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The Simulation Study of Space-Time Shunt in Jiuzhaigou Based on Bottleneck Theory

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Abstract: With the rapid development of tourism industry in Jiuzhaigou since 1984, the scenic has experienced an increasing use of its natural and cultural environment for tourism, resulting in tourism resources being adversely impacted. Especially in peak travel period, the imbalance of tourists distribution in time and space leads to undesirable environmental and socioeconomic impacts. It is necessary to design a reasonable tourists shunt strategy with the objective of minimizing the environmental effects arising from tourism. Focusing on the goal, this paper proposes an evaluation model based on bottleneck theory and several shunt strategies. To evaluate the performance of the proposed strategies, combination of different shunt strategies is developed through simulation, and finds that the strategy integrating both static shunt and dynamic shunt strategy outperforms other strategies. The further research direction is proposed in the end.

Keywords: Jiuzhaigou, tourists shunt, bottleneck theory, simulation.

1. Introduction

This paper focus on how to achieve sustainable operation of Jiuzhaigou, a World Heritage Site listed among Chinas most visited tourism spots. Jiuzhaigou is located in the eastern Qinghai-Tibet Plateau of China. The tourism in Jiuzhaigou is boosting the local economy and funding the maintenance of the regional environmental values. It is clear there are a number of environmental effects arising from tourism that are degrading the natural values of Jiuzhaigou. The two most affected spots are Yuanshisenlin and Wuhuahai [1]. The environmental effects arising from tourism are especially obvious in peak travel period, when a spot can be crowded with thousands of tourists and the amenity value for tourists is lowered. Therefore, limiting the number of tourists has become the main appeal to protect the environment in Jiuzhaigou. Figure 1 shows a scene of a peak travel period in Jiuzhaigou.

However, the root reason of the problem above is the imbalanced distribution of tourists. There can be thousands of tourists on some spots, but few on the others. The imbalance of different spots' load in time and space can be reflected by Table 1 and Figure 2 through the comparison of two spots, namely Penjingtan and Jianzhuhai. Therefore, limiting the total number of tourists isn't the best solution.

Figure 1 The sight of peak travel period in Jiuzhaigou

A better way to protect the ecological environment and improve the tourist satisfaction is to allocate the tourists more balanced in time and space.

To address this issue, the Jiuzhaigou Administration proposed a scheme named Three-Region Shunting after in-

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Table 1 The Comparison Table of Two Spots Load.

Time	9	10	11	12	13	14	15
Penjingtan	38	301	589	381	64	619	1028
Jianzhuhai	404	999	732	608	2875	687	0

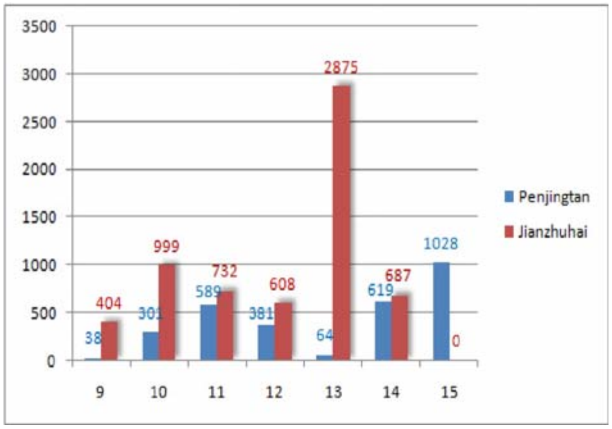

Figure 2 The Comparison Diagram of Two Spots Load

vestigation, which delivers the arriving tourists, according to their willing, to three different spots, namely Shuzhenggou, Rizegou and Zechawagou. But as the tourists travel between the spots, the density of the tourists on a spot varies and the utilization of the spot is not ideally stable.

