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Risk, profit, or safety: Sociotechnical systems under stress

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ABSTRACT

Sociotechnical systems are designed to perform technical functions under organizational management for the benefit of society, but face major challenges in high risk operations such as mining. The mining industry in Turkey confronts a set of conflicting goals. Underground mining is a dangerous operation that creates continuing exposure to risk for miners who extract the coal. Yet, coal is an essential commodity for the growing Turkish economy, with mining operations now largely conducted by private companies seeking to maximize profit. Known strategies for managing mining operations to increase workers' safety exist and have been legally adopted in law and policy in Turkey, but require substantial investment of resources and time to put into practice. These same requirements in practice reduce profit to mining companies and slow production. The challenge is to balance these conflicting pressures in the mining industry to achieve low-cost energy for society, maintain safety for the miners, and ensure reasonable return on investment for mining companies. Achieving this balance in practice represents a classic collective action problem in which maximum benefit to the whole society can only be achieved by reasoned, informed action taken by multiple actors adapting to changing conditions under constraints of limited time and resources. These conflicting demands require a continual process of monitoring uncertain conditions, calibrating investment in safety in relation to cost of failure, and adapting to changing operating conditions in near-real time. We explore this set of conflicting pressures as a policy issue that confronts the mining industry globally, but inquire specifically into conditions that led to the deadly mine fire in Soma, Manisa, Turkey on May 13, 2014 as a study of a sociotechnical system under stress.

1. The mining industry as a sociotechnical system

Conflicting goals among interdependent actors create cumulative stress in the underground mining industry. These goals include managing the technical constraints of underground operations, reducing physical risk to miners, and ensuring a profitable return to mining companies seeking to maintain their investment. These tensions are exacerbated by the mounting pressure for low-cost energy in rapidly advancing economies, and can be observed in many countries, for example, China, South Africa, India and Turkey (Sari et al., 2004; Geng and Saleh, 2015; Leger, 1991; Maiti et al., 2009). Approached from a strictly linear perspective, each separate goal limits the achievement of other, related goals. Reducing the risk of accidents and fires in underground mining operations increases safety for the workers, but likely increases the cost of operations for the mining companies, reducing their margin of profit. Reducing the margin of profit for the companies likely limits their incentive to invest in mining operations, decreasing employment opportunities for the workers. Reducing employment opportunities for workers likely slows activity in other sectors of the economy, limiting the advancement of the wider society. Consequently, the risk in underground mining comes not only from the uncertainties embedded in the operation itself, but from the uncertainties exacerbated by the loss of the energy resource that coal provides to the wider society.

Given the sobering losses in lives and mounting costs in productivity that are reported repeatedly from underground mining operations that depend upon legal regulation, market incentives, and informed practice, we reframe the problem of managing risk in underground mining as an interdependent, sociotechnical system. In doing so, we ask four basic research questions: 1. What major risks and benefits characterize underground mining? 2. Who are the major actors engaged in underground mining operations, and what are their points of potential conflict and collaboration? 3. What are the existing patterns of interaction among these actors? 4. What kinds of information and incentives would lead these interdependent actors to adapt their performance to create a sustainable, productive, safe mining industry?

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Three interacting conditions contribute to recurring tensions in the mining industry: (1) risk inherent in underground mining, including risks associated with conventional (non-mechanized) panels (Sari et al., 2004); (2) margin of profit claimed by the mining companies; and (3) cost of safety measures, equipment, and training for the miners. Each of these conditions operates on a continuum that intersects with the other two conditions. The interacting relationships among these conditions can be framed as propositions to illustrate the interdependencies that confront public, private, and non-profit managers as they seek to balance the competing interests endemic to the underground mining industry. The propositions are;

As risk in the mining industry increases, the cost of safety measures also increases.
As the cost of safety measures increases, the margin of profit decreases.
As the margin of profit decreases, the investment in safety measures decreases.
As the investment in safety measures decreases, risk in the mining industry increases.

The conundrum posed by this circular set of propositions warrants further investigation and explication. First, conducting underground mining operations involves inherent danger, with the risk of spontaneous combustion, emission of dangerous gases, and collapse of roofs and rock falls in mine galleries (Duzgun, 2014; Saleh and Cummings, 2011). Further, lack of mechanized panels increases the risk by escalating the impact of a possible accident, due to large numbers of workers in the underground mines at any given time. Reducing the risk of sudden threats in the internal operations of the mine requires a continuing investment in monitoring daily operating conditions, training miners to observe safety procedures, maintaining equipment in good operating condition, and building an informed knowledge base among all participants (Expert interview, Zonguldak, June, 2014). All of these actions are deemed essential, but they necessarily raise the cost of production and lengthen the time involved in the extraction of coal. Accurately calculating the cost of time, effort, and expertise essential to manage the risk of underground mine operations is fundamental to effective management of the mines.

