The Calculation Method of Safety Degree and Its Application in Coal Mine Enterprises

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Abstract

In order to evaluate the situation of safety production of coal mine enterprises effectively, quantitative analysis is necessary and very important. Safety degree of coal mine enterprises based on the concept of safety degree is defined and the method of calculating quantitatively the safety degree is put forward. The validity of this method is verified by empirical research in view of micro- and macroanalyses. In view of micro analysis the safety degree is derived with the calculation method based on information of one coal mine. The safety degree of this coal mine went through rapid increase period, stable period, and slow increase period. Macroresearch results show that the situation of safety production of coal mine enterprises in China has significantly been improving and the level of safety degree also has been increasing year by year since 1979, the year when the policy of reform and opening began. The reasons are the advancement of technology, strengthening of safety management and education, increasing of safety investment, and perfection of policies, laws, and regulations. These achievements can provide quantitative method for assessing the status of coal mines.

Keywords: coal enterprise, safety, safety degree, empirical researches

1. Introduction

China is one of the largest producers of coal in the world. The coal production in China accounted for 46.9% of the total coal production around the world. But the coal consumption in China accounted for 50.6% of the total coal consumption around the world (BP Group, 2015).
At the same time, the coal industry is considered as the most dangerous industry in China. And the number of new occupational patients tops all industry (Liao et al., 2009). All kinds of danger and risk exist during coal production. And not only personal casualty but also stoppages in production of coal mine may be induced by accidents, which cause huge loss to the coal enterprise (Xu, 2014; Mahdevari et al., 2014). So it is imperative to study the safety issues from the quantitative point of view. Many scholars did lot of researches. The quantitative methods for safety analysis include micro-level Markov models (Knegtering and Broracher, 1999), computer-aided fault tree synthesis method (Wang et al., 2002), dynamic fault tree method (Ćepin and Marko, 2002), and the decision tree method of incident management, and so on (Baumont et al., 2000). For example, safety technology investment model for assessing quantitatively the enterprise’s risks and potential threats was put forward (Bojanc et al., 2012). The safety level of traffic system was evaluated by SIL probability model, and its hazards were found out (Beugin et al., 2007). With a comprehensive method of quantitative analysis on energy security, the safety degree was assessed from five dimensions (Benjamin and Mukherjee, 2011). Furthermore, quantitative research was also applied to analyze coal mine accidents, and thus improvement measures were taken to ensure safe production (Paul and Maiti, 2007). According to the time of accident occurrence and intervals of mechanical failure, a model to analyze safety issues in coal mines was established and the study showed that accidents are related to reliability of mechanical equipment and management effectiveness (Vivek et al., 2011). Also, hazards and probability of accidents in the coal mine production system are found out by statistical methods, and multiple probability of accident by severity of damage can be conducted as a risk factor of the system (Denby and Kizil, 1992; Hatton and Whateley, 1995; H.S.B., 2005). A coal mine macro, meso, and micro dynamic warning system which is based on portable examination instrument, risk information card, and wireless communication network was also put forward (Wang et al., 2016).

In China the death toll is high when compared with other countries, but in recent years the safety status has improved and the death toll has been on the decline. In this chapter the safety degree of coal mine enterprises will be defined and quantitative calculation methods will be put forward based on the death toll and the number of injured. The safety status of coal mine enterprise in China will be assessed and the key factors affecting the safe production in coal mine enterprises will be analyzed.

2. The concept of safety degree of coal mine enterprise

For safety degree, there is no uniform concept, and most are defined from the perspective of the safety state of things. Related definitions include: describing the probability of things in a safe state; the safety level of the system; and the degree objective from danger. The safety degree was defined as a situation of production safety in enterprises by analyzing the relationship between safety level and safety degree (Huang et al., 1999; Golbraikh et al., 2003).
By comparative analysis of the definition of safety degree, the safety degree of coal mine enterprise is defined as: the probability where there are no casualties and economic losses suffered by coal mine enterprises in a certain period of time. The concept is a quantitative form on safety production, which reflects the safety situation of the enterprises.

