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Original Research Paper

Computing a ground appropriateness index for route selection in permafrost regions

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HIGHLIGHTS

- A ground appropriateness index is proposed to select route alignment in permafrost regions.
- The trapezoidal membership function is used to express the input space variable.
- Based on the theory of knowledge base and fuzzy mathematics, rule base and inference engine of the route selection is established according to the influencing factors.
- The program operation of the permafrost region selection method was completed by the fuzzy toolbox in MATLAB.

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ABSTRACT

The reasonable calculation of ground appropriateness index in permafrost region is the precondition of highway route design in permafrost region. The theory of knowledge base and fuzzy mathematics are applied, and the damage effect of permafrost is considered in the paper. Based on the idea of protecting permafrost the calculation method of ground appropriateness index is put forward. Firstly, based on the actual environment conditions, the paper determines the factors affecting the road layout in permafrost areas by qualitative and quantitative analysis, including the annual slope, the average annual ground temperature of permafrost, the amount of ice in frozen soil, and the interference engineering. Secondly, based on the knowledge base theory and the use of Delphi method, the paper establishes the knowledge base, the rule base of the permafrost region and inference mechanism. The method of selecting the road in permafrost region is completed and realized by using the software platform. Thirdly, taking the Tuotuo River to Kaixin Mountain section of permafrost region as an example, the application of the method is studied by using an ArcGIS platform. Results show that the route plan determined by the method of selecting the road in permafrost region can avoid the high temperature and high ice content area, conform the terrain changes and evade the heat disturbance among the existing projects. A reasonable route plan can be achieved, and it can provide the basis for the next engineering construction.

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1. Introduction

Permafrost is a kind of soil which is not suitable for road construction due to its characteristics of low capacity and instability (Ruan et al., 2014; Wang et al., 2014). The percentage of permafrost to the total land area of China is about 22.3%, which ranks the third place in the world. This situation illustrates the severity of this problem in China. Tibet Plateau, the uppermost permafrost region in China, has a percentage of 70% of the entire permafrost area in China. In the process of highway route selection, it is difficult for designers to minimize the influence of frozen soil environment on highway construction. In this context, this paper intends to propose a new algorithm for alignments selection in permafrost areas, which contributes to the road construction project.

Scholars have focused on two major fields of route selection theory and route selection method, and have achieved remarkable results. In route selection theory, scholars have put forward the flexibility design (FHWA, 1997; Huang and Wang, 2016), context sensitive design (Collings, 2004; Neuman et al., 2002; Officials, 2006) and multi-objective equilibrium processing (Cheng et al., 2007; De Luca et al., 2012; Ohazulike et al., 2012) and other advanced theories. In the aspect of route selection method, Jong (1998) first proposed using genetic algorithm (GA) for route selection, and GIS and GA are applied to the selection and optimization of highway plan (Jong et al., 2000). On the basis of existing researches, Jha put forward the route selection method based on GIS and economy (Jha, 2000, 2001, 2003), and he realized the visual processing of different route schemes by using computer technology (Jha and Schonfeld, 2001). After then, Jong and Schonfeld (2003) and Yang et al. (2014) put forward route optimization from the angle of 3D road, eliminating the disadvantages of the route optimization focusing on the horizontal and vertical of road, and the optimization model can choose the optimal scheme in complex geological conditions; Jha further established a genetic algorithm model from three-dimensional angle to optimize route alignment. The model provided references for the study on route selection (Jha and Maji, 2007). Based on GIS and GA, Kang developed a selection optimization tool of intelligent route, to assist the designer to obtain the optimal route (Kang et al., 2012). With the support of ArcGIS, many researches are able to optimize the road alignment. De Luca et al. (2012) proposed an algorithm for the design of rail track by multi criteria. Similarly, Dell'Acqua (2015) and Dell'Acqua et al. (2012) had a multicriteria analysis of road construction based on the ArcGIS cluster tools. However, the reliability of analysis results depends on the reliability of the cluster analysis, which usually tends to be lower compares to other methods. Wang (2002) imported the horizontal and vertical section coordinate in GIS system, and completed the route selection through the construction of digital elevation model. Based on the existing corridor selection methods, Wang (2006) put forward the method to complete the selection and evaluation of corridor by remote sensing (RS) technology. Yang et al. (2009) proposed a line intelligent selection method by considering the project cost, ecological protection, and the combination of GIS and GA. Liu et al. (2009) built a GIS green railway alignment selection decision support system through the study of route selection database, rule base and knowledge base. Xu et al. (2013) constructed the evaluation system with the 5 indexes, such as vegetation cover and gradient, and analyzed the route corridor, which has the weakest impact on ecology on the Karst area by GIS. There are many road alignments generate methods. At present, the route selection in permafrost is mainly geological route selection, Russo and Dell'Acqua (2014) and Dell'Acqua (2015) analyzed road safety from the perspective of driver gender. Wei (2003), Zhao et al. (2001), and Chen and Wang (2003) were aimed at the actual situations in permafrost regions, based on the analysis of the bad geological phenomenon, put forward different geological route selection priority principles and methods; Zhang et al. (2016) put forward route selection principle to avoid the permafrost, and completed the selection of route plan in permafrost regions by using GIS; Wang et al. (2016a,b) put forward the route selection layered target method in permafrost, and established the model under each level according to the differences in pattern of manifestation of surface features under different scale in permafrost.

As for the road route selection principle, the design concept of safety, aesthetics and tolerance have been integrated into the alignment design abroad, but the special environment in permafrost has not been studied in detail. The route selection method has experienced the transition from single objective to multi-objectives and has gradually been developed toward intelligent route selection. However, there is little research on the method of route selection in permafrost, and the method of route selection is not perfect. Therefore, this paper established the method of line location in permafrost, based on the permafrost area of Qinghai–Tibet Plateau and the study object of highway route selection, by using the knowledge base theory and fuzzy mathematics theory.

2. Analysis on influencing factors of route selection in permafrost regions

Many factors affect the route selection, and it has some unique environmental attributes for the permafrost regions of the Qinghai–Tibet Plateau. Because of the characteristics of the high plains in the permafrost regions, the elevation difference is small, and the influence on route selection is small. The terrain in the permafrost is rugged and the slope of the ground is obviously changed which have great influence on route selection. The frozen soil is the main geological feature, and the mean annual temperature and ice content in frozen soil are the important index of the characteristics of frozen soil. These should be considered emphatically. The corridor of Qinghai–Tibet project is narrow, and the route layout is influenced by the space constraint and thermal disturbance of the existing engineering which also have great influence on route selection.

The ground slope has great significance for the highway survey, construction, maintenance, operation. The smaller the slope of the ground, the more conducive to road

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