To tackle the problem, Feng proposed the Five-Region Shunting scheme on the basis of Three-Region Shunting. Five-Region Shunting starts a tour with one of the following spots: Huohuahai, Xiniuhai, Jianzhuhai, Yuanshisenlin and Changhai. The scheme also defines16 major routes according to the statistics of tourists over the years including the tourists stay duration on each spot. However, the details of the shunting strategy and the effectiveness of the schemes are not presented [2]. This paper further explores the impact of the tourism on the ecological environment, the infrastructure and the tourism satisfaction of Jiuzhaigou with different shunting strategies by simulation, and puts forward some hints for future research.

This study has three modules: the first module is to construct a reasonable evaluation of shunt strategy, and propose the Duration of Bottleneck (DOB) evaluation model which is based on the bottleneck theory. The second module is to formulate the shunt strategies, including initial shunt and steady shunt strategy. Initial shunt is the basis of steady shunt. A reasonable initial shunt program will have a significant impact on the steady-shunt; steady-shunt is the core part of the whole shunt strategy, and it plays a vital role on the effect of the shunt. The third module is to verify the effect of different shunt strategies by simulation through DOB evaluation.

The study belongs to the basic research of management mode based on space-time shunt navigation in Jiuzhaigou, and it is significant for further study.

The rest of the paper is organized as follows: the second section sorts out the relevant research literatures and raise issues. Section 3 establishes DOB evaluation model. Section 4 builds a simulation model of Jiuzhaigou tourist shunt and introduces two tourists shunt strategies. Section 5 uses DOB evaluation model to evaluate the above strategies and proposes improved shunt strategy. Section 6 summarizes the problems of this article and puts forward ideas for future research.

2. Description of the Issues

It is inevitable that the development of tourism induces impacts on the environment and social character of the tourism destination. However, the direction (i.e., whether positive or negative) and the magnitude of these impacts depends on the carrying capacity and management level of a destination [3]. How to reduce the bad impacts on the tourism destination becomes one of the hottest topics in the tourism management. The earliest research on the impact of tourism on the environment was carried out by Meinecke [4], while Bates had a significant contribution to this research. In UK [5,6], his system and experimental research was the foundation of later scholars study in the impact of tourism on vegetation. The increasing volume of scholars research has been documented in many countries, which shows that almost all the ordinary eco-tourism will have impacts on the ecological environment without effective management [7]. Catherine and Wendy [8] studied the impact of vegetation which relates to the tourism infrastructure, tourism activity and other relevant factors. Calais and Kirkpatrick [9] proposed that the level of impact caused by the tourism activities varies from vegetation to vegetation. Buultjens [10] discussed the implications of tourism behavior on the protected areas and proposed how to regulate the behavior of tourists, in order to minimize the implications. Recently the other group members have paid more attention to issues in Jiuzhaigou during the peak travel period. Feng et al. studied the tourists peak time and space shunt navigation management of Jiuzhaigou which is based on Entropy Management and RFID, they intended to use RFID, eB3S and other information technology, and designed diversion in the two dimensions of time and space for the scenic spots tourists. They established the time and space shunt navigation management model of peak travel period, in order to reduce the instantaneous load of scenic spots, and balanced time and space distribution of tourists, the goal of their study is to increase the capacity of tourists of scenic spots, to enhance the level of environmental protection and increase visitor satisfaction [11]. Qiu et al. also studied the load balancing issues of Jiuzhaigou. They analyzed the spatial and temporal variation of tourists traffic in the scenic spots during the tourist season and indicated the imbalance of tourist distribution in time and space leads to significant differences between the spots load. They provided ideas to analyze problems by building a mathematical programming model and making dynamic forecast scheduling and proposed to nest vehicle scheduling in forecast scheduling [12]. Previous studies chose variance of trench spots or the loading rate of regions as the only indicator of evaluation of diversion program, and used the variance which was to minimize the load rate of spots to build the objective function. Zhou [13] et al. and Dai [14] et al. and others analyzed the shortcomings of some specific issues of variance evaluation. Similarly, it is not a comprehensive evaluation of the merits of diversion programs to put variance as the only indicator of spots load equilibrium in the evaluation of tourist diversion program in the actual scenic spots. Because the variance just reflect the degree of deviation from the mean of the spot load rate, rather than reflect the extent of damage of scenic spots of travel behavior directly. Therefore, it is necessary to compare the extent of the impact of travel behavior on the scenic spots, and then evaluate the effects of shunt strategies.

