Research on Evaluation Index System of Mountain Expressway Landscape Coordination

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Abstract: To better evaluate the effect of mountainous expressway landscape restoration scientifically and reasonably, this paper discussed the evaluation index system of mountainous expressway landscape coordination. Based on scientifically grasping the meaning and characteristics of mountainous expressway landscape coordination, 15 first-level evaluation indicators and 36 second-level evaluation indicators were selected from four aspects: internal highway landscape coordination, external environment coordination, road landscape coordination, and landscape and safety coordination. The index constructed the evaluation index system of mountainous expressway landscape coordination and explained the significance of the evaluation index. To serve the purpose of evaluating the coordination of the mountain road landscape, the constituent factors of the secondary indicators were standardized and scored to achieve the grading and quantification of the indicators. This paper also discussed the evaluation method of highway landscape coordination, which can enrich the theory and method system of mountain highway landscape coordination evaluation to a certain extent.

1. Introduction

In recent years, the awareness of energy conservation and environmental protection and the concept of green development have gained popularity, and requirements such as safe travel, ecological environmental protection, and landscape aesthetics have gradually received attention in the process of highway planning, construction and operation. The main issue of highway landscape planning and design [1] is road environmental coordination (environmental aesthetics), and coordination [2] is the harmony and unity of safety and reliability, driving comfort, beautiful landscape, and environmental protection, and is also a basic requirement for highway planning and construction. Therefore, whether from the perspective of landscape quality, ecological protection or operational safety, the discussion of mountainous expressway landscape coordination is conducive to the construction of a better driving environment in mountainous areas.

The research of coordinated design in foreign countries started as early as the 1970s. The research in China started relatively late, and domestic and foreign researches mostly focused on landscape aesthetics[2][4], visual quality[5][6], road area ecology [7] [8] and other aspects, the research on road landscape coordination is also concentrated on tourist roads [9] [10] [11]. However, with the increasing demand for highway construction in mountainous areas in China, the corresponding research on the coordination of general mountainous highway landscapes is lacking.
Herein, started from the purpose of establishing an evaluation index system for expressway landscape coordination in mountainous areas, the author analyzed the characteristics of mountain road landscapes, discussed related indicators of landscape coordination, and then established a widely applicable expressway landscape coordination evaluation index system in mountainous areas.

2. Mountainous highway landscape analysis

2.1. Landscape features of mountain roads

Mountain highway design should be based on how to protect the natural landscape characteristics of the mountain along the road, and then consider the coordination of road landscape design and natural landscape. The expressway should not only meet the traffic demand, but also protect the natural environment of the mountainous area to the greatest extent. Therefore, it has the same characteristics as general roads such as multiplicity, diversity, multi-dimensionality, and multi-subjectivity [12], and also has the following characteristics.

a. The particularity of the site background

The mountainous terrain, hydrology, and geology are complex, forming high mountains and deep valleys, steep slopes and rapids. The highways built in mountainous areas have large undulations, abundant surrounding animals, plants and water bodies, and strong natural ecological sensitivity. Moreover, topography, landform, climate and other aspects have different degrees of influence on the highway landscape effect. Therefore, the highway in mountainous areas is built in a relatively special environment.

b. The heterogeneity of linear landscape

An important and difficult point in mountain expressway design is the route selection and alignment design of the highway, because the alignment of the expressway is a landscape of the highway itself, and the mountain highway has the characteristics of many routes and frequent changes. When designing, the road should be adapted to the change of mountain terrain, considering the direction of mountains and rivers, hence achieving the effect of coordination between the route and the environment.

c. The regional nature of the human landscape

In mountain highway landscape construction people began to pay more and more attention to the role of environmental protection. The mountainous highway landscape must not only provide the necessary habitat and activity venues and safe passages for wild animals and plants, to expand the space area for the survival and activity of wild animals and plants. Moreover, based on the regional characteristics of mountain highways, the highways should be in line with local customs and historical and cultural heritage, and coordinated development, give full play to the local characteristics, and show the cultural heritage and charm. At the same time, rendering the regional culture can also enrich and enhance the cultural connotation of the highway landscape.

2.2. The meaning of mountainous expressway landscape coordination

Coordinated landscape design can not only reduce the damage to the ecological environment along the route caused by construction, but also provide good visual effects, relieve driver fatigue and reduce traffic accident rates. For landscape coordination [13] [14], the road construction and natural landscape should be regarded as one part, and the various components of the road landscape system are coordinated and cooperated to improve the overall quality and effect.

