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Simulation study of coal mine safety investment based on system dynamics

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ABSTRACT

To generate dynamic planning for coal mine safety investment, this study applies system dynamics to decision-making, classifying safety investments by accident type. It validates the relationship between safety investments and accident cost, by structurally analyzing the causality between safety investments and their influence factors. Our simulation model, based on Vensim software, conducts simulation analysis on a series of actual data from a coalmine in Shanxi Province. Our results indicate a lag phase in safety investments, and that increasing pre-phase safety investment reduces accident costs. We found that a 24% increase in initial safety investment could help reach the target accident costs level 14 months earlier. Our simulation test included nine kinds of variation trends of accident costs brought by different investment ratios on accident prevention. We found an optimized ratio of accident prevention investments allowing a mine to reach accident cost goals 4 months earlier, without changing its total investment.

1. Introduction

In recent years, accidents have plagued the coal mining industry in China, and safety in production has become a constraint to the proper development of China's coal industry. Studies have shown that security investment by coal mining enterprises is closely correlated to safety performance and economic benefits [1–4]. Safety benefits manifest in a variety of ways including latent, hysteretic, indirect, and complicated; these variable features are likely to cause companies to pursue unscientific safety investment decisions, create irrational structures, and miss appropriate timing, so that limited investments in safety are not effectively utilized. The effective deployment of security budgets has become a serious problem. To address this issue, firms must be able to find the right investments within a reasonable time while maintaining high levels of safety performance. Firms that accomplish this will improve economic efficiency.

After the 1990s, foreign companies began to focus on the economic analysis of safety investments, mainly focusing on the following aspects: the comprehensive study of safety investment efficiency, research on occupational health and costs of safety, reasonable research on safety investment, and risk-based safety investment decision research [5–14]. Domestic coal mine safety investment research has mainly focused on coal mine safety investment economic benefit analysis, structural analysis of coal mine safety investment, coal mine safety investment efficiency evaluation, evaluation index system, and methods of coal mine safety investment [1,15–20].

Increasing coal mine safety involves a wide range of activities. It is a systematic project that requires management of multiple complex areas simultaneously. system dynamics (SD) refers to a computer simulation technique that can provide a scientific basis for the safety investment decisions and it has been widely used in land-use planning, regional economics, business management and other fields [21]. SD is also applied in the field of coal mine safety economics and management, but its use is concentrated in the research of accident causation, the human behavioral factors in coal production, and safety management systems, etc. [22–28]. Coal mine safety investment decisions based on SD analysis have not been previously reported. This article will study SD for safety inputs by dynamically considering the demand in safety investment and the change in the demand structure. Understanding safety investments from this perspective will allow policy-makers to adjust the scale, strength, structure, and timing of safety investments. From an enterprise security point of view, it is important to increase the use of science-based decision-making when allocating safety investments in the coal industry.

2. System dynamic model of safety investment on coal mine

2.1. Causal graph

Safety investments in coal mine operations consist of the following categories: safety training investment, occupational

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protection investment, safety management investment, and key factors of investment in accident prevention. Accident prevention investments are classified into six areas according to the main types of coal mine accidents. These areas are fire prevention and mitigation, water prevention and control, dust prevention, ceiling reinforcement, gas control, and prevention of electromechanical and transportation accidents. The above categories and classifications are used to analyze various factors that could affect coal mine safety investment, the validation of system boundaries, and the causality of safety investment systems. The causal relationships in safety investment categories are shown in Fig. 1 below.

2.2. SD flow chart and equation

A system flow chart design based on the previous causality chart is shown below in Fig. 2.

The main SD equation is defined as follows: (1) Safety training and education investment = INTEG (New investment in safety training and education-demand for safety training and education, initial value). (2) New investment in safety training and education = (1 + Adjustment coefficient of safety training and education input) ∗ Expectation of safety training and education input. (3) Demand for safety training and education = Cost of training ∗ Num-

