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A process mining approach to improve emergency rescue processes of fatal gas explosion accidents in Chinese coal mines

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ABSTRACT

Gas explosion has always been one of the major accident types in the coal mines of China, and reliable emergency rescue process is one of the key guarantees to minimize accident losses. As an emerging discipline to discover bottlenecks and position deviations of processes, process mining is widely used to improve various business processes in recent years. Nevertheless, scarcely does any research apply it to the field of coal mine emergency rescue to our knowledge. In this study, we apply the technique of process mining to domain of gas explosion accident emergency rescue in coal mines. 50 considerable and major gas explosion accidents, which occurred from the second half of 2006–2014 in Chinese coal mines, are selected as log data. The aspects of control-flow perspective, case perspective, helicopter view, organizational dimension and performance perspective are analyzed by process mining. In terms of control-flow perspective, the emergency rescue model is extracted by the inductive miner in ProM, correspondingly, conformance checking and comparison with real-life model have shown the validity of our work. Research also shows that the average length of cases is 23.72 events, and 60% of the cases are under the average length; 56% of the gas explosion accident emergency rescue processes last less than two days; emergency rescue headquarters, barmaster and medical staff share the highest centrality in social network of rescue; the rescue performance is more affected by accident grade, compared with the factors of accident site, region of coal mine and coal mine ownership.

1. Introduction

1.1. Prevention situation of gas explosion accidents in Chinese coal mines

As of now, China is the world's largest producer and consumer of coal (Wang et al., 2014). Although the number of fatalities has steadily decreased year by year, compared with the United States under the same safety performance index, the world's major coal-producing country, there is still a great gap of safety in coal mines between China and the USA (Nieto et al., 2014; Yin et al., 2017). For various types of coal mine accidents, gas explosion accident is undoubtedly one of the biggest threats to underground coal mines (Chen et al., 2013; Yin et al., 2017). Even with the downward trend of death toll during 2004–2014 for considerable and major gas explosion accidents in Chinese coal mines, the proportion of gas explosion accidents in total casualties of considerable and major coal mine accidents seems unstable, and what's more, has shown an upward trend between the year of 2010 and 2014 (Fig. 1).

1.2. Emergency rescue situation of coal mines in China

The definition of mishap is the results of unintentional death, injury, loss of property and so on (DoD, 2012). On the one hand, safety researchers focus on reducing the accident incidence, on the other hand, they pay attention to the reduction of the mishap severity. Once a gas explosion accident (GEA for short) in underground coal mine occurs, emergency rescue is the vital pathway to minimize casualties and property losses. As of 2013, there are 397 specialized mine rescue teams in China (SAWS, 2014), serving more than 12,000 coal mines nationwide (SCIOPRC, 2014). Though the state has been shutting down small coal mines in a large number of cases annually, the number of coal mines is still in the absolute advantage relative to the number of emergency rescue teams up to present.

Many correlative factors in an underground coal mine system are critical to a GEA emergency rescue, such as the workers' knowledge and response ability to complex and ever-changing underground (Kowalski-Trakofler et al., 2010). Furthermore, some rescue processes which have

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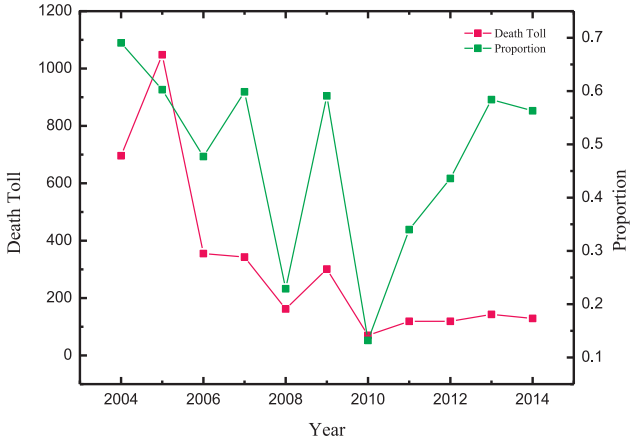

Fig. 1. Death toll of considerable and major GEAs, and proportion of GEAs in total death toll of considerable and major coal mine accidents (Data for death toll of gas explosion accidents and the proportion is from State Administration of Coal Mine Safety (SACMS, 2015)).

led to the expansion of the accidents are found as well (SACMS, 2015). This is directly related to decisions of emergency rescue commander. When searching the key words of improper coal mine rescue in the SAWS website, a large number of directly relevant messages will be represented.

