Analysis of influencing factors on the man-machine system efficiency in high-altitude mines

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Abstract. High-altitude areas contain a large amount of high-quality mineral resources in China, and the development of mineral resources in these areas has made significant contributions to social and economic development. However, due to the harsh climate conditions in such areas, it has become a key constraint on the efficient operation of high-altitude mines. In recent years, intelligent mining has become a focus of attention in the mining industry. With the continuous advancement of mining intelligence, more and more large-scale intelligent equipment is being applied to high-altitude mining production, greatly improving mining production efficiency. As the main operating object of underground production, production equipment and operators cooperate and influence each other, forming a complex man-machine system. The overall work efficiency is not only affected unilaterally by personnel, equipment, and environment, but also by the coupling effect between the three. Therefore, in order to clarify the impact of man-machine system efficiency in the underground production process, the key factors that affect man-machine operation efficiency are sorted out from the perspectives of man-machine-environment, and the impact of each factor on man-machine operation efficiency is discussed. This provides guidance for subsequent research on man-machine system efficiency and further improves the efficiency of underground production operations.

1. Introduction

With the continuous progress of China' mechanical equipment level, large-scale equipment has been applied to various production links of resource development, which has rapidly improved the mechanization level and production capacity of the mining industry, which is the pillar of national economic development. When mining operators operate mechanical equipment for production, various factors such as the complexity of the equipment, the level of personnel operation, and environmental impact affect the efficiency of the man-machine system composed of personnel and equipment, which cannot be fully utilized and becomes a bottleneck restricting the further improvement of mining production efficiency. In addition, although China has abundant mineral resources and continuously improved resource development capabilities, it effectively guarantees the rapid development of the national economy. However, many high-quality mineral resources are distributed in high altitude areas such as Xizang, Xinjiang and Yunnan in China. These areas have unique climatic conditions such as high altitude, high cold, low pressure and hypoxia, which seriously restrict the efficiency of resource development. Therefore, many experts and scholars have conducted research on the factors that affect mining production efficiency and achieved certain results.

Tsutsumi et al. studied the effects of different relative humidities on human thermal comfort and work efficiency. The results indicate that in environments with low relative humidity, most people are more excited and have less subjective thermal sensation differences. Under different humidity conditions, the work efficiency of personnel is basically the same, but when the relative humidity exceeds 70%, personnel are more likely to feel tired [1]. Ismaila analyzed the effects of different lighting conditions and temperature and humidity on the work efficiency of workers through laboratory experiments. And the Taguchi method was used to analyze the influencing factors, and it was found that environmental temperature is the main factor affecting work efficiency, while relative humidity and light have a relatively small impact on efficiency [2]. Trong et al. confirmed through experiments that drinking low-temperature menthol beverages in high temperature and high humidity environments can improve the exercise efficiency of participants [3]. Lan Li conducted experiments to study the relationship between personnel work efficiency and environmental factors. She analyzed the effects of different exposure times, sound environment, and light environment on personnel work efficiency, and established a mechanism model for personnel work efficiency under the influence of multiple influencing factors [4]. Yao Qian et al. studied the equipment efficiency of furniture edge banding machines based on