3. Calculation method of coal mine enterprise's safety degree

The safety degree of coal mine enterprises is the result of internal factors’ interaction and is the quantification of coal mine safety situation. The range of coal mine enterprise's safety degree $S \in [0, 1]$, that is, the absolute unsafely degree is 0 and the absolute safety degree is 1. The reverse concept of $S$ is risk degree, which is the probability of accidents in coal mine enterprises, $S = 1 - R$ ($R$ is the risk degree).

3.1. Calculation of safety degree in view of staff system in coal mine enterprises

It is not easy to count the safety degree of staff system in practice because there is a measuring standard. The safety degree of staff system can be obtained by estimating method based on the number of casualties in coal mine enterprises. Whether unsafe acts can cause injury or not is random. Also, a lot of unsafe acts may be not counted that do not cause consequence. According to the Heinrich accident triangle rule (Heinrich, 1980), serious injury and death:injuries:no injuries = 1:29:300, so the later (no injuries) is 10 times of the total of the two formers (serious injury and death, injuries). Thus, the total number of violations can be attained.

The safety degree of staff system can be expressed by the following formula:

$$S_H = 1 - \frac{n}{N}$$

(1)

where $S_H$ is the safety degree of staff system, dimensionless; $N$ is the number of enterprises staff in one statistical year; and $n$ is the number of casualties in one statistical year, where

$$n = (injuries + deaths) \cdot (1 + 10)$$

(2)

3.2. Calculation of the safety degree of coal mines enterprises

The theories of accident consequence chain show that the direct reasons of accident were unsafe act of staff and unsafe condition of logistics system. Therefore, the system’s situation can be reflected by an integrated study of unsafe act and unsafe condition. According to the research of a renowned Japanese scholar, 88% of factors in an accident is contributed by human’s unsafe act, 10% is attributed by unsafe condition of things, and other reasons account for 2%. Accordingly, the weight of human safety degree is 88%, the weight of logistics system 10%, and the weight of other factors is 2%.
Then, the total safety degree of coal mine enterprises is:

\[ S = 0.88 \cdot S_H + 0.1 \cdot S_M + 0.02 \cdot S_O \]  \hspace{1cm} (3)

4. Some common mistakes

Empirical research includes the micro and macro level. For micro level, one coal mine is taken into account and for macro level the information of the total coal mines of China is used. The safety degree of the cases will be calculated and safety status will be analyzed.

5. Empirical study in view of micro level

5.1. The original data of one coal mine

In view of micro level, one coal mine is used for study. The coal mine is located in the Shandong Province and is an old mine with more than 30 years of operation. For years, lots of coal was produced, but various accidents also caused some irreparable losses. During the periods 1974–2005, more than 11,600 injuries of workers are reported, of which 329 persons were seriously injured and 219 people lost their lives. The accidents and casualties for every calendar year are shown in Table 1 (Hu, 2006) and Figures 1 and 2.

5.2. Calculation of the safety degree of staff system

We can calculate the safety degree of staff system according to formula (1) and the data in Table 1. The accurate number of no injury is not known, but it is likely to cause an injury. The safety degree of the staff system can be got through transform method,

\[ \frac{n}{N} = \frac{\omega + 10\omega}{1000} \]  \hspace{1cm} (4)

where \( \omega \) is the casualty rate per thousand persons.

Due to lack of statistics of logistics system such as operating rates of machinery and equipment, and production lines and roadway repair, the safety degree of logistics system and the total safety degree cannot be calculated. But a large number of studies show that unsafe act of coal mines is one of the main causes of accidents and at least 80% of coal mine accidents were caused by unsafe act. Therefore, the safety degree of staff system can reflect the total safety degree of the enterprises by at least 80%.

