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# Analysis of Factors Affecting Plateau Mine Man-machine Efficiency Based on AHP

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**Abstract.** In this paper, the index system of influencing factors of human-machine efficacy in plateau mining enterprises was established, according to the special geographical environment and climatic conditions in Plateau area. First, the factors affecting the human-machine efficiency of plateau mines are analyzed from three aspects: personnel, equipment and plateau environment. Then, based on the analytic hierarchy process, the index system of influencing factors is established, and the weight calculation of each index is realized by constructing the contrast matrix. Through the analysis of the weight, it shows that in the three aspects of personnel, equipment and environment, the effect of personnel on human-machine efficacy is more obvious.

## 1. Introduction

The labor efficiency of man and machine are affected by the environmental factors in the process of operation. The environment conditions in high altitude areas are low oxygen, low air pressure, and extremely cold. The labor efficiency of man and machine decrease obviously. Moreover, the health of human is threatened by a bad environment. Therefore, manufacturers focus on factors affecting the man-machine efficiency in the industrial production process.

The plateau area with an altitude over 1000m is more than one-third of China's territorial area [1]. Hypoxia and low-temperature environment have a great influence on the physiological and psychological functions of the human body [2]. It is found that the initial impact of the hypoxic environment on cognitive function was mainly due to the decline of visual and auditory perception, decreased attention and attention transferability, short-term memory, complex thinking judgment and decreased thinking flexibility [3]. Michael Wiedman, et al. [4] tested the Himalayan explorers on the spot. By comparing the results of the three stages of climbing before, during and after climbing, the relationship between high altitude retinopathy and other high altitude related diseases was obtained, and the classification system of high altitude retinopathy was established. Anuj Chawla, et al. [5] defined the cut-off value and reliability of diagnosis of pulmonary edema at high altitude by analyzing clinical data and ROC curve analysis. Siqués P, et al. [6] observed the blood pressure of a group of male soldiers stationed at an altitude of 3550 m for 12 months. The blood pressure showed an increase in systolic and diastolic pressures, of which 40% exceeded the normal range



The plateau environment also has an impact on the machine. Compared with the plain area, the plateau area has lower air pressure, lower ambient temperature and lower medium density entering the cylinder. The diesel engine will suffer from frequent faults such as lower torque and power output, worsening combustion and difficult start-up, which will have adverse effects on the power, emission, economy, reliability, and durability of the diesel engine [7-10]. When other conditions remain unchanged, the effective power of loader is proportional to atmospheric pressure. That is, with the decrease of atmospheric pressure, the effective power decreases gradually. [11]. By testing the braking thermal efficiency of the diesel engine at four altitudes of 0 m, 1600 m, 3300 m, and 4500 m, scholars found that the braking thermal efficiency decreases gradually with the increase of altitude, especially at low speed and low load. [12] Peter L. Perez, et al. [13] studied the performance of a diesel engine at high altitude through simulation test. The test shows that oxygen-enriched air can effectively prevent the deterioration of specific fuel consumption of brake when simulated altitude increases. Peak combustion temperature is greatly affected by simulated altitude and oxygen volume fraction, and the influence of altitude is more obvious.

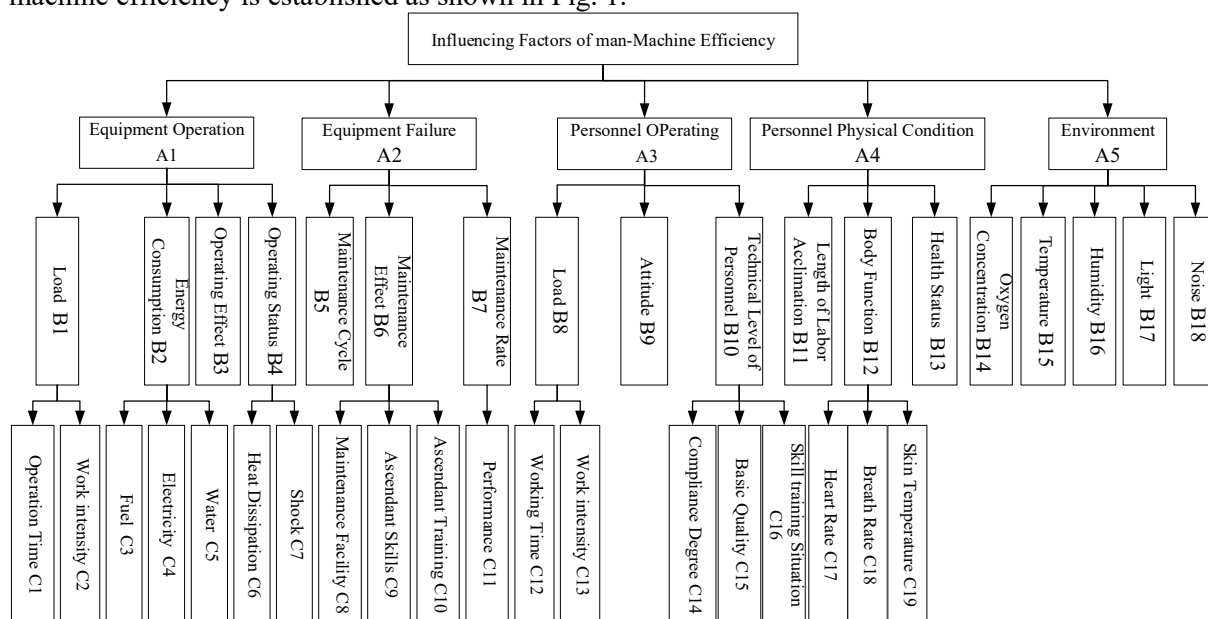
In summary, the plateau environment has a significant impact on man and equipment efficiency. So it is necessary for enterprises to analyze the factors affecting man-machine efficiency to find the solution to cope with the problem. This paper summarizes the influencing factors to establish an index system based on Analytic Hierarchy Process (AHP). Manufacturers could target the most crucial factor and take the appropriate method to reduce the negative effect to improve profit.

