Safety Science 80 (2015) 13–22

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Evolutionary game analysis and stability control scenarios of coal mine safety inspection system in China based on system dynamics ☆

Quanlong Liu [a,b], Xinchun Li [a,*], Maureen Hassall [b]

[a] School of Management, China University of Mining and Technology, Xuzhou 221116, China
[b] Minerals Industry Safety & Health Centre, The University of Queensland, Brisbane, QLD 4072, Australia

ARTICLE INFO

Article history:
Received 5 January 2015
Received in revised form 4 June 2015
Accepted 3 July 2015
Available online 17 July 2015

Keywords:
Coal mine accidents
Safety inspection
Evolutionary game theory
System dynamics
Stability control scenarios

ABSTRACT

In the process of coal mining safety inspection in China, the different interests and influences of stakeholders and their complicated dynamic interactions make the coal mining safety laws and regulations less effective. Moreover, the existing literature on China's coal mining safety inspection is short of research on revealling the dynamic interactions that can occur under the bounded rationality and also on proposals for effective interactions that will lead to improved safety outcomes. Therefore, this paper explores the use of evolutionary game theory to describe the interactions between the stakeholders in China's coal mining safety inspection system, which includes the State Administration of Coal Mine Safety (SACMS), the Local Regulation Departments of Coal Mine Safety (LRDCMS), and coal enterprises. Moreover, the paper also explores dynamic simulations of the evolutionary game model to analyze the stability of stakeholder interactions and to identify equilibrium solutions. The simulation results show that the strategy selections of the three stakeholders fluctuate repeatedly, which indicates that the evolutionary stable strategy does not exist in the current interactions between the stakeholders. Therefore, the dynamic penalty control scenario and an optimized dynamic penalty-incentive control scenario were proposed to control the fluctuations and then simulated again. And the simulation results indicated that the dynamic penalty control scenario can effectively restrain the fluctuations and make stakeholder interactions more stable. Furthermore, the optimized dynamic penalty-incentive control scenario can not only restrain the fluctuations effectively but also present an ideal evolutionary stable strategy in which coal enterprises could nearly choose safety production as their optimal strategy.

1. Introduction

China is the largest coal producer in the world, producing an estimated 3.87 billion tonnes of coal output in 2014 (The State Administration of Coal Mine Safety, 2014). It is also the largest coal consumer in the world (Niu, 2014). According to China's *National Energy Development Strategy Plan* (*2014–2020*), the coal will continue to dominate the energy strategy accounting for more than 60% of China's energy. This coal-dominated strategy is unlikely to change during the 13th Five-Year Plan period (2016–2020). However, China has an appalling record of fatalities in the coal mining industry. Fatalities in Chinese coal mines account for about 70% of the global coal fatalities (Chen et al., 2013). The frequent coal mine accidents have long been considered as one of the most significant outstanding problems in China. Those accidents not only caused huge loss of lives and properties damage, but also have a negative influence on society.

When exploring the underlying causes of China's appalling record of coal mine fatalities, the complicated geological condition, the backward technology and equipment, the insufficient skills of miners, the inadequate safety investment and poor safety management are all the factors that contribute to the frequency and catastrophic nature of China's fatal coal mining accidents. Furthermore, it suggests that problems with the coal mine safety regulatory regime might be contributing to China's bad safety performance (Andrew, 2009; Liu and Li, 2013).

Before 1999, China's administrative agencies for regulating coal mine safety had frequently and repeatedly changed, as shown in Fig. 1. The frequent and repeated changes of administrative agencies explain, at least in part, the fluctuations in China's coal mine safety performance from 1949 to 1999 (Fig. 2). During this period, these administrative agencies not only had the responsibility of

☆ This work was supported by the National Natural Science Foundation Projects of China under Grant 71271206, and Innovation Project of Graduate Education for Jiangsu Province under Grant KYZZ_0377, and China Scholarship Council under Grant 201406420018.

* Corresponding author at: A502, School of Management, China University of Mining and Technology, University Road 1, Xuzhou 221116, China. Tel.: +86 13815319956.
E-mail address: 715664665@qq.com (X. Li).

