Journal of Mineral Resources Engineering, 9(4): 39-59, (2024)

Imam Khomeini International University
Vol. 9, No. 4, Winter 2024

نشریه مهندسی منابع معدنی
Journal of Mineral Resources Engineering
(JMRE)

Research Paper

The Evolutionary Tripartite Game of the Government, Mine Management, and Miners in Ensuring the Safety of Mines

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Received: 09 Apr. 2023 **Accepted: 30 Oct. 2023**

Abstract: In order to investigate the relationship between the management and executive components of the mine and to improve the safety level of the system, this paper introduces a new method for evaluating and managing the safety of the mining system. For this purpose, game theory has been used to solve mining safety issues. Game theory is a structured tool that can examine interactions between two or more players to understand their actions in certain situations. In this paper, evolutionary game is used because of expressing the dynamics of relationships between players. The introduced model simulates the interactions between the government, managers, and miners under different conditions; also,the influence of regulatory factors on them in the system is evaluated. The results show that the effect of each factor on system safety is different and players affect the system safety according to each regulatory factor. Among these factors, the influence of punishments applied by game supervisors on the behavior of the mine management and mine workers was the greatest. So that with the increase of fines, the players adopted strategies aligned with safe production in a short time. Subsequently, the impact of government incentives was also investigated and it was determined that in exchange for increasing the reward factor to the management and mine workers, a change in strategy and safe production will be established in the mine.

Keywords: Evolutionary game theory, Triparitite game, Mine management, Safety issues.

How to cite this article
Fazli Allah Abadi, A., and Ataee-pour, M. (2024). *"The evolutionary tripartite game of the government, mine management, and miners in ensuring the safety of mines"*. Journal of Mineral Resources Engineering, 9(4): 39-59.
DOI: 10.30479/JMRE.2023.18489.1630

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INTRODUCTION

Safety within the mining industry is of utmost importance, demanding meticulous attention and effective management. Given the inherent high risks associated with mining activities, ensuring the well-being of workers and the provision of secure working environments are imperative. Safety incidents in mining operations persist as critical concerns [1]. The extensive nature of mining activities necessitates a comprehensive focus on safety and environmental considerations to attain desired objectives. The establishment of robust safety standards is intrinsically linked to the motivation and awareness of those engaged in mining operations [2]. Factors such as the absence of continuous supervision by supervisors, workers' indifference to safety protocols, and the inherent hazards of mining significantly contribute to accidents within mines [3]. In response to these challenges, this paper delves into the interplay between supervisory and executive components within the mining industry and introduces a novel approach aimed at elevating safety standards within mining systems. To enhance and sustain safety in mining operations, it is imperative to implement appropriate strategies and management approaches. This entails creating a communicative bridge between managerial and executive elements to heighten worker awareness regarding safety, deploying advanced equipment and technologies and fostering a culture of safety compliance within the mining milieu [4].

Diverse factors wield influence over mining safety, encompassing government regulations, financial incentives, safety transgressions, safety incidents, and the efficacy of safety management and supervision. A comprehensive examination of these elements and their impact on the behaviours and decisions of various stakeholders in safety management can facilitate the refinement and optimization of safety protocols in mining operations. Employing the potent analytical framework of evolutionary GT, this paper embarks on an exploration of the application of this theory in addressing safety concerns within the mining domain. By harnessing the power of game theory, the intricate interactions between the involved stakeholders can be scrutinized, especially under dynamic and specific conditions. The dynamic nature of this framework is underpinned by a dynamic synchronization approach, serving as a game-solving algorithm. Subsequently, this paper utilizes MATLAB software to investigate the influence of supervisory management parameters on the choices made by mine workers regarding compliance and non-compliance with safety protocols.

