



Mental fatigue, cognitive bias and safety paradox in chinese coal mines



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ABSTRACT

Many researchers have confirmed that most accidents occur during night shifts, but coal mine production in China is an exception. The frequency of accidents during day shifts is significantly higher than that of night shifts. We refer to this as a safety paradox. This study collected 1870 instances of the worst fatal accidents in Chinese coal mines from 2002 to 2013, which in total accounted for the deaths of 13,477 miners. We mainly employed frequency analysis to describe the imbalance in accident risks between day shifts and night shifts. Then we deployed a reaction time test and "psychometric fatigue assessment scale" to measure the differences in mental fatigue between day-shift and night-shift workers. In further, we analyzed the supervision records of the coal mines and found that the level of supervision was more intensive during night shifts. Based on these analyses, we put forward "the pendulum effect of mental fatigue" as an explanation for the safety paradox experienced in Chinese coal mines. Lastly, we suggest possible solutions that coal mine managers and the government policy-makers could undertake.

1. Introduction

China's Third National Economic Census revealed that there were 6.11 million people working in the Chinese coal industry in 2013,¹ meanwhile China also has the most coal mine fatalities in the world. Miners not only work in a dangerous environment, they also work under huge pressure due to improper work organization, this pressure can affect the stability of a miner's performance and thereby increase the risk of accidents.

Shift work is inevitable for some occupations, such as nurses, drivers, pilots, and coal miners, most of these occupations have a high risk of accidents and, intuitively, night shifts are considered to be more dangerous than day shifts (Folkard et al., 2005; Smith et al., 1979; Sonmez et al., 2014; Violanti et al., 2012). The biological clock will make a person feel mental fatigue during the night because their underlying rhythm is sleepiness, regardless of whether they are actually sleeping (Smith et al., 1994). During the night, people are more prone to make mistakes at work and accidents are more likely to happen. However, the time when most accidents occur in the Chinese coal mining industry is not consistent with this rule. The frequency of accidents and the death toll is remarkably higher during day shifts than night shifts; we call this the safety paradox of shift work. Does this mean that the biological clock of coal miners is different to other professions? Are night shifts safer than day shifts in coal mines? Are there some hidden factors that can explain this phenomenon? In this

study, we try to give preliminary answers to these questions.

Shift work can reduce cognitive performance and make people easily distracted during psychomotor vigilance tasks (Zhou et al., 2012). Wagstaff and Sigstad performed a meta-analysis of 443 studies in this area and concluded that both shift work and long working hours have substantial effects on safety, increasing the risk of accidents by 50–100% (Wagstaff and Lie, 2011). A survey that collected data on 1351 employees from 16 companies in six industries (including manufacturing, construction, transportation, and real estate) showed that night shift workers were perceived to have a higher level of injury risk (Meijman, 1997). Thus, night shifts are more dangerous than day shifts, but coal production may be an exception.

Stojadinovic et al. analyzed coal mine injury accidents in Serbia from 2000 to 2009 and found that 44.5% of the accidents occurred between 07:00 and 15:00, 32.6% between 15:00 and 23:00, and only 22.9% between 23:00 and 07:00 the following day (Stojadinovic et al., 2012). Zhang plotted coal mine casualties for accidents involving no less than three deaths in China during 1970–2003, and this showed that 09:00–13:00 was the peak time for accidents (Zhang et al., 2006). The accident data for the Huai-bei coal mining group during 1958–1984 also showed that the frequency of accidents was significantly higher during the day than at night (Liu and Zhao, 2012).

Stojadinovic suggested that this is because of the work schedule in mines: morning shifts have the highest frequency of activity and mining operations, and all the servicing and current maintenance

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¹ Please see details in: http://www.stats.gov.cn/tjsj/zxfb/201412/t20141216_653709.html.

duties are performed during the first shift. However, we think Stojadinovic's explanation is not quite applicable to the safety paradox in Chinese coal mines during 2002–2013 because China coal mines always run for 24 h, and the frequency of activity is balanced between day and night. The period 2002–2013, during which the coal price hit record highs, was called “the golden age” of China's coal industry (Song et al., 2017). Almost every mine operated at full capacity, with some even operating at over that level (Yu and Chen, 2013). From the Accident Inquiry System of State Administration of Coal Mine Safety we were able to retrieve the records of 3,091 fatal accidents that occurred at nighttime during 2002–2013, which infers that more than 3,000 coal mines had night shift records. According to the statistics of the China National Coal Association, China had 12,000 coal mines in 2013 (Sun and Guo, 2014), so if we divide this by 3,091, we can see that almost 25% of them recorded nighttime fatal accidents. Nevertheless, there was a massive number of 24-h coal mines that did not have a fatal accident. In 2016, the China State Administration of Work Safety released a document that encouraged some coal mines to gradually reduce night shifts,² which infers that the majority of coal mines still had night shift work until 2016. Accordingly, we believe that most coal mines were operated on a 24-h basis during 2002–2013. We investigated 16 coal mines, all of which were run on a 24-h basis, and the production tasks for each shift were same.

