has been added to the environmental objective to represent wastewater discharge, which can be expressed in the following form:

$$W = W_0 + d \cdot N \cdot (1 - k_3\alpha) \quad (12)$$

3). Constraint Adjustment

To limit wastewater discharge in the Maldives, to strengthen water management and to reduce marine pollution, the following constraints have been added:

$$W \le W_{max} \quad (13)$$

3.3. Application of the TriOptima-S3E Model to the Maldives Scenario

1.Visualization and Analysis

Still solving using NSGA-II, the set of Pareto optimal solutions for the TriOptima-S3E model applied to the Maldives is shown in Figure 3 below.

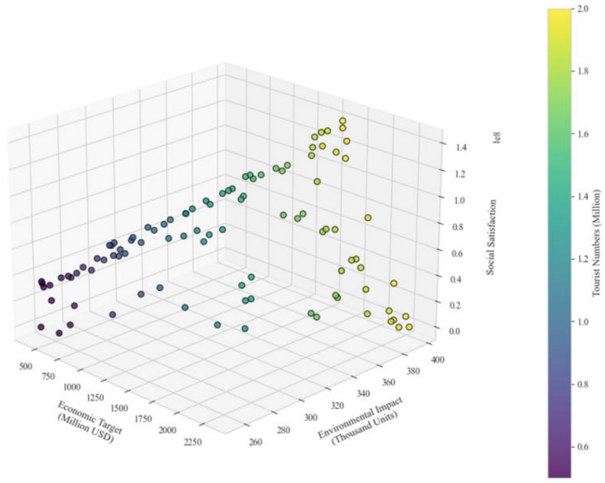

Figure 3. Pareto solution set in the Maldives figure

As can be observed in Figure 3, high economic income is usually accompanied by high environmental stress and moderate social satisfaction, while low environmental costs correspond to low income and moderate satisfaction. An increase in the number of tourists significantly increases economic income but exacerbates environmental stress and affects the quality of life of residents. The optimal solution lies in the middle of the Pareto frontier for balancing economic, environmental and social objectives.

2.Typical Solution Analysis of the Pareto Frontier

Next, three typical solutions from the Pareto frontier are selected for analysis:

Table.6 Comparison of Three Typical Pareto Frontier Solutions

Type	N	α	β	f_1	f_2	f_3
Optimal economy	1.95	0.05	0.10	2850	620	0.75
Optimal environment	0.80	0.25	0.05	420	310	0.82
Optimal society	1.20	0.10	0.20	1980	480	0.88

The optimal economic solution in table 6 shows that when the number of tourists is close to the upper limit of 1.95 million, the economic revenue is the highest, but the environmental pressure is high, and the social satisfaction is low. This strategy is suitable for scenarios that prioritize short-term economic benefits.

From the optimal environmental solution, when the number of tourists is low, the environmental pressure is minimized, but the economic income is low, and the social satisfaction is high. This strategy is suitable for scenarios that prioritize environmental protection.

From the optimal social solution, when the number of tourists is moderate, social satisfaction is the highest, and economic income and environmental pressure are also at moderate levels. This strategy is applicable to the long-term sustainable development scenario.

4. Conclusions

This study is based on the Non-dominated Sorting Genetic Algorithm II (NSGA-II) and the multi-objective optimization model to explore tourism development in depth. Methodologically, a TriOptima sustainable triple equilibrium model is constructed with economic, environmental, and social objectives, and the number of tourists as the decision variables, incorporating constraints such as investment and carbon emissions, and using NSGA-II to solve the Pareto optimal solution set. The key conclusions of the study are to clarify that the number of tourists and the tourism tax rate are the key factors affecting the tourism industry; and to provide the city with an optimized scenario with about 3,500 tourists per day, a tax rate of 0.9%, and 12% and 10% investment in environmental protection and community investment, respectively, to achieve a multi-benefit equilibrium. At the same time, the model is extended to over-touristed areas, and new objectives are added according to their characteristics. The research results have high practical application value and provide scientific decision support for the areas affected by over-tourism, considering the economic, environmental and social benefits, and help to realize sustainable tourism development.

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