5.3. Analysis of the safety situation of coal mine

We can get the trend chart of safety degree according to the data in Table 2. Figure 3 shows that the safety degree of this coal mine went through rapid increase period, stable period, and slow increase period, which indicates the improvement of situation since 1994.
| Year | Raw coal production (ton) | The annual average number of employed | The fatality rate per millions tons | The fatality rate per thousand persons | The serious injury rate per thousand persons | The injuries rate per thousand persons | The casualties rate per thousand persons |
|------|--------------------------|---------------------------------------|------------------------------------|---------------------------------------|---------------------------------------------|----------------------------------------|------------------------------------------|
| 1974 | 225,000                  | 6316                                  | 6.00                               | 1.58                                  | 2.69                                        | 82.01                                  | 83.60                                    |
| 1975 | 1,643,802                | 5172                                  | 8.51                               | 2.71                                  | 3.67                                        | 65.35                                  | 68.06                                    |
| 1976 | 1,317,570                | 5503                                  | 6.83                               | 1.64                                  | 1.27                                        | 58.33                                  | 59.97                                    |
| 1977 | 1,334,789                | 5441                                  | 7.49                               | 1.84                                  | 2.21                                        | 68.74                                  | 70.58                                    |
| 1978 | 1,322,312                | 5708                                  | 6.05                               | 1.40                                  | 0.88                                        | 41.70                                  | 43.10                                    |
| 1979 | 1,083,721                | 4640                                  | 3.69                               | 0.86                                  | 0.65                                        | 49.78                                  | 50.65                                    |
| 1980 | 1,220,258                | 4160                                  | 7.46                               | 0.72                                  | 1.44                                        | 77.64                                  | 78.37                                    |
| 1981 | 1,342,292                | 3819                                  | 3.72                               | 131                                   | 2.62                                        | 60.75                                  | 62.06                                    |
| 1982 | 654,939                  | 3707                                  | 4.58                               | 0.81                                  | 1.89                                        | 96.57                                  | 97.38                                    |
| 1983 | 443,283                  | 3803                                  | 4.51                               | 0.53                                  | 1.58                                        | 54.17                                  | 54.69                                    |
| 1984 | 667,629                  | 5163                                  | 7.48                               | 0.97                                  | 1.36                                        | 47.45                                  | 48.42                                    |
| 1985 | 1,195,572                | 5561                                  | 1.17                               | 0.36                                  | 2.34                                        | 69.05                                  | 69.41                                    |
| 1986 | 1,322,312                | 5745                                  | 3.78                               | 0.87                                  | 0.52                                        | 53.26                                  | 54.13                                    |
| 1987 | 1,419,797                | 5774                                  | 2.11                               | 0.52                                  | 0.87                                        | 48.67                                  | 49.19                                    |
| 1988 | 1,471,427                | 5790                                  | 3.39                               | 0.86                                  | 1.21                                        | 48.01                                  | 48.88                                    |
| 1989 | 1,163,186                | 6469                                  | 3.03                               | 0.62                                  | 0.77                                        | 43.90                                  | 44.52                                    |
| 1990 | 1,465,714                | 6426                                  | 5.45                               | 1.24                                  | 0.47                                        | 55.56                                  | 56.80                                    |
| 1991 | 1,216,473                | 6435                                  | 6.57                               | 1.24                                  | 0.62                                        | 49.41                                  | 50.66                                    |
| 1992 | 1,608,392                | 6443                                  | 3.10                               | 0.78                                  | 2.17                                        | 64.80                                  | 65.65                                    |
| 1993 | 1,847,960                | 6793                                  | 8.65                               | 2.36                                  | 1.47                                        | 68.16                                  | 70.51                                    |
| 1994 | 2,020,607                | 6897                                  | 3.46                               | 1.01                                  | 1.88                                        | 62.92                                  | 63.94                                    |
| 1995 | 1,782,517                | 7142                                  | 3.93                               | 0.98                                  | 1.68                                        | 47.04                                  | 48.03                                    |
| 1996 | 1,643,530                | 7144                                  | 2.43                               | 0.56                                  | 1.68                                        | 47.17                                  | 47.73                                    |
| 1997 | 1,816,656                | 839                                   | 2.20                               | 0.48                                  | 1.55                                        | 36.79                                  | 37.26                                    |
| 1998 | 1,841,486                | 8140                                  | 3.26                               | 0.74                                  | 1.11                                        | 35.01                                  | 35.5                                     |
| 1999 | 1,806,549                | 8105                                  | 2.77                               | 0.62                                  | 3.21                                        | 33.68                                  | 34.30                                    |
| 2000 | 1,802,670                | 8405                                  | 4.44                               | 0.95                                  | 0.83                                        | 24.27                                  | 25.24                                    |
| 2001 | 1,556,855                | 8227                                  | 2.63                               | 0.49                                  | 0.24                                        | 16.29                                  | 16.77                                    |
| 2002 | 1,536,553                | 7890                                  | 2.04                               | 0.38                                  | 0.51                                        | 15.34                                  | 15.72                                    |
| 2003 | 1,315,052                | 7865                                  | 4.02                               | 0.63                                  | 0.38                                        | 12.21                                  | 1.84                                     |
| 2004 | 1,231,467                | 7913                                  | 5.14                               | 0.88                                  | 0.13                                        | 11.37                                  | 12.26                                    |
| 2005 | 1,174,920                | 6977                                  | 1.99                               | 0.29                                  | 0.14                                        | 9.03                                   | 9.32                                     |