In fact, tourism behavior will cause damage to the spots only when the number of tourist is beyond the spots carrying capacity. At a time, the number of the overload scenic spots may be 0, 1 or even greater than 1. We define the most serious damage of spots as the bottleneck spot when the number of overload spots is more than 1; obviously the number of bottleneck spot at a time is up to one. According to Theory of Constraints (TOC), bottleneck is the main factor which limits the system advances toward the goal and determines the overall systems performance. In the scenic spots management, the region with the most seriously affected ecological environment and the most confusing management is always called the bottleneck spot where needs key monitoring. Therefore, it is necessary to compare the interferences intensity and duration of the bottleneck spots travel behavior under different shunt strategy, when evaluates the effects of the shunt Strategy. Taking variance as the only evaluation indicator is not a comprehensive way to evaluate the shunt Strategies. Its necessary to consider the temporal and spatial changes of the bottleneck spot of the scenic spots.

Based on the above observations, this paper presents DOB, designs to do a more comprehensive evaluation of tourist diversion program of Jiuzhaigou so as to develop an appropriate shunt strategy.

3. Evaluation Model of DoB

3.1. Concept and Definition

(1)Space-Time Capacity

The meaning of capacity is deepened continuously with the development of society. PE Forest, the Belgian mathematician and biologist, is the first one proposed the concept of environmental capacity. He believed that there is a maximum value of food intake of biological populations in the environment, and there is also a limit of corresponding increase of animals and plants, this limit value is defined as ”environmental capacity” in ecology [15]. The theory first applied to the national parks and protected areas in the 1930s, which proposed the concept of Recreation Carrying Capacity. In 1960s, with the development of mass tourism, there are an increasing number of people concerned about protection of tourism land. Lapage [16] first proposed the tourism capacity (TCC) in 1963, pointing out that the number of the reception of tourists should be a certain limits during a certain period of time to ensure the quality of the tourism environment, and the satisfaction of the majority of tourists. Subsequently, the American scholar Wagar [17] first proposed the concept of tourism environmental capacity in his academic monograph, ”with recreational features of the wilderness of the environmental capacity”, he argued that recreational capacity is recreational consumption of a recreation area to maintain product quality in the long-term. Lime and Stankey first proposed that the capacity of the environment should be divided into Biophysical Capacity, Social Cultural Capacity, Psychological Capacity and Managerial Capacity [18]. As with the study of the tourism environmental capacity continues deepening in recent years, foreign scholars generally believe that effective management can improve the tourism capacity of the environment, computational model of the tourism environment capacity which obtained with the help of the computer technology are gaining more and more attention. Tony [19] proposed a new definition of the tourism capacity of the environment, that the capacity is not measured by the number of tourists, but the natural resources and the acceptable impact of human beings. And AEM (Adaptive Ecosystem Management) and MASTEC (Multiple Attribute Scorning Test of Capacity) were introduced as support tools and application model system of spatial decision in order to eliminate the adverse effects of tourism activities. Steven et al. monitored the capacity of the social environment of Arches National Park with the application of computer simulation models [20]. Zhang and Zhu also defined the tourism capacity [21]. They pointed out that tourism capacity is the largest number of tourists that a tourist destination can accommodate when acceptable environmental quality and visitor experience are declining. Therefore the capacity of tourism depends not only on capacity of the environment, but also on mental capacity, resources capacity, ecological capacity and economic capacity of tourism.