METHODS

Through the evolutionary GT, a dynamic feedback loop has been constructed to model interactions between the management and operational elements, aimed at enhancing the safety of mine workers and optimizing the managerial approach in mining operations. GT involves the mathematical modeling of outcomes in a strategic environment where individual success in decision-making is contingent on the choices made by others [5]. To formulate a game, certain assumptions regarding the game type, player strategies, and associated rewards and punishments must be established. In the context of evolutionary GT, the superiority of a strategy is determined by examining the changing frequencies of different strategies over a specified modeling period. This dynamic assessment can be carried out using a replicator dynamics model, which tracks how the prevalence of various strategies evolves within a population over time. Within the framework of the safety monitoring game in mining, the players are driven by the objective of maximizing their payoffs over the modeling period. As the model progresses through time, players monitor and assess the consequences of their chosen strategies, subsequently fine-tuning their strategies for future rounds. This dynamic adaptation allows players to strive for the ultimate goal of optimizing the mine safety. The game comprises three pivotal players: the government, mine management, and mine workers, each serving as the principal participants in the core game. The government assumes the role of overseeing safety regulations within the mine, while mine management is entrusted with the responsibility of ensuring safety at the mining site. Acting as external entities, the government and mine management are charged with the task of guaranteeing safety within the mining environment. The third player in the game is the mine workers, and all three players are driven by rational decision-making, with their strategic choices designed to maximize their respective outcomes. After specifying the game's parameters and making assumptions about the chosen strategies, players achieve various payoffs. In order to check the stability of the players, after determining the game payoff matrix, the achievement of each player can be determined with the probability of choosing each of the stated strategies. Using the function of each player's payoff, one can

understand how to choose a strategy during the duration of the model. Ultimately, utilizing the predefined data, the payoff functions for each of the three players are computed. This simulation serves as a valuable tool for comprehending how the regulatory parameters of the overseeing authority (as represented by the government) impact the behavior of operational players and how different strategies are selected over the course of the modeling period.

FINDINGS AND ARGUMENT

For a more in-depth analysis of the players' outcomes in the evolutionary game, considering constraints and dynamic equilibrium equations, this study employs MATLAB software for the simulation of the evolutionary game. Subsequently, to simulate the evolutionary game model effectively, the parameters influencing the players' achievements must be defined. As previously mentioned, the study aims at revealing the connection between players' strategies and their payoffs. To examine the players' behaviors, government punishments with various values were initially introduced into their achievements. Equal punishments for the supervisors in the game were simultaneously simulated at four values of 5, 10, 15, and 20.

To further investigate the evolutionary behaviour of the players, their equilibrium equations were analyzed in a time interval called "Time". This interval is divided into 100 time units for simulation purposes. At every time unit, the likelihood of selecting the government's strategy is determined by the value of F(x), while the mining management's choice is influenced by F(y), and miners' decisions are shaped by F(z). In the next analysis, the effect of government subsidies to achieve safety provision is discussed. The amount of government subsidy for the provision of equipment, which is determined by the parameter μ, varies between 0 and 1. The influence of punishments and subsidies on the evolutionary path of the safety game is shown in Figure 1.