Table 1. Statistical table of accident and casualty rates of calendar year.
Figure 1. The fatality rate per thousand persons and per million tons.

Figure 2. The casualty rate and injuries per thousand persons.

| Year | The safety degree of flow systems | Year | The safety degree of flow systems |
|------|----------------------------------|------|----------------------------------|
| 1974 | 0.91641                          | 1990 | 0.94320                          |
| 1975 | 0.93194                          | 1991 | 0.94935                          |
| 1976 | 0.94003                          | 1992 | 0.93442                          |
| 1977 | 0.92942                          | 1993 | 0.92948                          |
| 1978 | 0.95690                          | 1994 | 0.93607                          |
| 1979 | 0.94936                          | 1995 | 0.95198                          |
| 1980 | 0.92164                          | 1996 | 0.95227                          |
| 1981 | 0.93794                          | 1997 | 0.96273                          |
| 1982 | 0.90262                          | 1998 | 0.96425                          |
| 1983 | 0.94530                          | 1999 | 0.96570                          |
| 1984 | 0.95158                          | 2000 | 0.97478                          |
| 1985 | 0.93059                          | 2001 | 0.98322                          |
| 1986 | 0.94587                          | 2002 | 0.98428                          |
| 1987 | 0.95081                          | 2003 | 0.98715                          |
| 1988 | 0.95113                          | 2004 | 0.98775                          |
| 1989 | 0.95548                          | 2005 | 0.99068                          |

Table 2. The safety degree of staff systems in certain coal mine.
6. Empirical study on the macro level

6.1. The accident statistics of China’s coal mine industry

The safety degree of China’s coal mine industry can be expressed through the number of casualties, injury, and potential injury of the accidents. According to statistics, the death rate per 100,000 persons is used to reflect safety situation, as shown in Table 3 (Chen, 2012).

| Year | The numbers of deaths | The death rates of per 100,000 persons |
|------|-----------------------|---------------------------------------|
| 1964 | 1350                  | 6.49                                  |
| 1965 | 1104                  | 4.81                                  |
| 1966 | 1556                  | 6.28                                  |
| 1967 | 1431                  | 5.65                                  |
| 1968 | 1687                  | 6.46                                  |
| 1969 | 2017                  | 6.99                                  |
| 1970 | 3027                  | 9.03                                  |
| 1971 | 3766                  | 9.91                                  |
| 1972 | 3597                  | 8.83                                  |
| 1973 | 4079                  | 9.53                                  |
| 1974 | 3722                  | 8.29                                  |
| 1975 | 4736                  | 9.65                                  |
| 1976 | 4948                  | 9.26                                  |
| 1977 | 5637                  | 10.15                                 |
| 1978 | 6001                  | 9.07                                  |
| 1979 | 5566                  | 8.11                                  |
| 1980 | 5165                  | 7.04                                  |
| 1981 | 5162                  | 6.77                                  |
| 1982 | 4873                  | 6.13                                  |
Due to the lack of the number of wounded and unsafe act in the statistics, we can estimate the number of injuries and unsafe act by applying the Heinrich accident triangle rule: serious injuries and death:slight injuries:no injury = 1:29:300. In formula (1):