## 2. Establishment of index System for Man-machine Efficiency

### 2.1. Selection of Indicators Affecting Human-Machine Efficiency

AHP is a multi-criteria decision-making method that combines qualitative and quantitative analysis, which can quantify the subjective judgment of human and scientifically express them. AHP is suitable to analyze influencing factors of man-machine efficiency. Because it is very useful for determining influencing factors and establishing a clear hierarchical relationship among influencing factors. Some indicators are selected following some specific principles (i.e. representation, hierarchy, comparability [14] and comprehensiveness).

Based on the characteristics of Plateau environment, the factors are classified into five main categories from three aspects of human, machine, and environment. The index system affecting man-machine efficiency is established as shown in Fig. 1.



**Figure 1.** The index system affecting man-machine efficiency

## 2.2. Weight Analysis of Factors Affecting Human-Machine Efficiency

**2.2.1. Establishing the hierarchical model and constructing judgment matrix.** The hierarchical index system determines the subordinate relationship of factors between the upper and lower levels. The uniform matrix method is used to decide the weight of each factor. The judgment matrix is constructed in the form of 1-9 to express the relative importance of the indicators in each level. Experts and scholars who have been engaged in plateau work for a long time are surveyed by questionnaire. The relative importance of indicators in each level is determined based on the scores given by the experts.

Taking five indicators of the first level as an example, the judgment matrix is established according to the scaling method.

$$A = \begin{bmatrix} 1 & 4 & \frac{1}{3} & \frac{1}{4} & 4 \\ \frac{1}{4} & 1 & \frac{1}{3} & \frac{1}{5} & 2 \\ 3 & 3 & 1 & \frac{1}{3} & 3 \\ 4 & 5 & 3 & 1 & 5 \\ \frac{1}{4} & \frac{1}{2} & \frac{1}{3} & \frac{1}{5} & 1 \end{bmatrix} \quad (1)$$

**2.2.2. Calculate the weight of each influencing factor.** Each column element of judgment matrix in the first level is normalized as follows:

$$A_0 = \begin{bmatrix} 0.12 & 0.30 & 0.07 & 0.12 & 0.27 \\ 0.03 & 0.07 & 0.07 & 0.10 & 0.13 \\ 0.35 & 0.22 & 0.20 & 0.17 & 0.20 \\ 0.47 & 0.37 & 0.60 & 0.50 & 0.33 \\ 0.03 & 0.04 & 0.07 & 0.10 & 0.07 \end{bmatrix} \quad (2)$$

The normalized matrix is added by rows. The following vectors can be obtained.

$$w_A = [0.87 \quad 0.40 \quad 1.14 \quad 2.28 \quad 0.30]^T \quad (3)$$

Then, the vector is normalized and the following results are obtained.

$$W = [0.17 \quad 0.08 \quad 0.23 \quad 0.46 \quad 0.06]^T \quad (4)$$

**2.2.3. Consistency Test** In order to ensure that the weights obtained are effective and reasonable, the weights obtained need to be checked to verify the consistency of the matrix. Firstly, the maximum eigenvalue of a matrix is calculated.

