Physica A 515 (2019) 419–429

Contents lists available at ScienceDirect

Physica A

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

Time-statistical laws of workers' unsafe behavior in the construction industry: A case study

Shengyu Guo [a], Pan Zhang [b,*], Lieyun Ding [b]

[a] *School of Economics and Management and Institute of Management Science and Engineering, China University of Geosciences, Wuhan, China*

[b] *School of Civil Engineering and Mechanics and Institute of Construction Management, Huazhong University of Science and Technology, Wuhan, China*

HIGHLIGHTS

- Time-statistical laws are explored to analyze the fluctuations in unsafe behavior during construction.
- The interevent time distributions of workers' unsafe behavior exhibit fat-tailed distributions.
- Workers' unsafe behavior has the characteristics of burstiness and memory.
- Frequent and widespread unsafe acts are found in different worker types and construction phases.

ARTICLE INFO

Article history:
Received 24 May 2018
Received in revised form 28 July 2018
Available online xxxx

Keywords:
Unsafe behavior
Statistical law
Human dynamics
Association rule
Apriori algorithm

ABSTRACT

The construction industry is extremely high risk, and the unsafe behavior of workers is thought to be a critical factor in that risk level. Considering the limitation that existing studies merely analyze the relationship between unsafe behavior and the time factor, this paper uses a case study to explore two aspects of the time-statistical laws of workers' unsafe behavior: (i) the characteristics of interevent time distributions and (ii) association rules for different worker types. First, workers' unsafe acts at one metro construction site are collected and classified. Second, interevent time distributions of workers' unsafe behavior from different types are analyzed via a human dynamics approach. Finally, a rule mining database is built, from which association rules concerning unsafe behavior, worker type and construction phase are determined using the Apriori algorithm. The results indicate that the interevent time distributions are fat tailed and show that workers' unsafe behavior has the characteristics of burstiness and memory. Furthermore, the strong rules 'construction phase → unsafe behavior' exist for different worker types. The research presented in this paper can facilitate a better understanding of workers' unsafe behavioral patterns and can accordingly be used to control frequent and widespread unsafe acts among different types of workers in different construction phases.

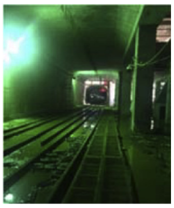
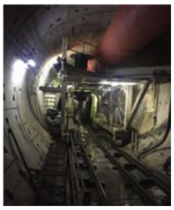
1. Introduction

As one of the safety risks at construction sites, workers' unsafe behavior often causes accidents and incidents that can result in death and economic losses. After studying nearly 75,000 accidents, Heinrich found that 88% of all industrial accidents were caused primarily by unsafe acts [1]. The statistical results obtained by Du Pont over the last ten years

* Corresponding author.
E-mail address: zhangpan2017@hust.edu.cn (P. Zhang).

https://doi.org/10.1016/j.physa.2018.09.091
0378-4371/

Table 1
Examples of unsafe acts in specific construction phases of the shield tunneling construction.

Construction phase	On-site photos	Unsafe act	Possible consequences
Shield launching (the shield machine is pushed into reinforced soil at the starting point of the tunnel)		Workers stand near unstable tunnel portal with exposed soil mass	Fall from height
Shield driving (the shield machine is driven on the track, and waste is cleared by vehicles)		Drivers are overspent Workers climb moving vehicles in the tunnel Workers play with their smart phones in the operating room of the shield machine	Mechanical damage Fall over Mechanical damage
Duct piece assembly (duct pieces are assembled by segment erector after shield driving)		Unnecessary workers enter the gyration radius of the segment erector	Collision injury

indicated that 96% of injuries were due to unsafe acts rather than unsafe conditions [2]. To understand the behavior patterns of workers for accident prevention, many studies focused on exploring interrelationships between unsafe behavior and various factors. In terms of the temporal aspect, insufficient data from construction sites hinder the process of analyzing unsafe behavior [3]. Combined with advanced technologies, state-of-the-art studies have begun to explore how to acquire real-time behavioral data from construction sites and control workers' unsafe behavior using such data. For instance, Guo et al. [4] developed a skeleton-based real-time identification method to recognize unsafe behaviors by simplifying dynamic motions into static postures. Li et al. [5] used the Proactive Construction Management System (PCMS) to provide post-event visualization analysis of unsafe behavior in training. Teizer and Cheng [6] designed a framework around real-time location tracking technology to analyze the spatial–temporal conflicts between workers-on-foot and identified hazards. However, data generated on site have not been fully mined to explore the relationship between unsafe behavior and the time factor. Because of the unique construction industry characteristic of changing work locations, a stochastic process was used to formulate workers' individual behaviors [7]. The situation is different when workers' behaviors are considered as different types of group behaviors during construction. Zhou et al. [8] noted that the risk level on construction projects rises and falls continuously during the whole construction, but failed to discuss the fluctuations of unsafe behavior over time.

Indeed, some types of unsafe behavior change dynamically with construction phases due to fluid and intensive construction work. Table 1 lists several possible unsafe acts that occur in specific construction phases of the shield tunneling construction. They have previously been identified through expert experience, leading to subject biases and inaccurate results. Fluctuations in common unsafe acts, such as workers failing to wear helmets, may also occur during construction. Time inhomogeneity in unsafe behavior needs to be verified by time-statistical laws. Time-statistical laws address behavior analysis, and two aspects are examined in this study: (i) the characteristics of interevent time distribution and (ii) association rules for different worker types. The laws reflect the fluctuations in unsafe behavior in the construction process. Once these laws are identified, temporal distributions of unsafe behavior will be revealed to better understand workers' negative behavioral patterns in the construction industry. In addition, critical unsafe acts among different worker types in different phases of construction can be clearly determined for further control on site. It is of great theoretical and practical significance for safety management and accident prevention.

Our understanding of human behavior has improved with the development of complexity science. In recent years, studies on human dynamics have attracted increased attention [9,10]. Considering that certain behaviors do not occur randomly over time and space, the law changes from a Poisson distribution to a power-law distribution [11]. Some data-driven methods, including complex networks, cluster analysis and association rule are used to further explore the detailed statistic characteristics reflected in such a distribution. Among these methods, the association rule reflects mutual dependency and