Liu and Zhao considered that the “safety paradox” was caused by differences in shift times between the day shifts and night shifts: there are two shift times for the day shift and only one shift time for the night shift. Miners tend to work perfunctorily toward the end of their shift to leave on time, which creates a hazard for the next shift. They considered that this explains the difference in risk between day and night. Liu and Zhao's research can partly explain the safety paradox in Chinese coal mines, but it cannot explain why the fatalities are always higher during the daytime, we will research this further in part 4.

2. Data interpretation

This study focused on coal mine accidents with more than three fatalities and the data were derived from the accident inquiry system of the State Administration of Coal Mine Safety (China).³

According to the official accident classification, if an accident results in three or more fatalities, it will be recorded as a “relatively serious accident and above” (RSAA). After 2006, the accident inquiry system only reported accidents with three or more casualties, so data for accidents with less than three casualties are missing after this date (Nie et al., 2013). Accordingly, only the RSAA data were used in this study. The Longman Dictionary of Contemporary English defines night shift as “a period of time at night during which people regularly work”. We assumed that the lengths of the day and night are equal,⁴ so the daytime ranged from 06:00 to 18:00 and the nighttime from 18:00 to 06:00. We distinguished “night shift time” and “day shift time” in accordance with these definitions.

An overview of coal mine accidents in China with fatalities in the last 12 years is shown in Table 1.

Table 1 describes the longitudinal data of Chinese coal mine accidents for 2002–2013. It shows that both the accident frequency and death toll progressively declined over that period, but the figures for the day were always higher than those for the night. During 2002–2013, there were only two years where the frequency of RSAAs was higher at nighttime and three times where the death toll was higher at nighttime. Why does the accident risk increase in what people regard as a relatively safe time? Is this phenomenon inevitable for coal mines? During 2002–2013, 13,477 miners died in RSAAs, so if we can find

methods to reduce the death toll due to RSAAs in coal mines, many families will benefit from this.

Most coal mines use a “four-team-three-shift” schedule for their working time arrangements, which means that there are four teams on each work face, and every team has the same number of members. Three teams work successively for one day, with every team working for 8 h, and the fourth team rests. The four teams have shift cycles: whereby if one team works a night shift, they can rest for 24 h, and come back to work in a morning shift, at which point another team will work the night shift.

3. Description of the safety paradox of shift work

Table 2 shows that in the past 12 years, 1870 RSAAs occurred in Chinese coal mines, which caused the deaths of 13,477 miners. The frequency of RSAAs during the day was 39.74% higher than that at night, and the death toll due to RSAAs during the day was 37.52% higher than that during the night. The average death toll per accident was roughly seven, but the variation in the death toll during the night was significantly higher than that in the day. The most serious daytime accident occurred in 2004; this was the Chen Jia-shan coal mine gas explosion accident, in which 166 miners died. The most serious nighttime accident occurred in 2005; this was the Dong-feng coal mine dust explosion accident, in which 171 miners died.

Fig. 1 shows the frequency of accidents at different death toll levels, where each point represents a range from 1 to 27 accidents. At the same death toll level, each point has the same meaning, so a higher intensity of points indicates a higher frequency of accidents. Thus, we can see that accidents involving three or more deaths occurred frequently during both the nighttime and daytime. However, the intensity of points is significantly higher during the daytime than the nighttime for death tolls of less than ten. The intensity of points is almost the same when the death toll is greater than ten. Thus, the main difference in the RSAA frequency between the daytime and nighttime is related to accident death tolls of less than ten people.

According to the definitions provided by the Chinese government, there are eight different types of coal mine accidents, the frequencies of which are shown in Table 3.

Table 3 shows that the frequencies of RSAAs differed greatly among the accident types except for “machine accident” and “blasting accident”, where RSAA frequency during the daytime was obviously higher than during the nighttime.

4. Cause analysis for the shift work paradox

If we list the frequency and fatalities of RSAAs by hours, we can determine the hours in which the difference in the accident risk between the daytime and nighttime is greatest.

Fig. 2 shows the trend in RSAA frequencies and death tolls over the course of 24 h. This demonstrates that they occur at various times, and the figures during the day are significantly higher than those at night. There is no standard for the shift time, but most coal mines set the shift times as 00:00, 08:00, and 16:00. Fig. 2 shows the death tolls increased during the time of shift changes. This indicates the importance of shifts, where miners tend to work less actively to leave on time, which creates a hazard for the next shift. There are two shifts in the daytime and only one shift in the nighttime, and some researchers have suggested that this explains the difference in risk between the daytime and nighttime (Liu and Zhao, 2012). But it only can explain the death tolls related to RSAAs, the frequency of RSAAs is not consistent with this. There are examples of accident levels that decreased after shift changeovers in the night shift, so shift changes do not always lead to an increase in accidents. Besides, if the safety paradox is only caused by the time of the shift, its effect will fade gradually, and the figures will gradually fall into a normal level, but both the death tolls and accident frequency in the daytime are not consistent with this. Here we consider

² Please see details in: http://www.chinasafety.gov.cn/newpage/Contents/Channel_5330/2016/0614/270981/content_270981.htm.

³ Please see details in <http://media.chinasafety.gov.cn:8090/iSystem/shigumain.jsp>.

⁴ For example, this will be the case in the equinox.

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