Then the consistency index of the judgment matrix is calculated.

$$CI = \frac{\lambda_{\max} - n}{(n-1) \times RI} = 0.09 \quad (5)$$

RI is a constant which indicates the average random consistency indicator. The values can be referred to in Table 1. Therefore, the weights of the five factors in the criterion level are 0.17, 0.08, 0.23, 0.46 and 0.06, respectively.

**Table 1.** Index RI of Mean Random Consistency of Matrix of the Same Order

| Matrix order | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|--------------|------|------|------|------|------|------|------|------|------|------|
| value of RI  | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.52 |

In the same way, we can get the weights of each factor at all levels as shown in Table 2. From the consistency test results of the weights of indicators at all levels in the table, it is found that the weights of indicators at all levels are available.

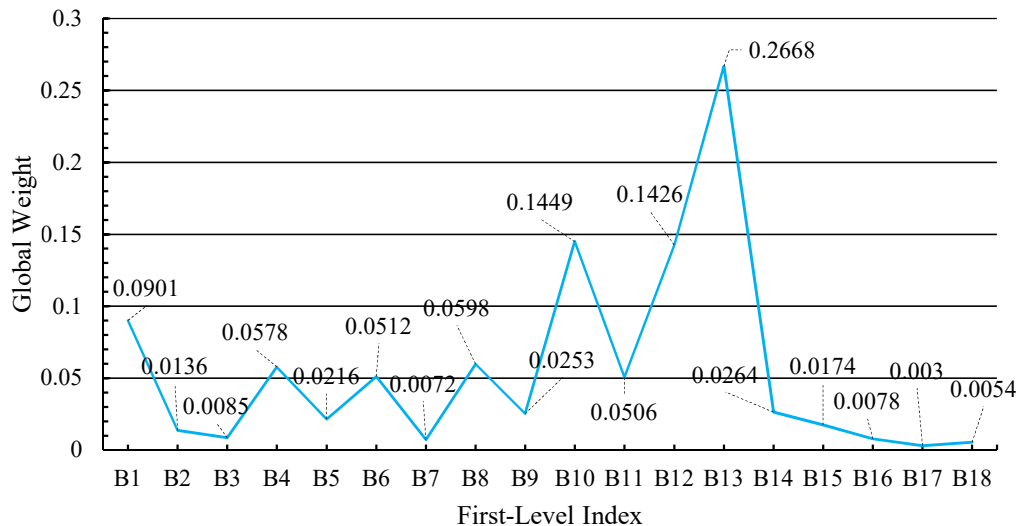
**Table 2.** Weight Calculation and Consistency validation of index system

| Criteria Level Indicators | Weight | First Level Index | Weight | Second level index | Weight |
|---------------------------|--------|-------------------|--------|--------------------|--------|
| A <sub>1</sub>            | 0.17   | B <sub>1</sub>    | 0.53   | C <sub>1</sub>     | 0.60   |
|                           |        |                   |        | C <sub>2</sub>     | 0.40   |
|                           |        | B <sub>2</sub>    | 0.08   | C <sub>3</sub>     | 0.54   |
|                           |        |                   |        | C <sub>4</sub>     | 0.30   |
|                           |        |                   |        | C <sub>5</sub>     | 0.16   |
|                           |        | B <sub>3</sub>    | 0.05   |                    |        |
|                           |        | B <sub>4</sub>    | 0.34   | C <sub>6</sub>     | 0.25   |
| A <sub>2</sub>            | 0.08   |                   |        | C <sub>7</sub>     | 0.75   |
|                           |        | B <sub>5</sub>    | 0.27   |                    |        |
|                           |        | B <sub>6</sub>    | 0.64   | C <sub>8</sub>     | 0.56   |
|                           |        |                   |        | C <sub>9</sub>     | 0.12   |
| A <sub>3</sub>            | 0.23   |                   |        | C <sub>10</sub>    | 0.32   |
|                           |        | B <sub>7</sub>    | 0.09   | C <sub>11</sub>    | 1.00   |
|                           |        | B <sub>8</sub>    | 0.26   | C <sub>12</sub>    | 0.55   |
|                           |        |                   |        | C <sub>13</sub>    | 0.45   |
|                           |        | B <sub>9</sub>    | 0.11   |                    |        |
|                           |        |                   |        |                    |        |
|                           |        | B <sub>10</sub>   | 0.63   | C <sub>14</sub>    | 0.25   |
| A <sub>4</sub>            | 0.46   |                   |        | C <sub>15</sub>    | 0.10   |
|                           |        | B <sub>11</sub>   | 0.11   | C <sub>16</sub>    | 0.65   |
|                           |        | B <sub>12</sub>   | 0.31   |                    |        |
|                           |        |                   |        | C <sub>17</sub>    | 0.62   |
|                           |        |                   |        | C <sub>18</sub>    | 0.28   |
| A <sub>5</sub>            | 0.06   |                   |        | C <sub>19</sub>    | 0.10   |
|                           |        | B <sub>13</sub>   | 0.58   |                    |        |
|                           |        | B <sub>14</sub>   | 0.44   |                    |        |
|                           |        | B <sub>15</sub>   | 0.29   |                    |        |
|                           |        | B <sub>16</sub>   | 0.13   |                    |        |
|                           |        | B <sub>17</sub>   | 0.05   |                    |        |
|                           |        | B <sub>18</sub>   | 0.09   |                    |        |