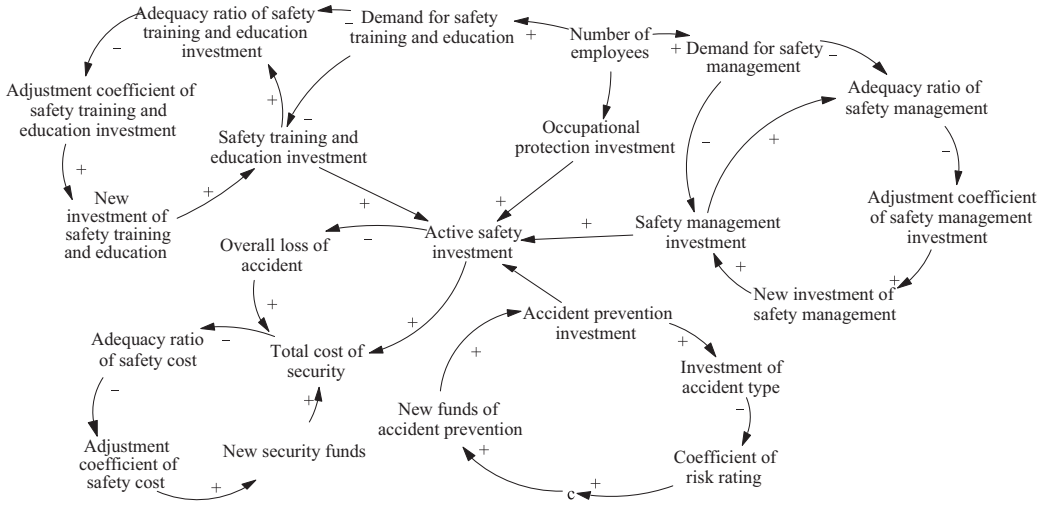

Fig. 1. Causal relationships of safety investments in coal mines.

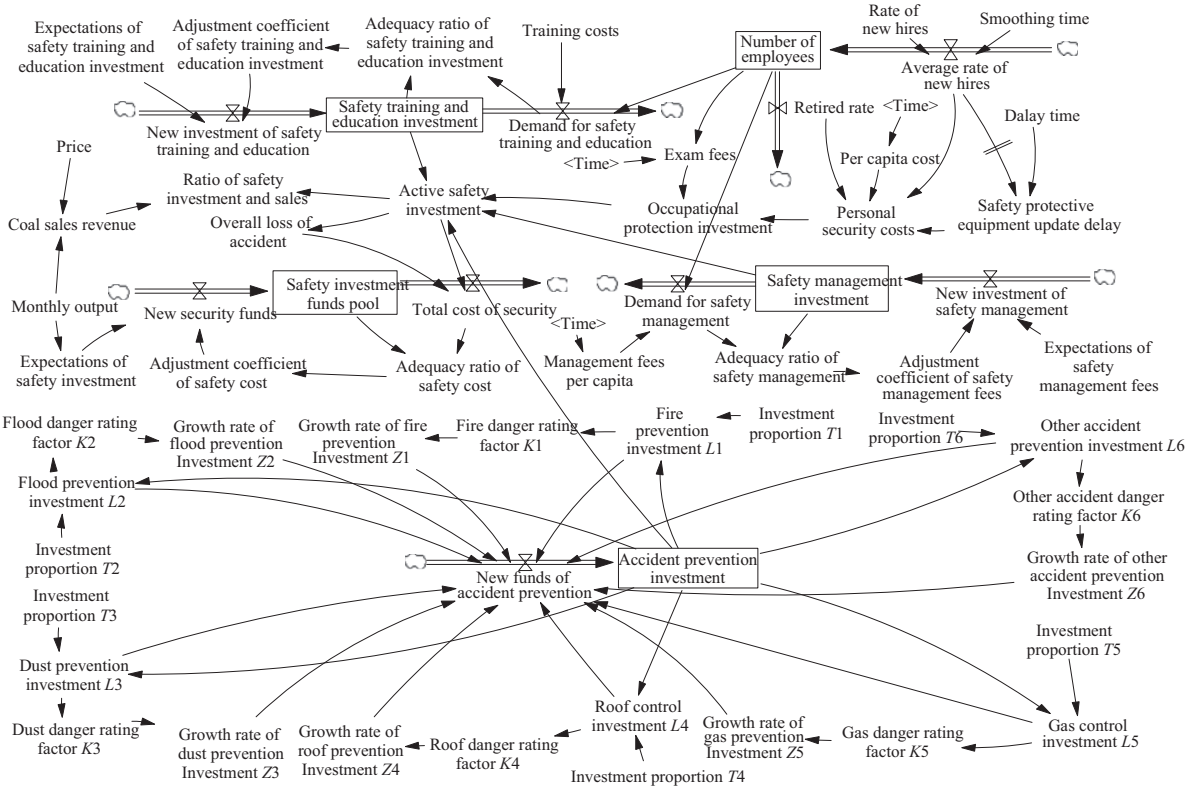

Fig. 2. System flow chart of safety investments in coal mines.