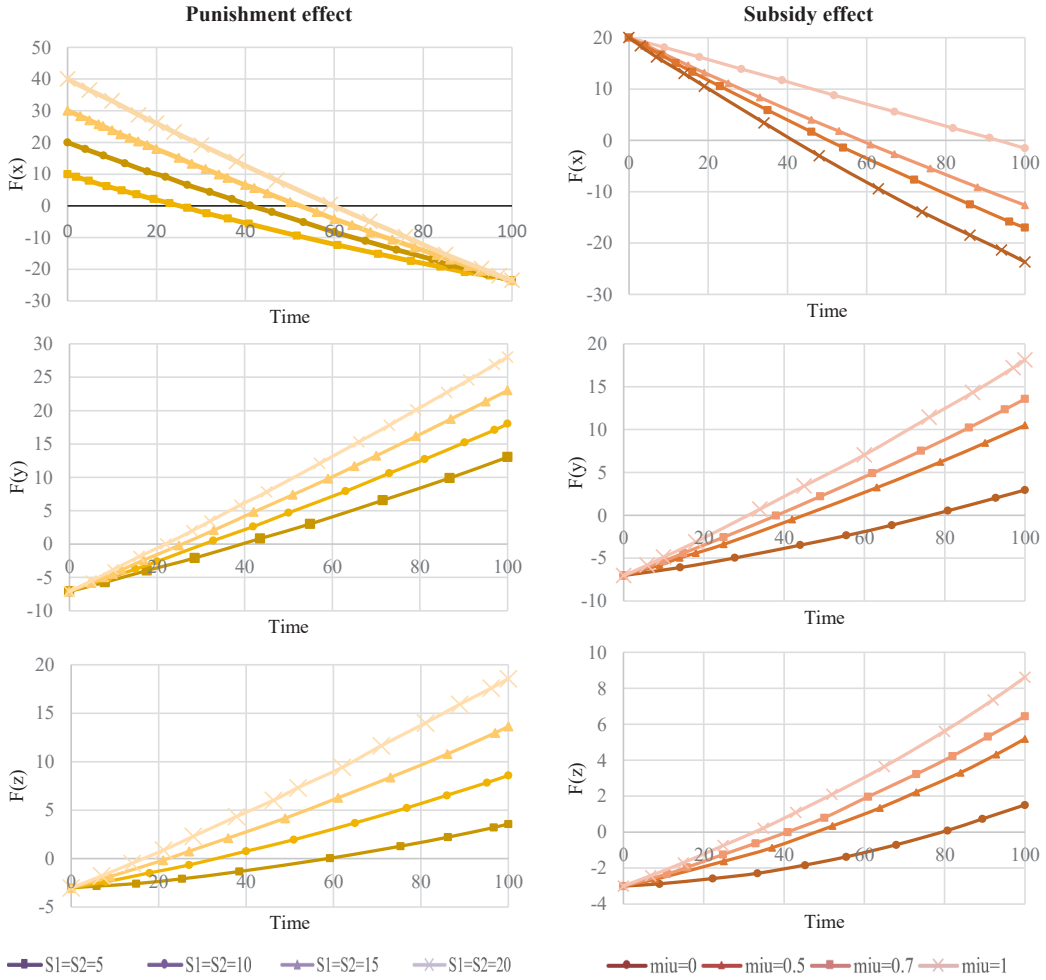

Figure 1. The effect of punishments and subsidies on players' strategy choices

The study investigated the impact of government punishment on the behaviour of three key players involved in the mining safety game, namely the government, mine management, and miners. Various punishment scenarios were examined and it was observed that the higher punishment increased the government's inclination toward the stricter regulation. The management's behaviour shifted from non-regulation to adopting safety measures as punishment were imposed, and miners tended to comply with safety regulations when subjected to higher punishment. In addition, the study explored the influence of government subsidies on safety equipment purchases. It was found that as the subsidy coefficient (μ) increased, the government quickly shifted towards non-regulation and non-support, reflecting rational decision-making to maximize their income. Overall, the study provided valuable insights into the dynamics of safety management in mining, highlighting the importance of regulatory measures and incentives in shaping the behaviour of the involved parties.

CONCLUSIONS

In the context of a three-player evolutionary game, the initial phase involved a comprehensive analysis of interactions and achievement functions for each participant within the mine safety system through the use of game tables. Subsequently, following the establishment of the three-player game model, the study delved into the evolutionary dynamics of the safety system under various regulatory scenarios. Based on the core premise, the government imposes punishment on executive participants, specifically miners and mine managers, in the event of their adoption of unsafe strategies. The simulation of the evolutionary game model revealed that the decision-making behaviours of these executive participants significantly influence the overall outcomes for the regulator. This interplay gives rise to conflicting interests within the game, ultimately resulting in a stable equilibrium at the coordinates (0, 1, 1). This equilibrium signifies that the government opts for a non-regulatory strategy, while mine managers and workers choose strategies involving the implementation of safety equipment and compliance with regulations, respectively. The application of punishment values was executed in a fixed and incrementally ascending fashion within the evolutionary model. This ascending trend induces a transformation in the strategies employed by the executive participants, directing them toward safety assurance strategies, and thereby swiftly curbing the incidence of unsafe practices within mines. Conversely, an escalation in the government subsidy rate proves highly effective in mitigating safety-related incidents in mining operations. Notably, when the government subsidy rate falls below 0.5, the motivating impact of utilizing safety equipment by the mine management and adhering to regulations by workers takes longer to manifest, compared to situations with a subsidy rate exceeding 0.5.

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