In summary, through the basic theories related to road landscape design such as road area ecology [15], road design specifications [16], road traffic safety [17], and based on ensuring driving safety and efficiency in highway landscape present situation and its change in a mountainous area, this paper argued that the mountain area highway landscape coordination can make driving personnel to appreciate the scenery along the way to enjoy a pleasant journey and increase the landscape quality, and is an expression that can minimize the disturbance and damage to the ecological environment of the road area so that the comprehensive effect of highway landscape can reach the optimal degree.
3. Selection of evaluation indexes

3.1. Connotation of the indicator system
Highway landscape is a complex system. To study the coordination between its components and the whole, it is necessary to use objective, concise and practical indicators to analyze its operating principles. A single index cannot reflect the main characteristics of the highway landscape coordination system. For a good evaluation, a comprehensive and systematic index system must be established. In the evaluation of mountainous expressway landscape coordination, the index system can describe and express the overall state, development trend, and degree of coordination of various aspects of the landscape coordination system, and can become a basis for guiding the landscape planning and evaluation of high-grade highways.

3.2. Principles of Index Selection
The establishment of the index system in this paper took the road landscape coordination as the goal, considering the road rights classification theory and operation safety theory of the road, from the road itself coordination, external coordination, road area overall coordination and safety coordination between the road and the environment, etc. On the one hand, the goal decomposition method was used to refine it to representative indicators. The selected indicators shall comply with the principles of clear goals, representativeness, comparability, conciseness and feasibility, and ensure that the selected indicators are easy to operate in practical applications. It should be noted that the main manifestation of the complexity of the system lies in the certain connection between the indicators. Therefore, in addition to following the above principles, the selection of indicators in the indicator system should also consider the independence of the indicators to minimize the overlap of information they reflect.

4. Landscape evaluation index system

4.1. Construction of the evaluation index system
This paper took the internal road landscape coordination (function), road landscape coordination (aesthetics), external environment coordination evaluation (ecology), landscape and safety coordination (safety) as the first-level evaluation indicators, and each indicator has a corresponding secondary evaluation indicators form the main structure of the landscape coordination evaluation (Table 1).

| Criterion layer | Indicator layer | Sub-indicator layer |
|-----------------|-----------------|---------------------|
| Mountain highway landscape coordination A | Internal highway landscape coordination $B_1$ | Road shape evaluation $B_{11}$ |
|                  | Highway cross section evaluation $B_{12}$ | 3D linear evaluation $C_{111}$, Four-dimensional linear evaluation $C_{112}$ |
|                  | Highway Landscape Space Evaluation $B_{13}$ | Cross-sectional form and terrain suitability $C_{121}$, Monotonicity of cross-sectional form $C_{122}$ |
|                  | $B_2$          | Landscape space ratio $C_{131}$, Landscape space extension ratio $C_{132}$, Landscape space composition $C_{133}$ |
|                  | Highway Landscape Space Evaluation $B_{21}$ | Earthwork volume per unit of roadbed $C_{211}$, Road project area $C_{212}$, Road design rationality $C_{213}$ |
|                  | Evaluation of the coordination between $B_{22}$ | Structure shape $C_{221}$, Structure color $C_{222}$, Structure composition $C_{223}$ |
4.2. Research on the internal coordination of highway landscape

The internal coordination design research of highway landscape includes the coordination research of highway linearity, the coordinated design of highway cross section and the coordination research of highway landscape space. Linear coordination research is to discuss the linear 3D coordination and visual psychological effects of highways on the basis of dynamic visual principles; cross-sectional landscape design is to study the form and beautification methods of cross-sections, especially the slope beautification methods; The highway landscape space coordination research discusses the proportion, scale, structure type and landscape composition method of the highway landscape space in the form of aesthetic principles. The three are both the basis and the main content of the internal coordinated design of the highway.