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the basic principles and calculation methods of equipment comprehensive efficiency, and obtained the main influencing factors of equipment production efficiency, providing guidance for improving the comprehensive efficiency of furniture edge banding machines [5]. Jin Cong et al. conducted research on the management of operational efficiency of medical equipment, and analyzed the evaluation effect of different input-output indicators on the operational efficiency of similar equipment through data envelopment analysis. The research results showed that method can effectively analyze the operational efficiency of equipment and is suitable for equipment operation management [6]. Wu Gaohua et al. conducted research on the comprehensive efficiency evaluation of urban rail transit equipment. The authors analyzed the factors affecting the comprehensive efficiency of rail transit equipment from the perspectives of equipment input resources and output capabilities, and proposed a comprehensive efficiency evaluation method for urban rail transit, which provides a reference for the evaluation of rail transit equipment [7]. Lv Zhijia analyzed the operational efficiency of electrical equipment, elaborated on the main influencing factors of electrical equipment operational efficiency, and proposed improvement measures for low equipment operational efficiency, as well as methods for optimizing electrical equipment management. Based on the analysis of the structure and principle of the pumping unit [8]. Xia Muhu analyzed the factors that affect the operating efficiency of the equipment and proposed effective measures to improve the operating efficiency of the equipment [9]. Tian Yanchun analyzed the current characteristics and production status of mineral processing in mines, as well as the requirements for equipment. Based on this, measures were proposed to improve the operational efficiency of mineral processing equipment [10]. Bi Kegang et al. conducted experiments to compare and analyze the external characteristics, load characteristics, effective thermal efficiency, and mechanical efficiency of naturally aspirated diesel engines fueled with mixed fuels at different altitudes, providing guidance for the efficient use of diesel engines in high-altitude areas [11]. Li Qi et al. analyzed the impact of high-altitude environment on the mechanical efficiency of construction equipment, and obtained the degree and regularity of the influence of various environmental factors (atmospheric pressure, temperature, oxygen concentration) on the mechanical efficiency of construction equipment in high-altitude areas [12].

Through summarizing and analyzing the literature, it is found that existing research focuses on analyzing the impact of individual aspects such as personnel, equipment, and environment on operational efficiency, with less emphasis on studying personnel and equipment as a holistic system. However, in the process of underground mining operations, personnel operate equipment for production, which is a process of mutual cooperation between personnel and equipment. Under the comprehensive action of human machine environment, the efficiency of ore mining is jointly determined. Therefore, comprehensively sorting out the factors that affect the production efficiency of underground mining in high-altitude mines, clarifying the impact of various factors on the man-machine systems efficiency, has become a necessary step and prerequisite for subsequent research on man-machine system efficiency and improving system operation efficiency.

2. Overview of man-machine system

A system is a whole composed of multiple parts that interact and connect with each other to achieve specific goals. With the improvement of mechanization levels in various industries, when analyzing the production process, it is necessary to treat equipment and personnel as a system, fully considering the working status of personnel and equipment, in order to improve overall work efficiency and safety. Such a system is called a man-machine system. That essentially combines personnel and machines to form an intelligent man-machine interaction whole, and completes specific production tasks safely and efficiently through mutual cooperation and complementary advantages [13]. Under normal circumstances, man-machine systems provide the effect of transforming work objects. The main task of this system is to effectively convert external inputs (such as information, energy, materials, etc.) under certain time and space conditions. The specific function is shown in Fig. 1.

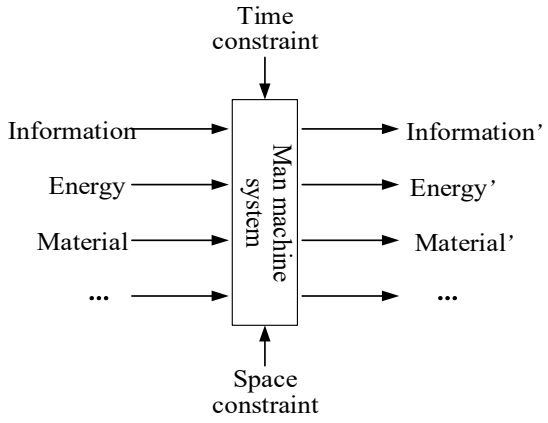

Figure 1. Schematic diagram of man-machine system functions.

The man-machine system is a system composed of two major elements: personnel and machine equipment, and the properties possessed by these two elements are completely different. The characteristics that humans possess compared to machines include having thoughts, being able to summarize and generalize based on practical experience, and forming theories by summarizing and generalizing conclusions. Man can use experience to explore and innovate, and enhance their own work abilities, and have a high degree of flexibility and can change their work methods in real time according to changes in the situation. They have the ability to adapt to the environment and can process and receive environmental information. People also can selectively store a large amount of useful information and use their memory information in real-time to analyze and judge

based on their own situation; Human beings possess sociality and subjective initiative. The machine has high precision and good stability, and can work continuously and efficiently. It can efficiently and accurately complete multiple operations simultaneously; The impact of harsh working environments on machine operation is much less than that on humans; The machine moves quickly, with short time required for transmission, processing, and reaction, and can complete reactions that humans cannot achieve. In the design of man-machine systems, by comparing the characteristics of humans and machines, identifying their respective advantages, and following the principle of complementary advantages and overall optimization, determining which tasks are completed by humans and which tasks are completed by equipment, in order to achieve the maximization of man-machine system efficiency [14].