Normally, the guidance of coal mine emergency rescue is mine rescue regulations (by SAWS) and different levels of contingency plans based on the laws and regulations of governments and industry norms. For instance, law of the People's Republic of China on safety production clearly stipulates that the enterprises shall formulate contingency plans for accidents (NPC, 2014). To make procedural information comprehended by users of every hue, it has become a quintessential activity to apply textual process descriptions with conceptual process models in the enterprises (ver der Aa et al., 2017). With similar principle, at the end of the contingency plan, a flow-chart of emergency rescue is presented in the ordinary course of events (real-life model). Nevertheless, coal mine emergency rescue has not been paid enough attention up to now, and it is a weaker link in the safety work system of coal mine in China (Niu et al., 2012). As a matter of fact, both governments and enterprises at different levels have varieties of emergency plans. In the case of ignoring the individual contingency plans, only integrated plans are often more than 100 pages, and even if the professional safety staff can hardly dig out useful information in good season (Guo et al., 2013). According to our interviews with several safety supervisors in two provinces of China and investigating emergency plans of two large coal mines in the other two provinces in China, for one thing, the contingency plans of coal mines follow the laws and regulations to a certain extent, for another, largely based on experience. Furthermore, excessive reliance on paper plans will weaken the efficiency of emergency management in coal mines (Cui, 2015).

1.3. State-of-the-art for process mining application

Extracting knowledge from event logs to discover, monitor and improve real workflows is the basic idea of process mining (PM for short) (van der Aalst, 2016). PM has been widely applied in plenty of fields, e.g., human reliability analysis, workflow redesign of gas industry manufacturing process, healthcare process improvement and so forth (Kelly, 2011; Park et al., 2016; van Beest and Maruster, 2007; Park et al., 2015; der Weerdt et al., 2013; Gupta, 2007; Rojas et al., 2016; Rebuge and Ferreira, 2012; Perimal-Lewis et al., 2012; Poelmans et al., 2010; Mans et al., 2015; Bogarín et al., 2018; Intayoad and Becker, 2018).

In more concrete terms, Kelly (2011) incorporated PM into human reliability analysis; Park et al. (2016) did a feasibility study in a nuclear power plant scene to assess the quality of work process; for the sake of identifying appropriate process redesign, van Beest and Maruster (2007) used PM and simulation techniques in a Dutch company belonging to gas industry; PM was applied to analyze the workload and delay in manufacturing process by Park et al. (2015); der Weerdt et al. (2013) verified the value of PM to position organization inefficiency in insurance company; Gupta (2007) found the association rules that the complications C_*-VKF*, *atrium-flutter* and C_*Oligurie* (< 5 ml/kg/24 u) always occur together for the patients in the ICU and the patients receiving treatment B_*Thoraxdine* always received the treatment B_*Beademing* as well with the technique of PM; Rojas et al. (2016) summarized the PM algorithms, techniques, tools, methodologies and approaches in the domain of healthcare improvement; Rebuge and Ferreira (2012) utilized the technique of PM to identify regular behavior, process variants, and exceptional medical cases for a hospital emergency service; Perimal-Lewis et al. (2012) presented a synergy of PM technique and statistical data analysis to discover inpatient process patterns, ward types, waiting time and length of stay; Poelmans et al. (2010) combined PM with data mining techniques to discover the cause of the patients who refused the key intervention "revalidation"; Mans et al. (2015) summarized the implementation of the PM in the field of healthcare, and the data quality issue was elaborated synchronously; Bogarín et al. (2018) did a survey on educational process mining, who outlined the application of PM to discover and analyze the educational process; Intayoad and Becker (2018) propose a methodology to elicit actual business process model in the scene of manufacturing and logistic for large transaction data.

However, scarcely does any researcher apply it to the field of coal mine emergency rescue process. Different from empirical emergency rescue process models in the contingency plans mentioned previously, PM can discover emergency rescue process models from GEA reports which have recorded the emergency rescue processes systematically, meanwhile, bottlenecks and deviations will be positioned when analyzing the mining results. It is important to point out that the models in this article are conceptual models (Friedrich, 2010).

Correspondingly, the structure of this paper is as follows. Above all, in Section 2, materials and methods of this research are provided. Afterwards, in Sections 3 and 4, the case study is addressed. Discussions are presented in Section 5. Finally, Section 6 provides some conclusions and anticipation of future work.

2. Materials and methods

Fig. 2 is the framework of this study, which outlines the main procedure. The first part addresses data acquisition, followed by data preprocessing. Then the technique of PM and data reprocessing is presented, which is followed by PM and data reprocessing until the mining results accord with the needs of business staff to the utmost. Final part of the framework is the analysis of mining results and the advices on the improvement of GEA emergency rescue processes in underground coal mines.

2.1. Data acquisition

As the principle of accident prevention depicted by Heinrich Pyramid Law, in a workplace, of the 330 accidents, 300 accidents result in no injury, 29 accidents cause minor injuries and 1 accident results in serious injury (Heinrich et al., 1980). Accordingly, for the target of accident prevention, all of the no injury mishaps, minor injury mishaps and serious injury mishaps of gas explosion in coal mines should be our source data. However, the central issue of this study is emergency rescue process, and data quality is one of the most important challenge the same as other PM practices (van der Aalst, 2016). As the case stands, coal mine accidents can be classified into four grades in China (considerable accident, major accident, serious and ordinary accident)