4.2.1. Highway alignment evaluation

The road shape evaluation is an important content of the road self-coordination evaluation, which should be evaluated as a whole. The highway line shape is a horizontal and vertical 3D space, while the highway structure and environment $B_{22}$, Evaluation of coordination between highway and natural landscape $B_{23}$, Evaluation of the coordination between highway and human landscape $B_{24}$, Coordination evaluation of landscape highway greening $B_{25}$, Evaluation of coordination between highways and animals and plants $B_{31}$, Soil erosion intensity $B_{32}$, Frequency evaluation of disaster occurrence $B_{33}$, Ecological environment damage evaluation $B_{34}$, Road alignment rationality $B_{41}$, Safety of transportation facilities $B_{42}$, Roadside safety $B_{43}$, Landscape separation $C_{231}$, Landscape fragmentation $C_{232}$, Landscape diversity $C_{233}$, Landscape separation $C_{241}$, Landscape fragmentation $C_{242}$, Landscape diversity $C_{243}$, Plant coverage $C_{251}$, Highway implementation GBM engineering rate $C_{252}$, Planting tree evaluation $C_{311}$, Evaluation of animal activity routes $C_{312}$, Soil erosion intensity $C_{321}$, Frequency of disasters $C_{331}$, Ecosystem stability $C_{341}$, Rationality of the construction plan $C_{342}$, Radius of horizontal curve $C_{411}$, Small radius curve and long straight line ratio $C_{412}$, Average slope $C_{413}$, Signs marking rationality $C_{421}$, Reasonable guardrail installation $C_{422}$, Side ditch and drainage ditch type $C_{431}$, Roadside clear area width $C_{432}$, Monotonicity of roadside greening $C_{433}$, Sight induction $C_{434}$.
line shape should be a four-dimensional space line shape considering the time factor. Therefore, highway alignment evaluation starts from 3D alignment and four-dimensional alignment evaluation.

4.2.2. Coordination degree of expressway cross section
The normal cross-sectional view at any point of the highway centerline constitutes the cross-sectional view of the highway. The topography of mountainous areas has complex topographical changes. Choosing the cross-sectional shape of the appropriate terrain, actively and flexibly applying the characteristics of various landscape factors can avoid the generation of monotony. It can be evaluated from two aspects: the cross-sectional form and the suitability of the terrain and the monotonicity of the cross-sectional form.

4.2.3. Evaluation of highway landscape space
Spatial vision plays a decisive role in the formation of highway landscape, and it is expressed both psychologically and physically. The physically aspect is related to the human object, and the size and physiological structure of humans need space, etc., which belong to the use function of space. The psychological aspect is mainly the visual psychological influence caused by the proportion, size, shape and direction of the physical space, which belongs to the spiritual function of the space and is an aesthetic category. It is evaluated from the composition of highway landscape space, the extension ratio of landscape space, and the proportion of landscape space.

4.3. Evaluation of road landscape coordination
The road area landscape coordination analysis is mainly based on the degree of influence of the road and the road along the terrain, the ecological environment and the natural landscape. The road internal landscape (i.e. its own landscape) and the road external landscape are regarded as a whole with a specific structural function to study. The evaluation is conducted from the coordination of highway and topography, highway structure and environment, highway and natural landscape, highway and human landscape and highway landscape greening.

4.3.1. Coordination of highway and topography
Due to the particularity of the mountainous area, whether for environmental protection or safety considerations, the construction project design requires full consideration of the local topography. It can start from the amount of earth and stone in the roadbed, the area per kilometer of the road project, and the rationality of the road design.

4.3.2. Evaluation of the coordination between highway structure and environment
The landscape evaluation of bridges, tunnels and other structures on highways is mainly carried out from the aesthetic aspect, which should include the evaluation content of structure form, color and combination, and can reflect the aesthetics of the structure and the degree of coordination with the surrounding environment.

4.3.3. Coordination between highway and natural landscape
The highway itself has a close relationship with the landscape along the route. The highway is embedded in the original landscape. This process has a more or less impact on the local landscape. Therefore, to achieve the integration of the two, it is necessary to master the appearance characteristics of the natural landscape along the line and the tone of the regional landscape such as history and humanities. We mainly inspected the index of landscape separation, landscape fragmentation, landscape diversity and so on.

4.3.4. Coordination between highway and human landscape
Human activities are an important factor leading to the fragmentation of landscapes and the discretization of landscape patches. They not only act on natural ecological landscapes, but also act on
human cultural landscapes. Cultural landscape is the product of human activities. In order to evaluate the coordination between regional cultural landscape and highway landscape, it is necessary to study the pattern and change process of regional cultural landscape on time and space scales. Referring to the indicators in 3.3.3. We mainly inspected the index of landscape separation, landscape fragmentation, landscape diversity and so on.