| Year | The numbers of deaths | The death rates of per 100,000 persons |
|------|-----------------------|--------------------------------------|
| 1983 | 5567                  | 6.73                                 |
| 1984 | 5872                  | 6.43                                 |
| 1985 | 6912                  | 6.98                                 |
| 1986 | 6888                  | 6.45                                 |
| 1987 | 7049                  | 6.32                                 |
| 1988 | 6902                  | 5.97                                 |
| 1989 | 7625                  | 6.69                                 |
| 1990 | 7360                  | 5.65                                 |
| 1991 | 6412                  | 4.85                                 |
| 1992 | 5992                  | 4.85                                 |
| 1993 | 6244                  | 4.41                                 |
| 1994 | 7239                  | 4.98                                 |
| 1995 | 6907                  | 4.64                                 |
| 1996 | 6556                  | 4.26                                 |
| 1997 | 7083                  | 2.51                                 |
| 1998 | 6302                  | 4.03                                 |
| 1999 | 6469                  | 4.14                                 |
| 2000 | 5796                  | 3.87                                 |
| 2001 | 5670                  | 3.66                                 |
| 2002 | 6995                  | 4.36                                 |
| 2003 | 6434                  | 4.01                                 |
| 2004 | 6027                  | 3.76                                 |
| 2005 | 5986                  | 3.73                                 |
| 2006 | 4746                  | 2.96                                 |
| 2007 | 3786                  | 2.36                                 |
| 2008 | 3215                  | 2.01                                 |
| 2009 | 2631                  | 1.64                                 |
| 2010 | 2433                  | 1.52                                 |
| 2011 | 1973                  | 1.23                                 |

Table 3. The number of deaths in China’s coal mine enterprises from 1964 to 2011.

6.2. Calculation of safety degree of China’s coal mine industry

Due to the lack of the number of wounded and unsafe act in the statistics, we can estimate the number of injuries and unsafe act by applying the Heinrich accident triangle rule: serious injuries and death:slight injuries:no injury = 1:29:300. In formula (1):
where $\omega$ is the death rate per 100,000 persons.

Table 4 shows the safety degree of China’s coal mine industry (see Figure 4).

6.3. Analysis of safety production of China’s coal mine industry

The trend chart of safety degree of China’s coal mine industry can be derived from the data in Table 4. The trend chart shows that safety degree of China’s coal mine industry has a sharp reduction from 1964 to 1971, has been stable from 1972 to 1978, but the overall trend has increased after 1979, which indicates that the safety production situation of China’s coal mine enterprises improved. Its reason may be that the policy of reform and opening began and the economy developed sharply. The improvement of the safety production situation reflects the important role of the advanced technologies and safety management, while coal mine enterprises improved the work environment by strengthening the safety investment and improved employees’ quality by strengthening safety training, which ultimately improved the safety degree of the staff system and promoted the improvement of enterprises’ overall safety degree. In addition, the related policies, laws, and regulations for coal mines in China have played a significant role in promoting the safety production.
7. Conclusion and discussion

The safety degree of coal enterprise is defined, the calculation methods of safety degree are put forward, and empirical researches on the micro and macro view are done according to this method. Studies show that the calculation method of safety degree is valid and the safety degree reflects the situation of safety production of coal mine enterprises to a large extent and it is significant to quantify the safety problems of coal mines. By analysis of the results of empirical research it can be concluded that the reasons for the increase of the safety degree are due to the advancement of technology, strengthening of safety management and education, increasing of safety investment, and perfection of policies, laws, and regulations.

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