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Auxiliary transportation mode in a fully-mechanized face in a nearly horizontal thin coal seam

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ABSTRACT

On fully-mechanized faces in nearly horizontal thin coal seams (NHTCS), the selection of the auxiliary transportation mode is difficult. Generally, auxiliary transportation mainly includes trackless or rail transportation. Combined with a familiar NHTCS fully-mechanized face, a multi-attribute decision-making model was set up for the decision. The index weight was objectively determined with the fuzzy number and entropy method. The priority order of auxiliary transportation modes was obtained from the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE). The results show that: the net flow of the mode can be expressed by the function of the surrounding rock deformation of the roadway, the dimension of equipment and the thickness of the coal seam; Based on the cost type index, there is a positive correlation between the net flow with the height and width of the trackless auxiliary transportation equipment, respectively. The trackless auxiliary transportation equipment selection principle should be "height first then width". Combined with the field application of the trackless auxiliary transportation in Liangshuijing coal mine, the proper method to achieve the safe and high-efficient exploitation of a NHTCS fully-mechanized face is trackless tyred vehicle auxiliary transportation.

1. Introduction

Thin coal seams are abundant in China. According to incomplete statistics on 95 national key coal production enterprises, there are 445 mines with the occurrence of thin coal seams in 85 group companies. The recoverable reserves of thin coal seams is about 6.5 billion tons, occupying 19% of the total recoverable reserves. With the gradual depletion of thick and mid-thick coal seams, the importance of mining thin coal seam gradually increases [1–3]. As the first choice for thin coal seam mining, NHTCS is widely located in mining areas such as Shendong, Datong, Huainan and Yanzhou. Compared with the development of fully-mechanized technology of NHTCS, research on the auxiliary transportation mode falls behind. As the key part in fully-mechanized technology of thin coal seams, the proper selection of the auxiliary transportation mode is crucial and has gradually become an important issue among scholars worldwide.

For example, Yan systematically analyzed the commonly-used auxiliary transportation mode in a modern mine [4]. From rail to trackless transportation, Zhang and Liang systematically reviewed the current situation in mine auxiliary transportation systems worldwide. At the same time, the trends in auxiliary transportation equipment development in mines were examined [5,6]. In addition, on the basis of a full investigation, the key technology for high efficiency auxiliary transportation in mines was proposed for the Yanzhou mining area, including the optimization of mine development layout and emphasizing research and development of key equipment [7]. What's more, the general procedure for the transformation of modern mine auxiliary transportation systems was explained [8]. In recent years, the "new coal mine" concept has been proposed with the development of trackless auxiliary transportation technology in China [9,10]. Meanwhile, feasibility analysis, type selection principle, design and application of trackless auxiliary transportation [11–14] have made great achievements. Many new methods were also applied in the auxiliary transportation selection such as virtual selection system based on Virtual Reality Modeling Language (VRML), the visual dynamic selection system, neural network design, analytic hierarchy process approach and other mathematical models [15–19].

However, relatively less research has been carried out on the auxiliary transportation of fully-mechanized face in a thin coal seam. Auxiliary transportation mode was decided on managers'

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experience mostly. Although trackless auxiliary transportation can relieve workers labor intensity, it increases the quantity of digging rock in a half-coal rock lane. Compared with trackless auxiliary transportation, rail transportation reduces the quantity of rock to be excavated, but it increases the workers' labor intensity and potential safety risk. In order to solve the decision problem of auxiliary transportation on a NHTCS fully-mechanized face, trackless auxiliary transportation and rail auxiliary transportation is demonstrated systematically in this paper, on the basis of literature [5]. The results can provide the technical indication for developing mining technology of thin coal seam and auxiliary transportation.

In fact, the auxiliary transportation mode decision can be summarized to a fuzzy multi-attribute decision-making problem. The key is to control the influence factors of the decision goal comprehensively. In this problem, factors can be divided into economic factors, technical factors and the man-machine environment. As a predictable quantitative index, the dominant key sub factor of the first one is the quantity of minimum digging rock of half-coal-rock lane which is restricted by the auxiliary transportation mode. Conveying efficiency, technical maturity, management difficulty and flexibility are included in the technical factors. The man-machine environment includes the degree of safety and labor intensity, both of which belong to the fuzzy index.

The comprehensive fuzzy ranking method, combined with the entropy method was first applied to the theory of auxiliary transportation mode decision. The principle of auxiliary transportation equipment selection was achieved. With the engineering background in Liangshuijing coal mine in Shaanxi, the auxiliary equipment of panel 43101 was successfully selected.