4.3.5. Coordination of landscape highway greening
The visual effect of highway greening can be reflected by vegetation coverage rate and the rate of highway implementation of GBM project. Landscape greening has an important impact on vision and psychology. It can not only afforest the environment and induce the line of sight, but also help drivers relieve visual fatigue.

4.4. Coordination evaluation of external environment
Coordinated evaluation of the external environment, starting from the degree of the ecological environment affected by the highway, we analyzed the impact of road construction on the stability of organisms, biological habitats, soil geology, ecological communities and the entire ecosystem. From the coordination of roads with animals and plants, soil erosion emphasizes, the frequency of disasters and the degree of damage to the ecological environment were evaluated.

3.4.1. Evaluation of coordination between highways and animals and plants
The construction of roads will have a direct impact on the animals and plants around the roads, such as the blocking of animal routes and the invasion of alien species, which may disrupt the balance of the original ecosystem. Therefore, it is necessary to investigate the coordination between roads, animals, plants and the extent of road damage to the ecological environment. Evaluation should be conducted from two aspects of planting trees and animal activity routes.

4.4.2. Intensity of soil erosion
The construction period of the expressway is long. During the construction process, it is easy to re-pollution and surface damage, which will have an extremely serious impact on the local geology. Large-scale soil erosion will cause the local ecological environment to lose balance.

4.4.3. Frequency of disasters
Frequency of disasters refers to the average annual frequency of some geological disasters in the highway construction project area. It starts from the geological state of the highway to the ecological environment, measures the impact of the highway on the ecological environment, and reflects the sensitivity of the ecological environment.

4.4.4. Degree of destruction of ecological environment
The degree of disturbance to the ecological environment during highway construction and operation. Ecological stability can be a good evaluation of the stability of ecosystem communities affected by highway construction and operation. The rationality of the construction plan has a very important impact on the ecological environment. A good road construction plan can effectively reduce the damage to the ecological environment around the road. Therefore, the evaluation is made from the stability of the ecosystem and the rationality of the construction plan.

4.5. Landscape and safety coordination
The coordinated landscape helps the driver to concentrate and avoid monotony, thereby reducing accidents and ensuring the safe and smooth roads. The landscape form, color, layout, etc. of the road area that consider the requirements of safe driving also meet the visual and psychological requirements of driving in a coordinated design. To a certain extent, road landscape coordination is also part of the study of traffic safety, especially for mountain expressways, where safety is the foundation and the top
priority. Based on the classification of highway landscapes, four indicators are selected: rationality of road alignment, safety of traffic facilities, safety of road structures and roadside safety to measure the coordination of landscape and operational safety environment.

4.5.1. Rationality of road alignment
Road alignment design is the primary consideration of traffic operation safety factors, reasonable road alignment can increase the driving comfort of drivers, more conducive to traffic safety operation. Generally, for the monotonous straight line, people prefer the curve shape full of changes, and the gentle curve and slope can make people's vision more pleasant under the condition of meeting the operation safety. Therefore, it is evaluated from three aspects: radius of horizontal curve, small radius curve and long straight line ratio and average slope.

4.5.2. Safety of traffic facilities
Traffic safety facilities are protective facilities set up to ensure the safety of pedestrians and driving. Reasonable safety facilities can not only ensure safe driving, but also induce sight and beautify the environment. Highway traffic facilities are mainly traffic sign markings and guardrails. Signs that have a greater impact on driving safety, markings and guardrail settings are selected to evaluate the rationality of signs and markings and guardrails.

4.5.3. Roadside safety
It means that the elements on both sides of the road are well designed, have a certain degree of tolerance, good roadside greening, a certain line of sight guidance, and play a role in safety protection without affecting driving. The selected roadside safety indicators include: side ditch type (drainage ditch), roadside clear area width, roadside greening monotony, and sight guidance.

5. Evaluation criteria for each index

5.1. Determination of the weight of evaluation factors
Before evaluation, the weights of various evaluation factors should be calculated according to the weight analysis method. Analyzing and evaluating the complexity of factors, some indicators are difficult to use existing scales to determine and measure, especially the design psychology factors are usually judged by feeling, then the pair-by-pair comparison method can be used. The basic approach is to compare the factors of each indicator pair by pair, and compare the importance of each element at the same level with respect to a criterion in the higher-level indicator. Here is an example of 3D linear evaluation factor weight. Correspondence of horizontal and vertical lines, horizontal and vertical alignment and perspective view check as the 3D linear evaluation factors. (Note: The corresponding evaluation factors of each indicator selected, some of the content can be referred to The following documents [2] [9] [18–27].)