From a certain perspective, the workflow of man-machine systems is roughly presented as follows: personnel manipulate machinery and equipment during the production process, and the machinery and equipment feedback information to the human sensory organs through certain channels and means, such as glasses, nose, hands, etc. These information are transmitted to the brain through the sensory organs. After receiving the feedback information, the brain processes the information and commands its own motor nervous system to perform a specific action to manipulate the equipment, thereby enabling the equipment to complete a certain action. Due to a change in the device's status, new external information is transmitted back to humans through the device, thus entering the next cycle. From this, it can be seen that the information transmitted from the machine equipment returns to the machine equipment through the human link, thus forming a feedback loop [15]. As shown in Fig. 2

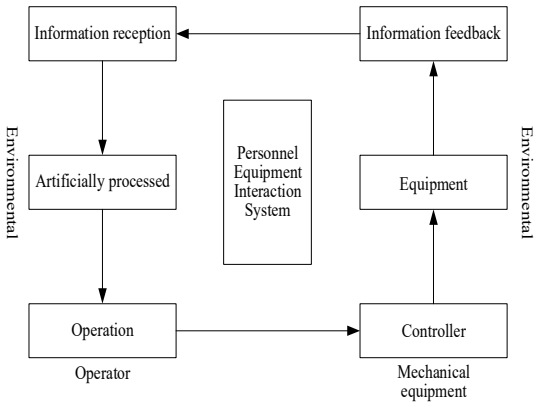

Figure 2. Personnel machine interaction system diagram.

3. Analysis of Factors Influencing the man-machine systems efficiency

As a complex system, its effectiveness is influenced by many factors, not only internal factors, but also various external environmental factors due to the special climate conditions in high-altitude areas. Therefore, this article analyzes the influencing factors from three aspects: personnel, machinery and equipment, and environment, as shown in Fig. 3.

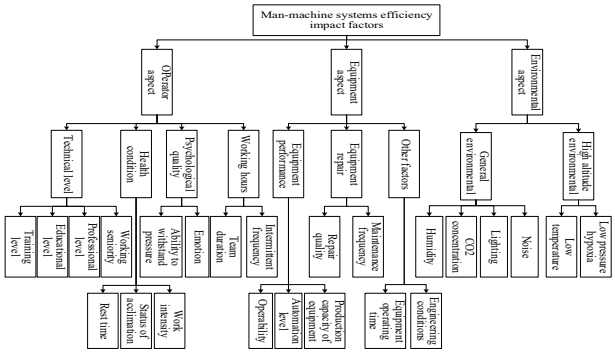

Figure 3. Factors affecting the man-machine system efficiency in high-altitude mines.

3.1 Operator

As the main operators of man-machine systems, personnel are subject to numerous influencing factors, which can be classified into four aspects based on different types of influencing factors: technical level, health status, psychological quality, and working hours, each of which contains several sub factors.

3.1.1 Technical level.

Mining production is a production process involving multiple personnel, trades, and operational procedures. Therefore, even when performing the same job in the same occupation, the level of technical proficiency displayed varies greatly. Technical proficiency refers to the level of proficiency and understanding of a worker's specific activities related to the process, methods, procedures, or skills involved in a job. Involving professional knowledge and analytical understanding skills in specialized fields, as well as proficient application of relevant tools and regulatory policies. The level of technical proficiency directly affects production efficiency. A high level of technical proficiency provides advantages such as smooth work, high efficiency, reduced accidents, and improved safety. The factors that affect technical proficiency include training level, educational level, professional level, and years of work experience.

