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Investigation of the causality patterns of non-helmet use behavior of construction workers

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ABSTRACT

Not wearing a safety helmet can result in serious injuries on construction sites, but the cause of such unsafe behavior is not yet well understood. This paper describes a practical field study to find the factors that influence non-helmet use on construction sites using a real-time tracking system (the Eye on Project or EOP), which is developed by our research team to provide an objective record of helmet use; and which overcomes the deficiencies of traditional recording methods (i.e. self-reporting). The application of association rules then combines designated risk factors and finds the causality patterns of non-helmet use. Based on the analyses, this paper develops a method of evaluating workers' risk level involving the intensity of multiple risk factors.

1. Introduction

The construction industry is considered to be one of the most hazardous and dangerous industries; there is a high accident rate within the field [21]. According to the Health and Safety Executive [22], construction workers suffer 10% of major injuries and 31% of fatal injuries. At same time, out of almost 4000 worker fatalities in private industry in a calendar year 2013, 796 or 20.3% were in the construction industry [36].

The International Labor Organization [24] and the Bureau of Labor Statistics [8] also published reports confirming a high fatality rate in the construction industry. Sousa et al. [40] stated that compared with workers in other industries, the construction workers are under a higher probability suffer from potential injuries and even die at work. In China alone, the State Administration of Work Safety reported that at least 2197 deaths occurs on construction site and almost 90% of the construction accidents are caused by human factors(i.e. unsafe behavior) 2014,the average death on construction site from 2005 to 2104 also reach at a formidable amount which is almost 2600 per year [23].

To enhance construction safety, a series of measures has been put forward to guide workers to wear helmets by both the law and construction managers. Kelm et al. [26] stated that employers should increase helmet use in three ways: (1) education and training, (2) incentives, and (3) enforcement. Despite large efforts and prevention techniques for accidents, many studies highlight the remaining factors that reduce safety on sites.

Head injuries are one of the most severe kinds of injury possible, as the head is both fragile and prone to collision [33]. On construction sites, traumatic brain injury is usually caused by falls and trench/scaffold collapse. Therefore, helmet is an important personal protect equipment (PPE) on construction site. Despite the great importance of helmet use, data collection of helmet use on construction sites is still in a relatively early stage. Previous studies always focus on the helmet use behavior itself and its contributing factors. Individual factors, such as gender, age, work experience and time of day have an obvious impact on unsafe behavior. Onsite data has always been collected after the occurrence of incidents and, until now, research has been forced to rely on data analysis and feedback. Current hazard-identification technology has obvious limitations [9]. Although modern eye–tracking technology can measure and analyze the eye position and movement of workers onsite [18], previous studies have failed to create a technology to supervise non-helmet use. This technology would be especially useful since helmet misuse/neglect is one of the most common forms of equipment misuse that can occur on construction sites, and can therefore be easily compared with other unsafe behaviors (i.e. loitering around dangerous areas). This paper provides such a technology: a real-time tracking system known as the "Eye on Project" (EOP), to provide an objective record of helmet use in construction sites. This improved hazard-identification technology can automatically monitor and record helmet misuse.

Another considerable improvement is made in this paper: previous research was mostly based on the reporting of accidents or near-accidents, which usually just consisted of a description of the individuals

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involved and the accident itself [32]. In addition, the frequency of incidents was also often used as data. The real-time tracking safety helmet designed by the researchers can identify and store the data by monitoring real-time non-helmet use behaviors, and then to improve the current hysteresis analysis based on accident reports.

This paper reports a field experiment investigating workers' common characteristics of non-helmet use and then assessing workers' risk levels on construction sites. Association rules were used as a data analysis method to find the obscure combination of risk factors hidden in the data collected. Many data mining techniques have been used for safety analysis in recent years [13,19,20]. Meanwhile, a risk assessment matrix system was obtained by the above association rules with levels classified by characteristics. The significance of this paper is to propose a more intuitional way to find and demonstrate risk contributors.

The paper is organized into four sections: (1) review of previous research on helmet use including the importance of helmet use, as well as current methods and technologies for helmet use inspection; (2) an experimental design comprising of the Eye on Project (EOP) system and a method of defining and evaluating workers' risk levels based on the common characteristics of non-helmet use; (3) experimental settings, procedure and results; and (4) discussion of the findings summarized from the previous results, the limitations of the current research and future research avenues.