According to expert opinions, we can compare the importance of the upper-level 3D alignment with respect to the corresponding situation of the horizontal and vertical alignment, the coordination of the horizontal and vertical alignment and the inspection of the perspective view to get the weight of the 3D linear factor (Table 2).

| Evaluation factor | Correspondence of horizontal and vertical lines | Horizontal and vertical alignment | Perspective view check | Cumulative score | Weight |
|-------------------|-----------------------------------------------|----------------------------------|------------------------|-----------------|-------|
| Correspondence of horizontal and vertical lines | —— | 1 | 1/2 | 3/2 | 3/14 |
5.2. Quantification and standardization of index scores

For the sub-indicator, the evaluation value is generally determined by the expert scoring method, and the score value is standardized to obtain the quantitative index. Taking the 3D linear index $B_{111}$ as an example, it also includes evaluation factors such as the correspondence of the horizontal and vertical lines, the coordination of the horizontal and vertical lines, and the inspection of the perspective view. The standard score can be obtained by scoring each evaluation sub-factor by experts (as shown in table 3)

| Index Evaluation factor and weight | Description of sub-factors and evaluation criteria | Evaluation value | Standard score |
|-----------------------------------|---------------------------------------------------|------------------|----------------|
| Correspondence of horizontal and vertical lines (3/14) |
| Flat and vertical line deformation slope point fit | Coincide | 5 |
| | Phase stagger $= (\text{taking as } 3 \text{ when staggered by } 1/4)$ | | 2~4 |
| | In contrast | 1 |
| Using a flat curve as the leader of a vertical curve | | 5~4 |
| | No | 3~1 |
| Coordinate of horizontal and vertical lines (3/14) |
| Radius of curvature of plane line and vertical section line | Meet the requirements of mix ratio (the ratio of the horizontal curve to the vertical curve is preferably 1:10~1:20, which is preferably 5) | 5~4 | $S_{c_{111}} = \sum \left[ \frac{\text{Weight} \times \sum \text{sub-factor evaluations}}{\text{Number of sub-factors}} \right]$. |
| | Does not meet the mix ratio requirements | 3~1 |
| Perspective view check (8/14) |
| Visual induction | Good | 5~3 |
| | Not good | 2~1 |
| | Maintain the visual and psychological coordination of the linear shape, | No visual illusion | 5~4 |
| | Basically no illusion, or does not | 3~2 |
and visual illusions appear affect the linearity
Contains serious visual illusions 1
Line distortion appears Smooth 5~3
Distortion 2~1

5.3. Classification of evaluation indexes of highway landscape coordination
As shown in Table 4:

| Rating | Grade description | Index classification range |
|--------|-------------------|---------------------------|
| I      | Very bad          | 1~1.5                     |
| II     | Poor              | 1.5~2.5                   |
| III    | General           | 2.5~3.5                   |
| IV     | Good              | 3.5~4.5                   |
| V      | Very good         | 4.5~5                     |

6. Evaluation method
This article focuses on secondary indicators, based on the principle of rigorous, meticulous and evidence-based, and still analyzes and refines to the corresponding impact factors and sub-factors. In the specific evaluation, the appropriate index weight determination method and evaluation system evaluation method are selected according to the actual situation of the project. At the same time, the content and weight of the evaluation factors corresponding to the index can be changed and then determined, which has certain flexibility and adaptability, ensuring that the evaluation model can make correct evaluation as much as possible based on the project characteristics of the target area.

7. Conclusion
1) The landscape characteristics of expressways in mountainous areas were discussed, combined with basic theories such as road area ecology, highway design specifications, and road traffic safety, the meaning of mountainous expressways landscape coordination was proposed. Based on the four aspects of environment, the overall landscape of the road area and the safety landscape, the indicators are selected based on the target decomposition method and selection principles, and the evaluation index system of mountainous expressway landscape coordination is established.
2) In order to increase the understanding of each index, the meaning of each index is explained, and the corresponding evaluation factor of the index is recommended.
3) The corresponding evaluation factors of the indicators are compared to determine the weights, and the expert scoring method is used to score the quantitative scores according to the factor evaluation standards, and the evaluation index level is finally determined.
4) The evaluation index system established in this paper still lacks practical application. The accuracy, reliability and certain flexibility of evaluation results need to be further verified, and then the evaluation index of mountainous expressway landscape coordination should be improved.

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