(1) Training level

The training system is crucial for an enterprise, and its completeness directly affects the technical level of workers, especially for those engaged in special operations. Pre-job training is even more important when working in special work environments. With the continuous development of technology and the increasing level of mechanization, it is objectively necessary for staff to receive regular training, learn how to operate new equipment, improve their technical level, and enhance their awareness of safety precautions. Enterprises that use complex large-scale equipment for operations in the production process should establish a reasonable pre-job and regular training system. A good training system can enable operators to receive systematic learning, comprehensively understand the process and key skills

related to the operation, and understand the performance and operation methods of the equipment. Through systematic training, the goal of effectively improving the technical level of workers in a short period of time can be achieved, especially for new employees. Underground rock drilling, blasting and other operations have certain risks and cannot be familiarized with operations through on-site practice. Therefore, training to quickly familiarize them with operating norms, clarify work processes, and master emergency methods is an effective way. In addition, before starting work after the training, a technical assessment of the training effect must be conducted. Only personnel who pass the assessment can start working normally, so as to ensure the overall technical level of the on-the-job personnel. According to measurement data, through training, human reaction time can generally be shortened by 10%, and manipulation speed can also be significantly improved. Therefore, only when the training system is implemented in place can the technical level of the operators be maximally improved, their work efficiency be enhanced, and the occurrence of safety accidents be minimized to the greatest extent possible.

(2) Educational level

The level of education not only represents the degree of education received and one's own quality, but also implies the ability to accept new things and innovate. For assignments with complex workflows, education level is very important. Employees with a high level of education are generally able to clarify work tasks more quickly, master work skills quickly, and have strong abilities and multiple ways to solve unexpected problems. The level of education indicates thinking ability and knowledge structure, which is a manifestation of cognitive ability. Faced with the same work problem, employees with higher cultural levels and those with lower cultural levels have more flexible thinking, more comprehensive considerations, and a more global perspective compared to the former. Moreover, employees have a high level of education and creativity, which allows them to combine professional knowledge with their work and develop methods, skills, equipment, etc. to assist in completing tasks, thereby improving work efficiency.

(3) Professional level

Engaging in work related to profession is a very advantageous way to fully utilize professional knowledge, which is even more evident for mining enterprises with numerous specialties. Solid professional knowledge is required to carry out development, preliminary mining, cutting, and stoping, as well as crushing, grinding, and flotation. Non professionals need to receive training to familiarize themselves with professional knowledge before starting work, while related professionals do not need to spend too much time supplementing professional knowledge. As long as they are familiar with the work environment and have a clear understanding of the work process, they can start working. Compared to non professionals, the time from entry to work is greatly reduced, and the safety during the work process will also be greatly reduced.

(4) Working seniority

Working seniority represent work experience, which is a highly valued indicator for practical enterprises such as mines. The work process is a process of accumulating practical experience, and the longer of service, the richer the work experience. Many key parameters and techniques in on-site work are not based on theory, but rather rely on experience to determine them. These experiences are accumulated over many years of working in the field and have been tested through practice, and are built on a certain number years of work experience. As a high-risk industry, mining production is inevitably prone to some unexpected accidents due to various reasons. For experienced employees, rich practical experience can ensure the success rate of handling unexpected accidents.

3.1.2 Health condition.

Physical health is a necessary prerequisite for personnel to engage in work, and a good physical condition is the foundation for ensuring work efficiency. For the harsh working environment underground in high-altitude mines, even healthy personnel who are exposed to this environment for a long time may experience discomfort, let alone those with poor physical condition who may deteriorate their physical condition, greatly reducing work efficiency and potentially leading to underground accidents. The physical condition of workers not only affects their perception of external factors, but also affects the reliability of their behavior. Therefore, when the physical condition of the workers is poor, it is easy to lead to unsafe behavior. The influencing factors of physical health status mainly include rest time, status of acclimation, work intensity, and other aspects.

