Highway Disaster Alignment Decision-making Model Under the Fragile Environment Condition in Mountain Area

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Abstract: Highway disaster alignment is a complex multi-object decision-making problem especially under the fragile environment conditions such as in mountainous areas, also these objects do not have public characteristics. This paper establishes the multi-object functional decision making model from the topographic, geologic environmental aspect that may grow and become the cause of all kinds of highway disasters. Using the multi-object decision making theory, this model considers the multi-object about the highway alignment from the qualitative aspect and the quantitative aspect, this has an important academic significance and applied value. In the end of this paper an example analysis is given which indicates the model and its effectiveness.

Keywords: Decision-making model, frail environment highway disaster alignment, mountain area.

1. INTRODUCTION

Construction of highway projects in mountainous areas where the environmental conditions are fragile usually poses a greater impact on the fragile environment and can contribute to development and occurrence of various highway disasters. This is one of the reasons for the predominant disaster and environmental problems with highway projects in mountain areas. People nowadays are getting to know more and more about the environmental problems and their perceptions are also changing. This paper looks into the disaster-based route selection and establishes a multi-object decision-making model based on the multi-object decision theory, on the basis of which the construction of highway projects in mountain areas may give rise to the development and occurrence of highways with the terrain-based route selection [1], geology-based route selection [2-4], and environment-based route selection [5-7] into consideration. This reflects the specific application of the disaster-based route selection concept in the highway project construction scheme and decision making in the fragile environmental condition of the mountain areas.

There are currently many studies being conducted on highway disasters. For example, Ma Baoceng [8] et al. proposed pre-disaster identification criteria respectively for highway collapse and landslide. Song Yanhui [9] et al. discussed about the geological disaster evaluation model for highways in mountain areas. Moreover, there are also a great number of studies being conducted on geological disaster risk evaluation [10-12] based on the same. The application of GIS technology [13,14] provides a new technical research means for the risk assessment of highway geological hazards in the mountain areas. With regard to highway route selection, Sun Qingzhen [15] has established a route optimization model for highways in mountainous areas based on the multi-object decision. Ye Liya [16] et al. conducted highway route optimization technology study on the basis of the geological disaster risk evaluation. This paper establishes a highway disaster-based route selection decision model according to the fragile environmental condition in the mountainous areas, using the multi-object decision theory [17], in order to reduce or avoid the risk of highway disasters from the source of highway construction.

2. FEATURES OF HIGHWAY DISASTER-BASED ROUTE SELECTION IN THE FRAGILE ENVIRONMENTAL CONDITIONS OF MOUNTAINOUS AREAS

Highway disaster-based route selection in the fragile environmental condition of mountain areas is a complicated systematical work and is also the key element that reflects the design characteristics and level of a project. Meanwhile, it is also the critical factor for guaranteeing safe operation for the routes and reduction of the building cost. Taking all these factors into consideration helps guarantee the safety, economy, reasonability and the environmental performance of the highways, especially for route scheme selection in mountainous areas where the terrain condition, geological condition and environmental conditions are complicated.

The fragile environmental conditions of the mountainous areas usually include rivers and mountains. The bank slopes are usually steep and the water flow is usually rapid. The
steep mountains make roadbed filing and excavation very difficult, and once there is any uneven filling, spoil treatment will be very difficult and a lot of earth would need to be borrowed. On the other hand, the bridge and tunnel construction cost is very high. Though we have already accumulated a very rich experience in route selection regarding the mountainous areas, such as mountain-crossing setting out, the work amount is really big, which may cause stiff route developments, poor linearity and unsatisfactory operating conditions and other adverse effects. Meanwhile, the complicated and steep terrain also contributes greatly to the development and occurrence of various highway disasters.

The geology under the fragile environmental condition of mountainous areas usually includes fault and its secondary fractured clamping zone or influence zone [2, 4]. Rock mass fracture, karst, landslide, debris flow, collapse, crag, separation, rock-fall, talus and other undesired geology could easily develop in those areas. Complicated geology provides very good material conditions for development and occurrence of various highway disasters and highway secondary disasters.