The traditional capacity of tourism of spots is determined by the ecological environment, infrastructure, satisfaction of tourists and other factors. However, the calculation models of capacity of tourism are almost static. The calculated capacity value is an ideal static result. In fact, the capacity of tourism is a dynamic system, it changes with consumer behavior of tourists, the development of tourism and the extension of travel time [22], besides, it also depends on the tourists stay duration. Therefore, in order to describe the capacity of tourism dynamically, Eleuch and Bahlouli [23] proposed the concept of space-time while Ge et al. defines the concept of space-time capacity of tourism [24], which is defined as follows: C_i^*, τ_i, $N_i(t)$ denotes the static capacity, stay duration and the number of tourists at period of spot respectively. Then the expression of space-time capacity and load of spot at period as formula 1 and 2.

$$C_i^* = \frac{C_i}{\tau_i} \tag{1}$$

$$R_i(t) = \frac{N_i(t)}{C_i^*} \tag{2}$$

(2)Bottleneck Spot

As described above, the bottleneck spot during the scenic area is the main factor which limits the system advances toward the goal and determines the overall systems performance, therefore it needs key monitoring. The number of bottleneck spot at a time is up to one. We define the spot i that meets formula 3 as bottleneck, then the system bottleneck spot $b(t) = i$ and the space load of spot i is defined as system bottleneck load $R^*(t)$. $b(t)$ and $R^*(t)$ are the two important indicators to control and evaluate tourist shunt strategies.

$$R_i(t) \geq 1 and R_i(t) = \max_{i=1,2\cdots n}(R_i(t)) \tag{3}$$

Scenic system has the ability to regulate interference and to remain relatively stable, but this ability is not unlimited. When external interference is beyond the system's self-regulation ability, then it will cause the system's imbalance. The external interferences intensity is denoted as System Equilibrium Threshold Limit (SETL), which won't cause the scenic system lose the ability to regulate, and wont exceed the systems resilience ability. The threshold size is related to the systems type, the external disturbances characters, methods as well as the function duration [25]. Figure 3 shows the control diagram of $R^*(t)$.

According to this definition, the bottleneck spot has the following properties:

P-1: The bottleneck spot does not exist all the time;

P-2: The bottleneck spot changes over time;

P-3: The bottleneck spots space-time load rate $R^*(t)$ characterize the degree of the transient damage arising from the tourists behavior;

P-4: The key to tourists shunt is to control the bottleneck spots, including eliminate bottlenecks, distribute bottlenecks and reduce space-time load rate of the bottleneck;

P-5: The purpose of reducing the duration of the same bottleneck spot is to ensure the spots self-recovery;

P-6: The purpose of reduce space-time load rate of the bottleneck is to prevent the irreversible damage caused by the tourism behavior which exceeds the ecological threshold.

