Chapter 24

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 (Čepin 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).

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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:

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

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

$$n = (injuries + deaths) \cdot (1 + 10) \tag{2}$$

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:

$$S = 0.88 \cdot S_H + 0.1 \cdot S_M + 0.02 \cdot S_O \tag{3}$$

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,

$$\frac{n}{N} = \frac{\omega + 10\omega}{1000} \tag{4}$$

where ω 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	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.

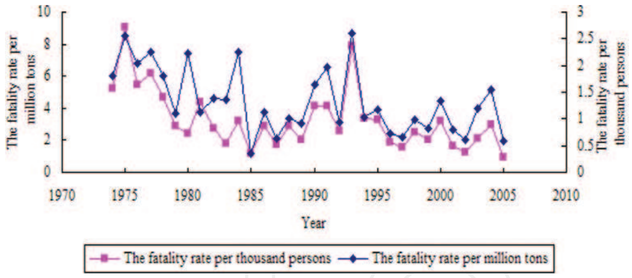

Figure 1. The fatality rate per thousand persons and per million tons.

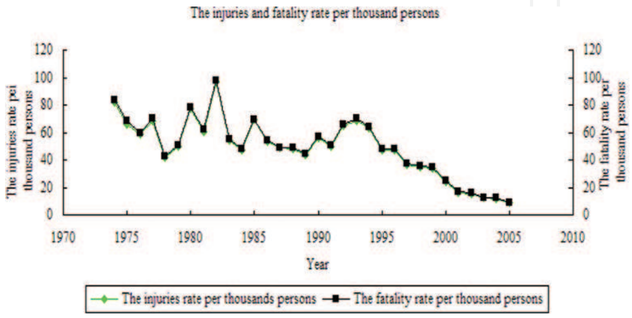

Figure 2. The casualty rate and injuries per thousand persons.

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.

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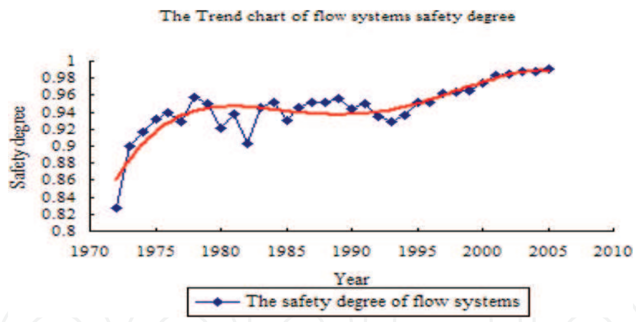

Figure 3. The trend chart of safety degree in certain coal mine.

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

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):

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$$\frac{n}{N} = \frac{30\omega + 300\omega}{100,000} \tag{5}$$

where ω is the death rate per 100,000 persons.

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

Year	Safety degree	Year	Safety degree	Year	Safety degree
1964	0.978575	1980	0.976778	1996	0.985956
1965	0.984116	1981	0.977676	1997	0.985130
1966	0.979272	1982	0.979775	1998	0.986708
1967	0.981371	1983	0.977777	1999	0.986347
1968	0.978686	1984	0.978784	2000	0.987228
1969	0.976929	1985	0.976952	2001	0.987927
1970	0.970188	1986	0.978717	2002	0.985600
1971	0.967290	1987	0.979151	2003	0.986755
1972	0.970857	1988	0.980312	2004	0.987593
1973	0.968535	1989	0.977939	2005	0.987677
1974	0.972632	1990	0.981343	2006	0.990230
1975	0.969443	1992	0.983999	2007	0.992206
1976	0.969443	1992	0.983996	2008	0.993382
1977	0.966512	1993	0.985445	2009	0.994584
1978	0.970067	1994	0.983561	2010	0.994991
1979	0.973252	1995	0.984687	2011	0.995938

Table 4. The safety degree of staff systems in certain coal mine.

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.

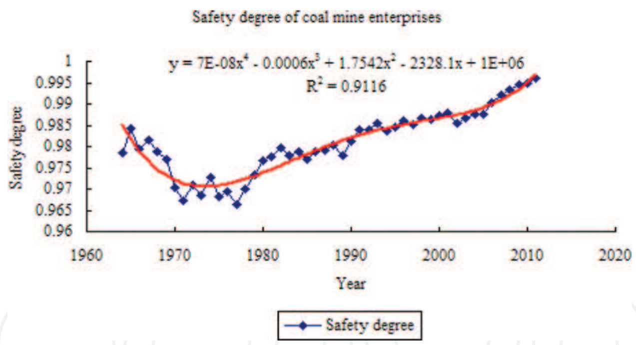

Figure 4. Trend chart of safety degree of China's coal mine enterprises in calendar year.

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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