2. Fuzzy PROMETHEE principle

The decision-making problem concerning the auxiliary transportation mode mainly focuses on the preference order of trackless and rail auxiliary transportation. Compared with the other ordering methods, PROMETHEE is flexible and easy to operate and is a relatively ideal method for decision-makers. The key of PROMETHEE ordering lies in the quantification of a fuzzy index. To solve this problem, the fuzzy PROMETHEE method was created with fuzzy set theory applied, which provides a new way of solving the ordering problem [20,21].

2.1. Fuzzy set theory

$f(x)$ is the membership function of fuzzy number x, in which $x = (m, a, b)_{LR}$, that is to say $m - a < x < m + b$ and $f(x) \in [0, 1]$. $f(x)$ is the linear monotone increasing function and monotone decreasing function, within the scope of $(m - a, m)$ and $(m, m + b)$, respectively [22], as shown in Fig. 1.

2.2. Preference ordering

PROMETHEE was developed by Belgian Professor Brans in 1984 [23]. It is a multi-attribute objective decision-making method,

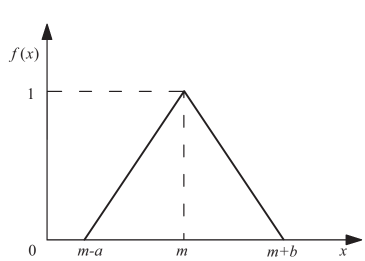

Fig. 1. Fuzzy number.

which takes advantage of a preference function, criterion value and criterion weight given by a decision-maker to determine the scheme with optimal order.

Supposing scheme $A = (a_1, a_2, \ldots, a_m)$, comprehensive ordering is operated under the condition of criteria set $c = (f_1, f_2, \ldots, f_n)$ and weight vector $W_k = (w_1, w_2, \ldots, w_n)$. As a result, the optimal order intensity $G_k(d_{ij})$ of a_i and a_j under the condition of criteria c is the preference function value of criterion value difference and can be expressed using the function as follows:

$$G_k(d_{ij}) = P_k(a_i, a_j) \in [0, 1] \tag{1}$$

The optimal order intensity of a_i goes from $G_k(d) = 0$ (no difference) to $G_k(d) = 1$ (strict priority) relative to that of a_j. The multi-attribute preference optimal sequence index can be expressed as follows:

$$H(a_i, a_j) = \sum_{k=1}^{n} W_k P_k(a_i, a_j) \tag{2}$$

In PROMETHEE I, the positive direction and the negative direction of preference priority rating of a_i can be respectively shown as follows:

$$\Phi^+(a_i) = \sum_{j=1}^{m} H(a_i, a_j) \tag{3}$$

$$\Phi^-(a_i) = \sum_{j=1}^{m} H(a_j, a_i) \tag{4}$$

where $\Phi^+(a_i)$ is the degree that a_i is superior to a_j, $\Phi^-(a_i)$ is the degree that a_i is inferior to a_j. The scheme is superior with the higher positive direction or the lower negative direction. Complete sorting of the scheme set can be obtained according to PROMETHEE II. The optimal relationship of different schemes depends on comprehensive optimal level value, which can be expressed as follows:

$$\Phi(a_i) = \Phi^+(a_i) - \Phi^-(a_i) \tag{5}$$

2.3. Preference function

Brans and other professors [19–21] have offered many kinds of preference functions. In this research, a linear preference function with no difference interval was adopted. The accuracy of the results can meet the needs of solving this problem. Supposing d_{ir} is the virtues or defect degree of different schemes with the same parameter properties. Linear preference function can be expressed as follows:

$$P_k(a_i, a_j) = \begin{cases} 0 & d_{ij} \leqslant q \\ \frac{d_{ij} - q}{p - q} & q < d_{ij} \leqslant p \\ 1 & d_{ij} > p \end{cases} \tag{6}$$

where $d_{ij} = t_{ir} - t_{jr}$ ($i, j = 1, 2, \ldots, m$; $r = 1, 2, \ldots, n$), and t_{ij} is the virtues or defect degree function of attribute value. q and p are the parameters of preference function, respectively showing the lower limit, being 0, and upper limit, being 1, of the virtues or defect degree [21–24].

2.4. Weight vector

In the auxiliary transportation mode decision-making problem, criteria has a different influence degree. Therefore, it is significant to endow weights for kinds of criteria. Quantitative and qualitative evaluation index should be considered separately. The entropy method cooperated with fuzzy number is introduced to the weight analysis, which can reduce the effect of decision-makers' subjective wishes on the final results in maximum [25–27].