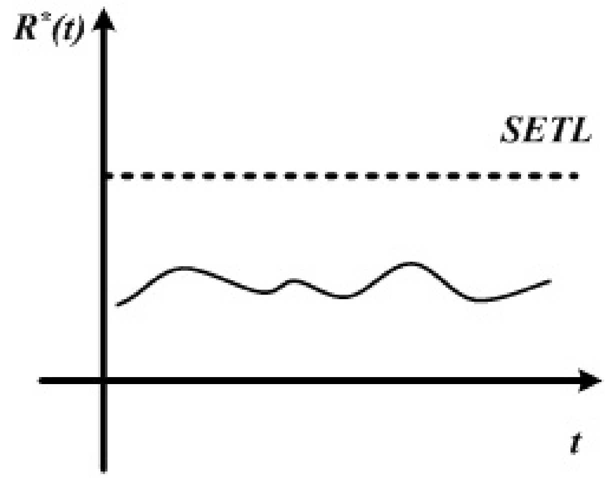

Figure 3 Control Diagram of $R^*(t)$

3.2. DOB Evaluation Model

3.2.1. Theory of DOB Evaluation Model

As mentioned above, the bottleneck spot is the most seriously ecological damaged scenic and the most chaotic at a moment, it needs focused monitoring. The longer duration of interference in a bottleneck spot is, the greater degree of threat for the spot will be. The resilience of ecosystems is inversely proportional to the threat level [26]. Therefore, the key to tourist shunt is to eliminate or distribute bottlenecks. When the bottleneck spot cannot be avoided, reducing the duration of bottleneck can be considered instead, so as to make the spots have sufficient time to achieve self-healing. The principle of DOB evaluation model is to establish joint evaluation model of the duration of bottleneck, and to evaluate the threat level of tourism behavior on the bottleneck spot in different tourist shunt strategy.

This paper introduces DOB evaluation model to the evaluation model of tourism shunt strategy. Obviously, the shorter the duration of the bottleneck, the least ecological damage is to the scenic, and the better the shunt strategy is.

3.2.2. Modeling

In the case of equally spaced observations

$$z_t^k = \begin{cases} 1, b(t) = b(t-1) and z_t^{k-1} = 1 \\ 0, else, \end{cases} \tag{4}$$

where $z_t^0 = 1, t \geq k+1$.

The objective function $Min \sum_{k=1}^{N-1} \sum_{t=2}^{N} z_t^k \times k$

k is the coefficient of damage that interfere of the duration of the bottleneck spot. Obviously, the longer the duration of interference, the greater the extent of damage is.

This paper assumes that the degree of damage is proportional to the duration of interference. An example is shown in Table 2, it can better explain the problem.

Table 2 DOB Evaluation Example.

t	$b(t)$	z_i^1	z_i^2	z_i^3
1	3	–	–	–
2	2	0	–	–
3	2	1	0	–
4	2	1	1	0
5	1	0	0	0
6	1	1	0	0
7	1	1	1	0
8	1	1	1	1
9	2	0	0	0
10	2	1	0	0

At this moment the objective function value is $\sum_{k=1}^{N-1}\sum_{t=2}^{N} k\cdot z_t^k = 1\sum_{t=2}^{10} z_t^1 + 2\sum_{t=3}^{10} z_t^2 + 3\sum_{t=4}^{10} z_t^3 = 15$

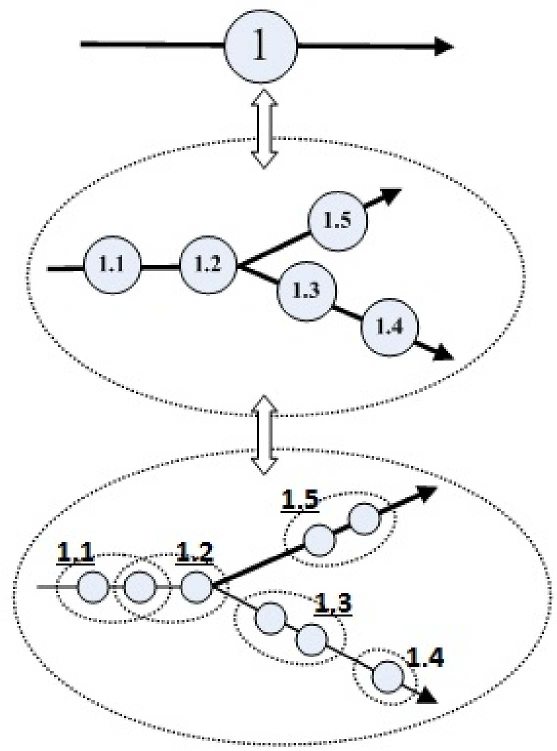

Figure 4 Multi-Resolution Shunt Model

4. Simulation Modeling and Analysis

4.1. Network Layer Theory

The scenic area is divided into five regions in Five-Region Shunting strategy, each region contains several spots, and each spot can be further divided into smaller spots if necessary. We define this model as Multi-Resolution Model (MRM) and divide the scenic into a MRM with 3 layers, shown as Figure 4.