2. Literature review

2.1. Individual factors influencing unsafe behaviors on construction sites

Since non-helmet use is a common unsafe behavior in site conditions, it is important to refer to the contributory factors influencing unsafe behaviors. Previous studies classified the key factors leading to unsafe behaviors on construction sites. According to previous studies, one of the most significant factors influencing unsafe behaviors is individual characteristics [25]. Seven items were identified from previous studies, namely gender, age, work experience, time of day, attitude and motivation, psychological distress and intended acts. The related items of literature are listed in Table 1.

2.2. Importance of helmet use for construction workers

Helmets are an important way of reducing fatal injuries and evaluating workers' safety performance on construction sites. Head injuries are a common source of trauma in the workplace worldwide, since the human head is the part of body with the highest potential for serious injury and even death [33]. Medical Online, for example, states that about 230,000 Americans suffer traumatic head injuries each year, with more than a fifth dying. Similarly, the Center for Disease Control and Prevention [10] estimates that head injuries account for almost half (49%) of fatal injuries. Moreover, a survey focused on worksite accidents and injuries collected by the Bureau of Labor Statistics [8] demonstrated that not wearing head protection results in almost 90% of all traumatic brain injury. This is especially true in the case of the construction industry, which has the highest rate of traumatic brain injury of all industries. Therefore, on-site construction workers are required to wear a helmet or a hardhat on site.

Table 1
Literature related to individual characteristics.

No	Individual contributory factors	Studies
1	Gender	[4,7] [15,34]
2	Age	[2,4,7] [12]
3	Work experience	[3,14,42] [43]
4	Time of day	[28]
5	Attitude and motivation	[11,21]
6	Psychological distress	[44]
7	Intended acts	[39,42]

Safety performance is a key factor influencing the decision to evaluate construction workers' risk level and adopt further safety management on those of high risk. On the other hand, non-helmet use is a direct safety performance indicator for predicting the occurrence of incidents. Safety helmets are one of the most widely used pieces of personal protective equipment (PPE) which help to mitigate the severity of injuries to humans in hazardous conditions [31,41,44]. Government departments have published a series of booklets to provide safety-related regulations and rules to reduce safety helmet misuse. Employees in the U.S., for instance, are protected by the Occupational Safety and Health Administration [35], which has developed a series of regulations to ensure that employers provide appropriate head protection and bear the responsibility of supervising its use in conditions where objects might fall from above and strike workers on the head. Over the past decade, several studies concerning the evaluation of wearing PPEs as a safety performance indicator have been reported, which vary in their purpose and focus.

2.3. Current methods and technologies on helmet use inspection

Previous researchers have attempted to figure out the major causes of helmet misuse on construction sites [45]. However, it is hard to obtain data about helmet misuse (i.e. time spent without wearing a helmet, periods of the day where it is more likely to occur, and correlation between personality and helmet misuse). Due to the hysteresis of accident prediction and warning functions in the construction sector, the research is always based on accident reports instead of real-time data. For example, statistics of the lack of PPE use during daily construction processes have always emphasized self-reports of construction staff by construction site managers [39]. Incident reporting systems (IRSs) are also widely used for post hoc analysis, which provides proactive analysis for safety management [38]. The current analysis is mainly based on reporting that cannot visually display workers' unsafe behaviors and their updated risk. Therefore, current studies may fail to provide effective safety analysis for a complex industry such as construction.

Because of the danger present on construction sites, the use of safety protection equipment, such as PPE, has gained much of attention from researchers. The current method of worker supervision using PPEs is simply visual surveillance by supervisors or construction managers. However, this method is ineffective and time-consuming, since such surveillance is executed only at scheduled times. In the past few decades, studies have moved from this manual method of supervision to the use of advanced remote sensing, which negates the need for human interference entirely. Kelm et al. [26], for example, use various existing commercial automated identification (ID) and information technologies (IT) to design a mobile RFID to check the use of PPE by workmen. Barro-Torres et al. [5] have introduced an advanced cyber-physical system (CPS) to check in real time whether a PPE is worn by workers based on an architecture composed of a wireless local area network and a body area network. Since the helmet is a widely used piece of personal protective equipment (PPE) on construction sites that can directly reduce the risk of head injury or prevent workers from injury from falling items [16,41,44], proactive research is urgently needed to promote the workers' safety [27].

Therefore, it is necessary to develop methods and technologies to inspect helmet use based on real-time and visual data. Meanwhile, performance should be not only evaluated in terms of the behavior itself, but also from the workers' common characteristics of non-helmet use. This study aims to investigate the evaluation of non-helmet use in both frequency and duration.

3. System framework and methodology

In this section, the EOP is used as the non-helmet-use behavior inspection system in an experiment. The features and operational procedure are introduced in detail. Then, a method of evaluating workers'

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