### 3. Result analysis

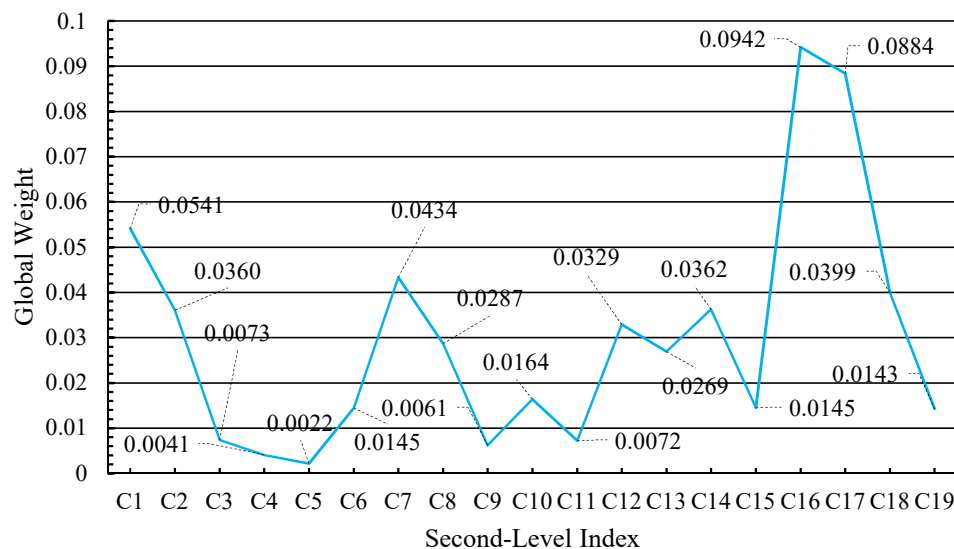
Table 2 shows the weight of indicators in all levels. At the first level, the weight of the human body status and the human operation factors are larger than the other three factors, which are 0.46 and 0.23 respectively. The result indicates that the two factors have a more significant impact on the man-machine efficacy. As the machine is operated by man. The physical condition and working efficiency of man will inevitably determine the overall working efficiency of the man-machine system. The poor physical condition or working efficiency of man will probably lead to problems in the operation of the equipment. The negative effect of human-machine cooperation will make the equipment unable to operate in a normal state and affect work efficiency. Therefore, enterprises should strengthen the monitoring of workers' physical condition to ensure the best working status of workers.

According to the weight results in Table 3, the global weight relationship diagrams of the first-level index and the second-level index are obtained, as shown in Fig 2 and Fig 3.



**Figure 2** The relationship between the global weight of the first-level indicators

Fig 2 shows that the weights of B10, B12, and B13 are obviously larger than those of other first-level indicators, which means that the technical level, body function and health status of man have a great impact on the effectiveness of the human-machine system. With the popularization of mechanization, the technical requirements for workers are gradually improved. The equipment operation level is important to improve the production efficiency and reduce the labor intensity of the workers. Health status and physical function indicators reflect the workers' physical status and degree of fatigue. Healthy physical status and good working status are prerequisites for working quality, quantity, and efficiency.



**Figure 3.** The relationship between the global weight of the second-level indicators

Fig. 3 demonstrates that the indicators C1, C16 and C17 are obviously higher than the others, which means that the equipment working time, the skill training of operators and the heart rate of man have a great influence on the effectiveness of the human-machine system.

The equipment status will in a “fatigue state” when the working time is too long, which results in lower equipment efficiency. Skills training is a regular activity for manufacturers, which enable employees to develop working skills. Therefore, systematic and good skill training is a necessary method to improve the working efficiency of workers. Heart rate is one of the four vital signs of the human body. The stability of heart rate directly reflects the health status of workers [15].

#### 4. Conclusion

This paper analyses the influencing factors of man-machine efficiency at high altitude from three aspects of the man, machine and environment based on AHP. Through the analysis of various influencing factors, an index system is established, which includes three levels. It is concluded that man is more significant than the other two aspects. The corresponding suggestions are put forward for the two aspects of physical condition and working skills of man.

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