Second, commercial companies engage in mining to make a profit, and consequently seek to keep costs low. This objective is further complicated by the tension between short-term profit and long-term sustainability of mining operations. If risky conditions are ignored and safety precautions are not taken, the mine may yield short-term profits that win fleeting political support, but belie the actual long-term costs of operations in an inherently dangerous industry. Consequently, unanticipated fires and sudden losses in manpower and production may erase short-term gains, making the mine unprofitable long-term.

Third, the cost of safety carries the implicit price of credibility of the mining industry as a reliable enterprise in a developing economy, as well as the credibility of decision makers, public and private, who assume responsibility for managing the system. If the larger benefit of mining is to produce energy for the welfare of the society, but, in fact, the price of that energy is paid with the lives of miners in an unprotected industry, the judgment of the political and private managers is called into question.

In summary, the dynamic tensions that drive the search to reduce risk, increase profit, and enhance safety lead the major actors committed to those goals in opposing directions, creating a thin margin for error in any direction. Managing the operations of underground mining involves high risk of economic loss to investors and threat to life and injury for miners, potential benefits in profits for private companies and steady jobs for miners, countered by high costs of failure in an industry characterized by high uncertainty and cascading interdependencies. To explore these tensions in more detail and consider an alternative model for managing this conundrum more effectively, we undertook a case study of the conditions, actions, and decisions that characterized the mine fire of May 13, 2014 in Soma, Manisa, Turkey. The remaining sections of this article follow in five parts. Section 2 will present a theoretical framework of complex, adaptive systems of systems to guide the inquiry. Section 3 will briefly describe the methods and data used in this analysis. Section 4 will summarize the context of underground coal mining in Turkey at the time of the Soma mine fire on May 13, 2014. Section 5 will describe briefly the operating conditions at the Eynez mine in Soma where the fire occurred, the actors engaged in mining operations and the interactions among them, as well as the points of actual breakdown and potential collaboration in the system. Section 6 will summarize the interdependencies among the actors, showing the cascade of decisions that resulted in the deadly fire, and possible strategies to reframe the interactions in a more constructive way through a Bayesian influence diagram. In Section 7, we draw conclusions from the analysis, and offer suggestions for considering the mining industry as a complex, adaptive system of systems, a more flexible, interactive framework for managing the inherent risk more effectively.

2. Analytical framework

2.1. The mining industry as a 'complex adaptive system of systems'

The issues of mine safety and occupational health have attracted significant interest and attention by researchers in a range of disciplines: engineering, industrial safety, occupational health, geology, decision making, and psychology (Mallett et al., 1993; Braithwaite, 1985; Jiping, 2011; Bahn, 2013). Much of the earlier research has treated the mining industry as a set of independent components that could be managed separately, without acknowledging the interactions among the components that make the system function or fail as a whole. For example, researchers have analyzed the design of engineering strategies for safer extraction of coal, but omitted the training needed for the miners to execute them. [Expert reference, Zonguldak, June 2014]. Others have designed mechanical devices to monitor toxic gases, but missed the time and expertise required to install the devices and analyze the data collected by them [Expert reference, Istanbul, June 2014]. Legal policies have specified regular procedures for inspecting the operating conditions in the mines, but failed to allocate the funding necessary to send experienced inspectors to the mines to conduct the inspections. [Mining Law, 1985; expert reference, Soma, May 2014] Recent research has considered the mining industry as a system (Saleh and Cummings, 2011), an insightful approach, but these authors still view the mining industry as a distinct system focused on its operational components.

In contrast, we propose that the mining industry operates as a sub-system embedded within the larger sociotechnical system of the wider society. This approach represents a 'complex, adaptive system of systems' (Glass et al., 2011), a set of concepts and metrics developed at Sandia National Laboratories to characterize and measure change in dynamic, interdependent systems as they adapt to new conditions and novel interactions among their components. A complex adaptive system emerges as a result of continued interaction of its constitutive actors. While the actors have some degree of independence and strategies, their behavior is very much constrained by the structure of the system that emanates from the totality of interactions. Similarly while the system constrains individual elements, the larger structure is also shaped by

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