The environmental condition in the fragile environmental condition of the mountainous areas is usually extremely fragile, such as sparse vegetation environment, complicated hydrological environment and severe weather environment. Any improper treatment in the highway project construction in the mountainous areas can be very hard to repair, and will pose significant impact on the fragile environment as the mountainous areas cause great troubles to the subsequent maintenance and operation.

3. SELECTION OF HIGHWAY DISASTER-BASED ROUTE SELECTION DECISION OBJECTIVE UNDER THE FRAGILE ENVIRONMENTAL CONDITION OF MOUNTAINOUS AREAS

Proper selection of highway disaster-based route selection decision object is the foundation for building a decision making model, and whether the decision making selection and quantification is reasonable, poses a direct impact on whether the building of decision making model [3,5] could be successful or not. Therefore, in building of highways, disaster-based route selection decision making model under the fragile environmental condition of the mountain areas, reasonable selection of decision making object is quite critical. The factors impacting the highway disaster-based route selection in aspects of terrain conditions, geological conditions and environmental conditions should be emphasized. The principal component analysis and clustering analysis theoretical method is based on the principles of relative uniformity. Dominance and comprehensiveness should be used to analyze and classify the highway route selection decision making indexes. After which the representative main objects should be taken as the decision making object to be studied according to the terrain, geology and environment [18].

Terrain object: the magnitude of terrain height difference is one of the critical factors impacting the route linearity and highway project quantity, and is also one of the main factors to be considered for route selection of highways in mountainous areas where the environment is fragile. If the consideration is not comprehensive, there will be high embankment and low cutting, thus increasing the damage of highway project construction to surrounding environment. If the bridges or tunnels are used instead, the project building cost will be drastically increased. In addition, the steep terrain could also contribute to the occurrence and development of various highway disasters, such as landslide, collapse and debris flow and other common disasters. Therefore, the use of terrain as one of the decision making indexes has great significance for the safety and economy of highway construction projects. A slope map was generated, using the space analysis function of GIS to analyze the original 3D terrain data. And, on the basis of this generated slope map, the terrain elevation of difference changes in information of various grids was generated as the information indexes reflecting the degree of impact of terrain objects on the linearity, safety and project quality of the route, and also as the information index reflecting the degree of impact of terrain objects on the occurrence of highway disasters. Based on the above analysis, the terrain information could be divided into flat terrain (with gradient below 30°), comparatively steep terrain (with gradient between 30° ~ 45°) and steep terrain (with gradient above 45°).

Geology objective: The formation lithology is one of the main factors to be considered for geology-based route selection of highways in the fragile environmental condition of mountainous areas. This is because the loose and fractured rock mass is regarded as the material condition foundation for various highway disasters. The development and occurrence of highway disasters in mountainous areas are closely related to rate of decay of rock and lithology. Considering the lithology of rocks differs when the locations and the change in the surrounding environment are different, the fracture and the degree of the decay are also different. Through analysis of rock mass in different strata and comparison of lithology and fracture of the rock masses, we can sub-divide the rock masses into rigid rock mass, loose rock mass and fractured rock mass based on the decision making objectives. As an information index reflecting the impact of lithology object on the safety of the travel route, geological structure is another key factor to be considered for the highway geology-based route selection in fragile environmental condition of mountain areas. Experiment results and experiences show that places near large geological structures, fractures are more vulnerable to highway geological disasters, which pose an impact on each other to cause a disaster chain with great destructive effects. Hence, fault zone and formation occurrence and other geological structure conditions pose a direct impact on development and occurrence of highway geological disasters in fragile environmental condition of mountainous areas, as well as on the safe operation of highways in mountain areas.
As such, regarding geological structure object as a decision making object is very important for improving the reliability and safety of the route and avoiding various highway geological disasters. The specific procedures are as follows: The geological structure lines should be classified to establish different layers, and then these lines should be analyzed using the buffer area analyzing function and the space analyzing function of GIS to obtain the information on strong influencing zones, comparing strong influencing zones and weak influencing zones. After this the significance of their impact on the travel route can be used as the information index that reflects the impact of geological structure object on safety of the travel route.