(1) Rest time

The reasonable arrangement of working and rest directly affects the labor efficiency and physical health status of workers. Due to various reasons such as humid and hot underground environment, poor air quality, and poor air circulation, workers may experience discomfort when exposed to this environment for a long time. Therefore, it is necessary to set reasonable working time. The geographical location and climate conditions of high-altitude mines are different from those of plain areas, and the work and rest schedule cannot be simply applied to the work and rest schedule of plain mines. It is necessary to fully consider the limitations of the local special environment on the human body. Most underground operations involve physical labor, and personnel are prone to fatigue, especially in high-altitude areas where the speed of fatigue will accelerate. At this time, it is necessary to rest in a timely manner and replenish physical strength. If you don't get timely rest, it will not only affect work efficiency, but also threaten the physical health of workers, and even cause safety accidents due to operational errors caused by excessive fatigue.

(2) Status of acclimation

Acclimation is a physiological phenomenon that refers to the body's adaptation to certain special environmental conditions. The internal structure and function of the body undergo certain changes in response to the environment. When personnel first arrive at high-altitude places with

special climatic conditions, they may feel uncomfortable and may experience altitude sickness. Over time, the discomfort gradually decreases until it subsides. Personnel engaged in underground work in high-altitude areas also need to undergo labor training. Only by adapting to working in this environment can work efficiency be effectively improved and their physical condition be maintained at a high level.

(3) Work intensity

Most of the workers engaged in mining work do physical labor, with varying degrees of labor intensity. Some operations have high labor intensity, such as in small mines with low mechanization levels, where air leg rock drills are still used for underground rock drilling operations, resulting in increased work intensity and leading to rapid fatigue and decreased work efficiency. Long term high-intensity operations may cause physical harm to workers. Therefore, it is necessary to strictly control the labor time of high-intensity operations while also improving the mechanization of high-intensity operation processes.

3.1.3 Psychological quality.

Psychological quality is an integral part of the overall quality of personnel. Good psychological quality is beneficial for overcoming adverse environmental conditions underground, handling unexpected events during the work process, and ensuring the efficiency and safety of work. Good psychological qualities mainly include the ability to withstand pressure and emotions.

(1) Ability to withstand pressure

The underground environment of high-altitude mines is dark, humid, low-pressure, and oxygen-deficient, which can easily cause significant psychological pressure on the operating personnel, and is itself a test for their mental health. In addition, tasks such as rock drilling and shoveling, which involve engaging in high-intensity work in harsh environments for extended periods, pose even greater challenges to the psychological well-being of personnel. Faced with these conditions, good stress resistance helps maintain the physical and mental health of the staff, enabling them to work normally without or with reduced interference from external factors.

(2) Emotion

Emotion is an important component of psychological quality, which can directly affect a worker's work efficiency. Fine emotions can enhance work motivation, thereby improving work efficiency. The harsh underground environment inevitably causes negative emotions such as anxiety and impatience among workers, which has a negative impact on them. It is easy to mislead their judgment, reduce work efficiency, and extreme emotions may even trigger safety accidents.

3.1.4 Working hours.

There is a positive correlation between a worker's workload and working hours, with longer working hours resulting in more completed work. However, work efficiency is different, it is only proportional to the duration of work within a certain range. As the duration increases, personnel become fatigued, leading to a gradual decrease in work efficiency. Therefore, reasonable working hours are beneficial for safe and efficient production in mines.

(1) Team duration

The working hours in underground mines are generally divided into teams. Therefore, the longer the team duration, the more workload it can complete. In plain areas, most work in three shifts, with each shift lasting 8 hours. However, due to the differences in climate conditions between high-altitude and plain areas, high-altitude mines cannot simply adopt the working system of the plain. It is necessary to develop reasonable team hours based on the special environmental conditions and personnel tolerance, which is crucial for improving personnel work efficiency and ensuring the safety of underground employees.

(2) Intermittent frequency

Intermittent frequency refers to the number of times a person takes a break. Due to the fact that most underground operations involve physical labor and personnel are exposed to high-altitude environments, they are prone to fatigue. Therefore, after working for a period of time, appropriate rest will be taken to replenish energy. So the frequency of rest has a very significant impact on work efficiency. If the frequency of rest is too high, it indicates that personnel often take breaks during working hours, resulting in less workload for a team and a decrease in work efficiency. If the frequency is too low, it indicates that the workers rarely rest, which can easily cause them to work in a state of excessive fatigue. This not only significantly reduces work efficiency, but also poses a threat to the health and safety of the workers.