http://dx.doi.org/10.1016/j.ssci.2015.07.005
0925-7535/

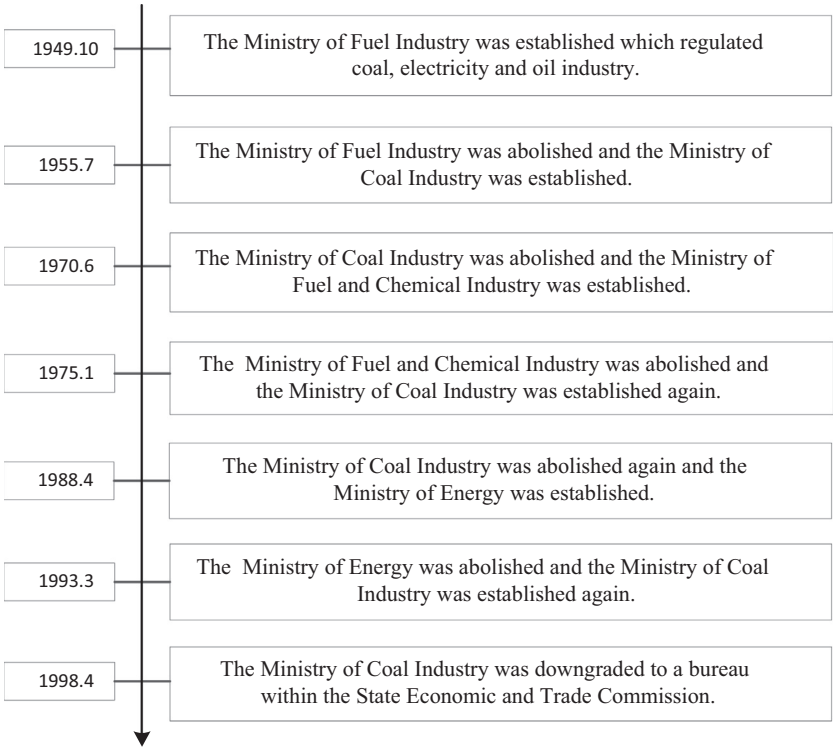

Fig. 1. China's administrative agencies changes of coal mine safety regulation before 1999.

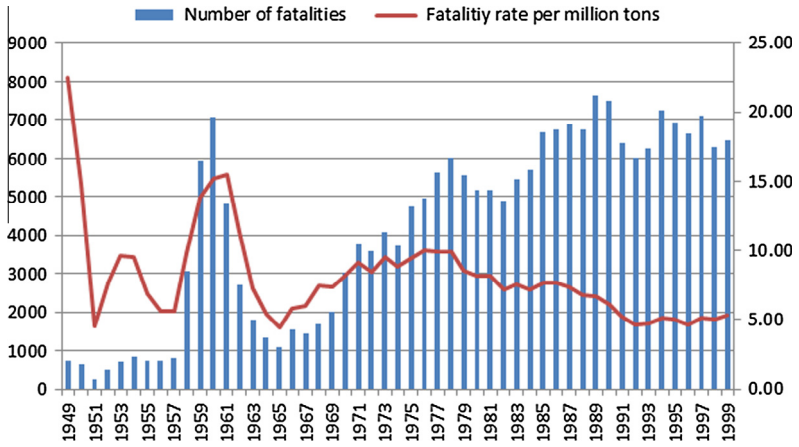

Fig. 2. China's fluctuations of coal mine safety performance from 1949 to 1999. *Source*: *China Coal Industry Statistical Yearbook* (*2013*).

regulating coal mine safety but they also had the responsibility of setting and meeting production quotas, which lead to in effective implementation coal mine safety regulations. Therefore, Chinese government reformed the coal mining safety management system between 1998 and 2000 (Song and Mu, 2013). The outcome of the reform process was the coal mining safety inspection system shown in Fig. 3 (Liu et al., 2011).

The last fifteen years has seen many significant improvements in the regulatory regime for coal mining safety and these improvements have made many significant contributions to coal mine safety performance as shown in Fig. 4. For instance, the fatality rate per million tonnes has decreased from 5.71 in 2000 to 0.29 in 2013 according to the *China Coal Industry Statistical Yearbook*. Although the total accidents, total number of fatalities and fatality rate per million tonnes have decreased year after year, the coal mine safety situation in China is still very grim compared with some developed countries. For example, in 2011, the total number of fatalities and fatality rate per million tonnes are 1973 and 0.564 respectively. If we compare to USA in the same period, we have 21 and 0.019 respectively. The comparison shows that China's death toll and fatality rate per million tonnes are approximately 94 and 30 times higher than America's death toll and fatality rate per million tonnes respectively (Wang et al., 2013). Therefore, coal mining safety remains as one of the most significant outstanding problems in China.

In the process of coal mining safety inspection, is the responsibility of the State Administration of Coal Mine Safety (SACMS) and the Local Regulation Departments of Coal Mine Safety (LRDCMS) as shown in Fig. 3. Different interests and influences of SACMS, LRDCMS and the coal enterprises lead to conflicts of interest. As a result, although China has established a set of strict laws, regulations and rules on coal mine safety, these laws and regulations are rarely implemented, which makes it difficult for central government to develop and implement the effective inspection strategies