Environmental object: Rainfall is one of the factors to be considered for highway environmental-based route selection in fragile environmental conditions of mountainous areas, it is a driving force for highway geological disaster and flood damage in mountainous areas, and is also the main source for triggering various factors that cause highway disasters in mountainous areas (water body). Therefore, rainfall is closely related to the development and occurrence of highway disasters. According to the analysis of the collected data, most of these disasters take place after a rainstorm or long-duration rains. Therefore, it is of great significance to take the rainfall factor be treated as an object for highway route selection decision making model under complicated environmental conditions in mountain areas. The rainfall intensity (the rainfall capacity within 10 minutes) is used for space statistical analysis, and the information on strong influence zones, comparatively strong influence zones and weak influence zones is obtained. The significance of their impact on travel route is used as information index reflecting the impact of rainfall object on safety of the travel routes. Vegetation is also one of the main factors to be considered for highway environmental-based route selection in fragile environment conditions of mountainous areas. Hence, the use of vegetation as the object for building the highway route selection decision making model for complicated environmental conditions of mountainous areas has great significance for the construction of highway projects and environmentally balanced development. Through space characteristics analysis of the environmental vegetation conditions, the area is divided into the zone with good vegetation, the zone with ordinary vegetation and the zone with weak vegetation. This will be used as the information index reflecting the degree of impact of vegetation on the environmental protection of the travel route.

4. DECISION MAKING MODEL FOR HIGHWAY DISASTER ROUTE SELECTION IN THE FRAGILE ENVIRONMENTAL CONDITION OF MOUNTAIN AREAS

4.1. Building of Single-object Function Model

The above decision making indexes are then sub-divided into 3 layers using the space analyzing function of GIS, namely the terrain object is divided into: steep terrain, comparatively steep terrain and flat terrain. The rainfall object is sub-divided into “heavy rain”, “moderate rain” and

<table>
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<tr>
<th>Object function</th>
<th>Weight</th>
<th>Index</th>
<th>Unit</th>
<th>Scheme I</th>
<th>Scheme II</th>
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<td></td>
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“light rain”; the lithology is sub-divided into stiff rock mass, loose rock mass and fractured rock mass; the geological structure object is sub-divided into strong influence zones, the comparatively strong influence zone and weak influence zones, the vegetation object is sub-divided into good vegetation, ordinary vegetation and weak vegetation. After the classification, the space extracting function of GIS is used to extract the number of unit highway sections in different areas of the route schemes and denote them as $n_1$, $n_2$ and $n_3$. Then the following single-object function could be established:

$$f_i(x) = \frac{n_3-n_2}{n_1+n_2+n_3}$$  \hspace{1cm} (1)

Where, $i=1, 2, 3, 4, \text{and } 5$.

4.2. Building of Multi-object Function Model

According to the previously built single-object function model [17], a group of object functions for highway route selection in complicated environmental conditions in mountainous areas were studied and then the different calculation results of different single-object functions were used to generate the optimal route scheme. To allow the single-object function to reach the optimal object, the object programming method was used in this study to build a multi-object function model as follows:

$$\min \sum_{i=1}^{5} w_i | f_i(x) - f_i^0 |$$  \hspace{1cm} (2)

Where the $w$ is the weight of a single object and the AHP calculation method was used.

5. APPLICATION EXAMPLE

In this paper, a highway section with fragile environmental condition was taken from a highway in the Three Gorges Reservoir Region as a sample and the design for the two schemes was conducted. The basic data of the decision making functions of each scheme are shown in Table 1. The single-object function value was calculated using Formula (1). Thus, the object-function optimal values of the two schemes were obtained as follows:

$=0.2207, 0.5380, 0.2850, 0.3123, \text{ and } 0.4550$. The multi-object function values were calculated using Formula (2) and the multi-object function values of 0.0671 and 0.0759 were obtained for Scheme I and Scheme II respectively. Thus it can be seen that Scheme I is better than Scheme II, as the calculation results of the model is coincides better with the actual condition.

CONCLUSION

In this paper, the multi-object decision making theory had been used to build a highway disaster route selection decision making model for fragile environmental conditions in mountainous areas, which is formulated based on the qualitative and quantitative analysis the terrain, geology of the environment and a number of other factors that may lead to highway disasters. The mathematical statistics theoretical method was used to classify and analyze the various highway route selection decision making indexes, and to extract the representative main indexes in order to build the decision making model. The built model enjoys rigorous structure, high operability, as well as computability and realizability using computers.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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