3.2 Mechanical equipment

Mechanized equipment, as an essential tool for mining enterprises, not only effectively reduces the physical labor intensity of underground workers, but also can complete some tasks that cannot be completed solely by personnel, greatly improving work efficiency. Therefore, production enterprises actively carry out mechanized production. The equipment in underground mines mostly engages in labor-intensive operations such as rock drilling and transportation. At the same time, the environment in which the equipment is located is also relatively harsh, which can have a certain adverse effect on the equipment and thus affect its operational efficiency, mainly reflected in equipment performance, equipment maintenance, and other factors.

3.2.1 Equipment performance.

(1) Operability

In order to achieve more functions, the operation of many equipment is more complex to reach the requirement of refinement. The operability of equipment is an important factor affecting work efficiency. The complexity of equipment manufacturing and the cumbersome operation steps required to complete a task can significantly reduce the speed of operators and lead to a decrease in work

efficiency. At the same time, complex operational steps can easily lead to omissions and may pose security risks. Therefore, simplifying the operation steps of the equipment as much as possible and improving the operability of the equipment are beneficial for improving the operational efficiency of the equipment.

(2) Automation level

With the development of technology, the automation level of large-scale equipment used in mining production is becoming higher and higher, such as intelligent rock drilling rigs. After the relevant parameters are set, the rig can automatically search for holes and complete self-service rock drilling operations, greatly reducing personnel operation error rates and improving work efficiency. The efficiency of equipment is directly proportional to the level of automation. The higher the level of automation of the equipment, the more flexible the operation, and the better the performance. The less work that needs to be completed by personnel, on the one hand, it saves manpower, and on the other hand, the higher the work efficiency.

(3) Production capacity of equipment

One important limiting factor for mining output is the rated production capacity of equipment. Currently, many equipment pursue large-scale production in order to maximize the rated production capacity of a single device. For example, in underground ore transportation, with a fixed blasting volume, the larger the capacity of the scraper and electric locomotive, the lower the frequency of transportation operations, thereby reducing transportation frequency, shortening transportation operation time, and improving work efficiency.

3.2.2 Equipment repair.

Equipment has its own service life, and various malfunctions may occur during operation. Reducing the occurrence of equipment failures is the key to ensuring the continuity of operations. Regular inspection and maintenance of equipment to ensure work efficiency has become the key to improving the quality of equipment operation. The factors that affect equipment maintenance can be divided into equipment maintenance quality and equipment inspection frequency.

(1) Repair quality

Equipment maintenance is aimed at extending the normal service life of equipment parts and reducing equipment failure rates. The quality of maintenance determines the life cycle of the equipment and the smoothness of its operation. Good maintenance and upkeep can bring the equipment to its optimal state, meet the technical parameters, conditions, and allowable errors specified in the maintenance standards, minimize losses during equipment operation, and make the equipment run more smoothly. Moreover, high-quality maintenance can reduce the repair rate of equipment, thereby ensuring long-term operation of equipment, reducing production interruptions caused by equipment failures and shutdowns, and ensuring more efficient completion of work tasks.

(2) Maintenance frequency

In order to grasp the health status of the equipment timely and accurately and ensure its normal operation, it is necessary to take appropriate measures to repair some parts before they are damaged. Maintenance personnel generally conduct regular inspections and repairs of equipment in accordance with safety inspection regulations. This is a passive inspection and maintenance method that is difficult to avoid sudden equipment failures. Therefore, inspectors should implement proactive maintenance, that is, irregular and short interval inspections and repairs of underground equipment, so as to have a higher probability of discovering problems before parts are damaged, avoiding serious equipment failures and affecting work progress. However, it is also necessary to grasp a reasonable maintenance frequency and minimize the losses caused by underground equipment shutdown due to equipment maintenance.