It becomes more difficult with the increase of the number of nodes in simulation modeling, for this reason, Res [24] proposed the theory of Network layer and split the network diagram. The paper follows the research, and splits the Figure 4 into Figure 5:

To illustrate easily, classify the spots in Figure 5:

(1)Decision spot: If the spot satisfies the condition

$$\sum_{i\in A,h\in A,i\neq A} y_{ih} > 1 \tag{5}$$

Then the spot is defined as the decision spot, where y_{ih} is a 0-1 variable, if spot i connected with spot h directly, and in its downstream, then y_{ih} takes 1, else takes 0. The spots such as 0, 2.2 and 7.2 in Figure 5 are all decision spots.

(2)Shunt spot: We denote the spot as shunt spot if it connects with the decision spots directly and in its downstream. The spots such as 5.1, 6.2 and 8.2 in Figure 5 are all shunt spot of decision spot 2.2.

(3) m_i is the number of shunt spots of decision spot i.

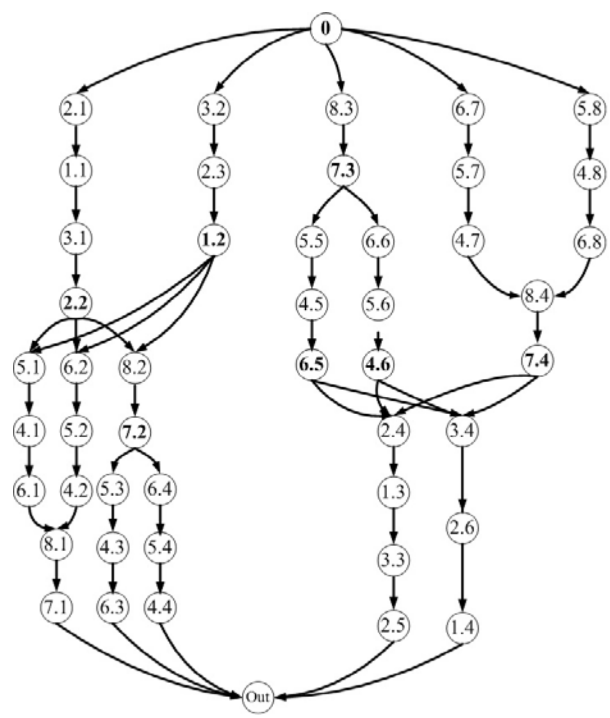

Figure 5 The Network Layer Diagram

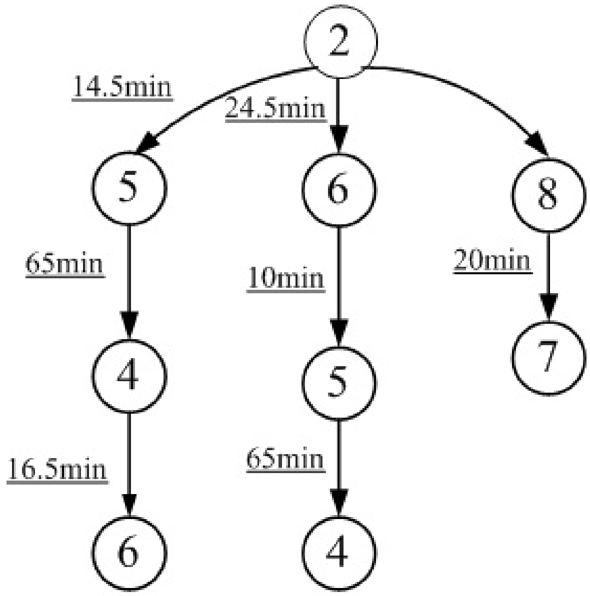

Figure 6 The Shunt Strategies of Decision Spot 2.2

Table 3 Simulation Results of Diversion Strategy.