3.2.3 Other factors.

(1) Engineering conditions

The working efficiency of underground equipment is related to the engineering conditions of the operation, for example, excavation operations require equipment to drill and crush rock masses. Therefore, the working efficiency of the equipment is closely related to the hardness of the rock. If the hardness of the rock is too high, the drill bit cannot break the rock, which affects the construction progress and may even cause damage to the drill bit. On the contrary, if the rock hardness is low and the rock mass is broken, the crushing operation is easy, and the excavation volume per unit time significantly increases. However, the poor support of fractured rock masses can also pose a threat to the safety of underground equipment and personnel.

(2) Equipment operating time

The equipment has no fatigue, so it can operate continuously for a long time. Although the longer the working hours, the more work is completed, it does not mean that work efficiency increases with the extension of time. At the beginning stage of equipment operation, the efficiency of the job gradually increases. As the working time increases, the efficiency gradually reaches its highest point, and then gradually decreases with the extension of the working time. If the equipment runs for too long, it may cause excessive heat generation and even malfunction of the motor due to excessive load.

3.3 Environmental factors

As a whole, the man-machine system is always in a certain environment, constantly exchanging materials with the external environment, and therefore is constantly influenced by the surrounding environment. At the same time, as a whole man-machine system, it also has an impact on the surrounding environment.

3.3.1 General environmental conditions.

For underground operations, the environmental conditions are relatively harsh, and in this case, it is more important to clarify the impact of the environment on

personnel and equipment. Similar to plain areas, underground air humidity, CO_2 concentration, lighting, noise, and other conditions can all have a certain impact on the efficiency of personnel and equipment.

(1) Humidity

With the consumption of shallow mineral resources, many mines have entered deep mining, with some large mines reaching depths of over kilometers. The surface climate change leads to differences in the humidity of the air flowing into the mine, and the presence of underground aquifers also makes the mine air more humid. When there is a large amount of water inflow or dripping underground, the underground environment becomes more humid. The air humidity underground in general metal mines is around 80% to 90%, and higher humidity can have an impact on the man-machine system. The humid air can make people feel uncomfortable and difficult to concentrate. When the humidity is too high (greater than or equal to 70%), people are more likely to experience fatigue. In addition, humid air can cause corrosion and rust of underground equipment, damage equipment parts, and affect the smoothness of equipment operation.

(2) CO_2 concentration

With the increase of production equipment in mines, a large amount of CO_2 will be generated during the operation of fuel equipment. As a greenhouse gas, CO_2 can to some extent alleviate the severe cold conditions underground in high-altitude mines. However, when the equipment releases too much CO_2, due to the limited underground space, the concentration of CO_2 rapidly increases. The high concentration of CO_2 causes the underground air to become turbid, making workers in this environment prone to symptoms such as dizziness, chest tightness, rapid heartbeat, and hypoxia. As a result, one cannot fully devote themselves to the task, which affects work efficiency.

(3) Lighting

The demand for lighting environment by staff is inseparable from their work and life. In workplaces, appropriate lighting can enable personnel to carry out production operations efficiently, comfortably, and safely. The lighting conditions in underground mines, especially in the working face, are poor and the environment is relatively dark. Operators who are exposed to such environments for a long time may feel depressed psychologically, which has a certain negative effect on their mental health and can also have an impact on their physical health. May lead to personnel fatigue, decreased vision, difficulty concentrating, thereby reducing work efficiency and increasing the probability of work-related accidents. Increasing underground lighting can not only enhance the visual experience of personnel, but also improve the recognition speed of operators, and enhance the efficiency and accuracy of the work process.

(4) Noise

Noise hazard is one of the many hazards in mine. Currently, drilling and blasting methods are still mainly used for underground excavation in metal mines, which require rock drilling operations. During the rock drilling process, the noise is huge, causing certain harm to the operators. Firstly, the loud noise can have an impact on the auditory system of workers working in close proximity. As the working years increase, the negative effects on workers gradually transition from physiological to pathological, resulting in pathological hearing damage. In addition, noise can also have an impact on the nervous system. Under the prolonged stimulation of strong noise, personnel may experience headaches, tinnitus, and other symptoms. In severe cases, it can also cause accelerated breathing and pulse, elevated blood pressure, arrhythmia, and other symptoms, seriously affecting the physical health of personnel. At the same time, it can significantly reduce work efficiency and even lead to safety production accidents.

3.3.2 High altitude environmental conditions.

In addition to the impact of plain areas on man-machine systems, high-altitude areas, due to their unique environmental conditions, can cause changes in the physical condition and equipment performance of personnel and equipment that could have worked normally and efficiently in plain areas, which can have an impact on system efficiency.

(1) Low temperature

The temperature gradually decreases with increasing altitude. For every 1000m increase in altitude, the temperature drops by about 6℃. Due to the high altitude and low temperature, the human body's functions decrease, and various tissues and organs in the body cannot respond flexibly to external stimuli, affecting work efficiency. For equipment, low temperature can affect the performance of underground fuel equipment. The combustion efficiency of the cylinder decreases during the compression of the oil and gas mixture, making combustion difficult. Sometimes, it may not be able to burn, resulting in equipment startup failure. At the same time, the exhaust gas emitted contains a large number of small particles of insufficiently burned or unburned oil and gas mixture, exacerbating environmental pollution underground and causing harm to human health.

(2) Low pressure hypoxia

With the continuous increase of altitude, atmospheric pressure continues to decrease. Although the volume fraction of oxygen in the atmosphere remains constant, the decrease in pressure makes the air thin, resulting in a decrease in overall oxygen content, further exacerbating the current situation of oxygen deficiency caused by the small underground space. Under low-pressure hypoxia conditions, the blood oxygen content in the human body will decrease, causing hypoxia in various tissues of the body, which will affect the function of the body, leading to symptoms such as dizziness, nausea, shortness of breath, and affecting the health of workers. Due to insufficient oxygen content in the air, the amount of air entering the equipment cylinder decreases, resulting in insufficient mixing of oil and air in the cylinder and a high concentration of mixed oil and gas, which leads to insufficient combustion and seriously affects the power source of the equipment.

3.4 The Impact of Man-Machine-Environment Coupling on System Efficiency

The factors affecting the man-machine systems efficiency include three aspects: man machine and environment, each of which contains several factors. In addition to being affected by internal factors of man-machine-environment, man-machine systems are also influenced by the interactions between the three, thereby affecting the overall operational efficiency of the system.

Improper operation of equipment by personnel not only reduces work efficiency but may also result in poor equipment operation. For example, when personnel drive a loader for ore loading operations, improper operation may increase the exhaust emissions of the loader, exacerbating the severity of the working environment. The harsh underground environment can also affect the physical and mental health of workers, indirectly leading to further laziness and resistance towards work, increasing the risk of equipment misoperation, and thus forming a vicious cycle. The work attitude and technical level of personnel have an impact on the quality of equipment operation. If the work attitude is not correct and the technical level is not up to standard, personnel may manipulate the equipment, resulting in the inability to complete the correct operation completely according to the working conditions, leading to poor equipment performance and even equipment failure, increasing equipment vibration and noise, aggravating the severity of the underground environment, thereby affecting personnel functional indicators and health status, and reducing overall work efficiency. Low temperature and oxygen conditions lead to insufficient energy consumption of equipment, exacerbating the pollution level of tunnels caused by exhaust emissions from vehicles and other equipment, and having a negative impact on the normal operation and health of personnel and equipment.

From this, it can be seen that the interaction and influence between man, machine, and the environment together form a whole, which affects the man-machine systems efficiency. Therefore, in order to effectively improve the production efficiency of underground mines, optimizing and improving only based on unilateral factors may not achieve ideal results. Therefore, a systematic thinking should be established to optimize from the three aspects of man machine and environment.

4. Conclusion

This article analyzes the factors affecting the man-machine systems efficiency, dividing them into 9 main factors and 25 sub factors in terms of man, equipment, and environment. Not only did it discuss the impact on system efficacy from a single perspective, but it also analyzed the impact on the system from the coupling effect between the three. The roles of various factors in the man-machine system have been clarified, laying the foundation for future research on the man-machine systems efficiency and improving system operational efficiency.

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