$Strategy$	$Average$ $Shunt$	$Space - Time$ $Shunt$
$\overline{R^*(t)}$	6.615	8.487
DOB	531	161

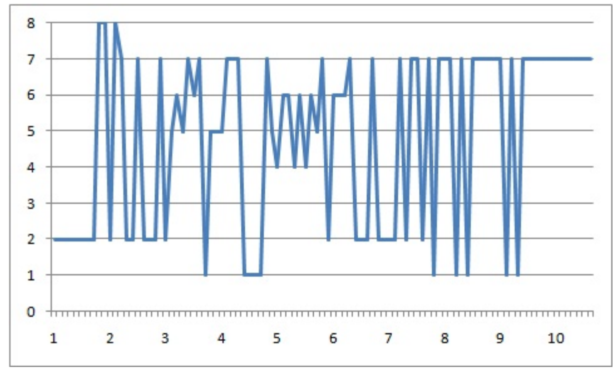

Figure 7 Bottleneck Fluctuations of the Average Shunt Strategy

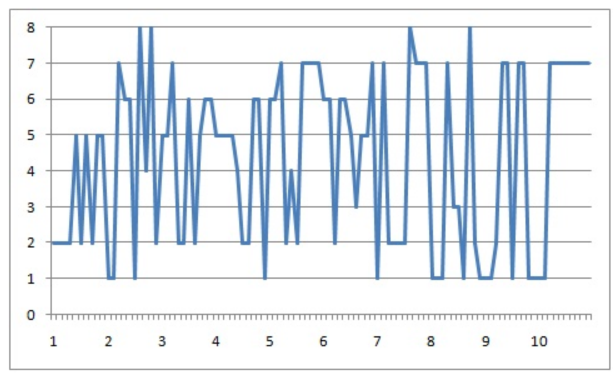

Figure 8 Bottleneck Fluctuations of the Space-Time Shunt Strategy

4.2. Description of Shunt Strategies

There are 8 decision spots in Figure 5 such as 0, 2.2, 1.2, 7.2, 7.3, 6.5, 4.6 and 7.4. Dividing the spots into two categories, one is initial decision spots; the other is steady decision spots. Therefore spot 0 is initial decision spot, and the other 7 spots belong to steady decision spots.

(1) Average Shunt: The shunt proportions of each shunt spot under decision spot are $\frac{1}{m_i}$, so the shunt proportions of shunt spots: 5.1, 6.2 and 8.2 under decision spot 2.2 is $\frac{1}{3}$.

(2) Space-Time Shunt:Consider the space-time load of shunt spots: 5.1, 6.2 and 8.2, select the spot i satisfies the condition $\{i \in 5, 6, 8 | Min(R_5(t), R_6(t), R_8(t))\}$, and then the tourists route will be determined after the spot is selected.

4.3. Simulation results of shunt strategies and illumination

The shunt effect of two shunt strategies is shown in Table 3, Figure 7 and Figure 8, the comparative effect of them is shown in Figure 9

5. The improved shunt strategy

It's easy to find out that the DOB value of average shunt strategy is much larger than the one of space-time shunt strategy from the above simulation results. It shows that the bottlenecks duration of former is longer than the one of latters. The instantaneous damage level of former is more serious than the latter through the comparison between the two strategies bottleneck space-time load. Its obviously that the greater the instantaneous space-time load of bottleneck spots, the easier for the scenic to get irreversible damaged. From the perspective of scenic protection, both the two shunt strategies are not optimal. Therefore, we consider the combination of the two shunt strategies, which combine initial shunt and steady shunt, static scheduling and dynamic scheduling, to integrate the strengths of two strategies. Therefore, using average shunt strategy during initial shunt while space-time shunt strategy in steady shunt. The effects of improved shunt strategy are shown in Table 4, Figure 10 and Figure 11:

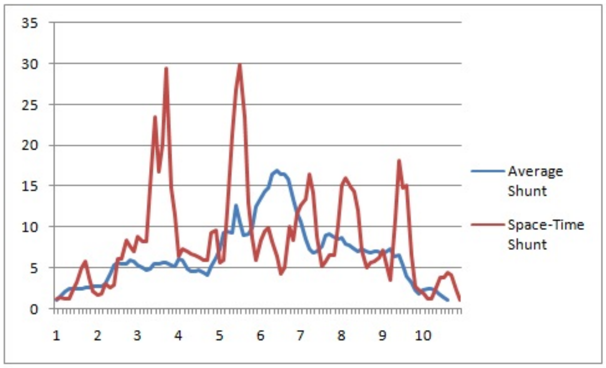

Figure 9 Simulation Results of Two Shunt Strategy

Table 4 Simulation Results of Shunt Strategy.

$Strategy$	$Average$ $Shunt$	$Space-Time$ $Shunt$	$Improved$ $Shunt$
$\overline{R^*(t)}$	6.615	8.487	6.305
DOB	531	161	153

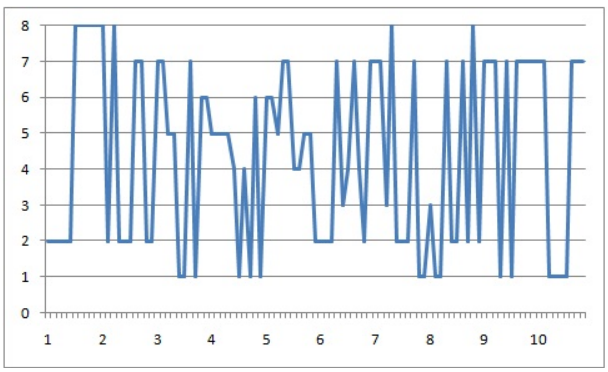

Figure 10 Simulation Results of Two Shunt Strategy

Its not difficult to find that both the values of DOB and $R^*(t)$ are better than the other two shunt strategies from the simulation result of improved shunt strategy. Therefore, the sustained devastation and transient damage on bottleneck spots caused by tourism behavior are less slight than before.

6. Conclusions

Tourism in Jiuzhaigou has the potential to provide economic development as well as sources of the funding for maintaining the environmental values of the region. A simple limitation to the tourists capacity isnt a essential solution to the problem. This paper explores two dimensions (space and time) of shunt strategy in tourism, aims to achieve

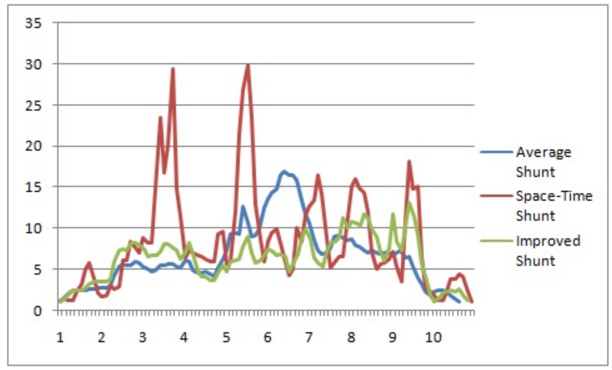

Figure 11 Simulation Results Comparison Diagram of Shunt Strategy

the sustainable development of economic and environmental in Jiuzhaigou. In specific shunt, the bottleneck spots often have the greatest impact on the ecological environment, infrastructure, and tourist satisfaction. The spot with the most confusing management needs focused monitoring. Therefore, it is important to take the control of the bottleneck spot into consideration when formulate the tourists shunt strategy. This paper establishes the DOB evaluation model, then evaluates the two shunt strategies by it, and finds that the strategy integrating both static shunt and dynamic shunt strategy outperforms other strategies. The paper is a foundational research; the main contribution lies in a reasonable evaluation construction of the shunt strategies and proposes several shunt strategies. We will focus on the following problems in the further research:(1)The effects of different frequency during initial shunt and steady shunt; (2) the measures that guide tourists to tour based on a predetermined route.

Acknowledgement

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