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Analyzing risk factors in crane-related near-miss and accident reports

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ABSTRACT

Learning lessons from near-miss reports is a well-known procedure in various high-hazard industries. The construction industry tends to adopt near-miss management systems, but the procedure is relatively new and has not yet been fully explored or understood. Although the management of near-miss reporting systems in construction has been investigated, no effort appears to have been made to suggest a methodology for technically investigating the content of near-miss reported events. This paper reports a study that implemented both qualitative and quantitative analysis methods for a structured investigation of tower-crane-related incident stories (near misses and accidents). The study began by collecting a large number of incident stories (51 accidents and 161 near misses) that were qualitatively analyzed to form an incident database that served as raw material for further quantitative analyses. The database structure definitions contained categories, which in turn contained variables, such as defining the event severity outcomes on a six-point scale from '1' – near miss to '6' – fatality. Further quantitative analysis suggests comparing groups of similar or identical incidents. The groups (clusters) were established by implementing *k*-means clustering based on the database definitions as variables. The relative risk potential of each cluster was then quantified by comparing each cluster's severity outcome occurrences to those of the other clusters and to the entire database as well. Findings from the analyses suggest that technical failures are the most hazardous risk factors within the tower crane domain.

1. Introduction

The increasing industrialization of construction emphasizes the centrality of cranes as the main transportation equipment on site. While cranes largely determine the site's production rates, they are arguably also the main generators of onsite safety hazards. Factors involved in crane accidents have been studied extensively, relying mostly on various accident databases such as the case files of the US Occupational Safety and Health Administration (OSHA) (Aneziris et al., 2008; Beavers et al., 2006; Häkkinen, 1993, 1978; Shepherd et al., 2000; Suruda et al., 1999). Nevertheless, very little investigation has been carried out regarding accident reports that refer specifically to *tower* cranes. Moreover, the exclusive reliance on reported full-scale accident data, without referring also to low-severity yet high-frequency incidents such as near-miss events, ignores a significant portion of the risk, limits the exposure to incident statistics, and reduces the potential of learning from a much larger body of cases (Bier and Mosleh, 1990; Hallowell and Gambatese, 2009; Heinrich et al., 1980). Indeed, the use of near-miss management in construction is relatively new and its effective application suffers from gross underreporting (Cambraia et al., 2010; Shapira et al., 2012). Consequently, existing knowledge on tower-crane safety-related incidents is rather limited.

The aim of the current study was threefold: (1) to expand the existing knowledge on tower-crane safety-related incidents by establishing an extensive structured tower-crane-related incident database using unambiguous definitions that build upon the existing nomenclature, as reported by Raviv et al. (2015a,b); (2) to use the structured database definitions as categorical variables in applying statistical methods to obtain the risk potential of future safety incidents; and (3) to enable the analysis of clusters of high-risk potential incidents.

The paper first presents the existing knowledge on the definitions of accidents and near misses, the classification of safety terms, the evaluation of crane-related safety hazards, and the categorization of crane-related accident data. Next, the methodology of integrating qualitative and quantitative analyses in evaluating the entire spectrum of safety events – from near misses to full-scale accidents – is presented in detail, followed by our findings and a discussion. Finally, the main insights this study produced are highlighted and the envisioned solution for what appears to be a limitation of the current study is briefly outlined.

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2. Literature review

Hallowell and Gambatese (2009) argued that obtaining frequency of event data pertaining to construction safety is difficult. This is particularly true when it comes to low-severity events such as near misses; ignoring this significant risk component results in a major flaw in construction safety risk analysis (Hallowell and Gambatese, 2008). This idea is not new and indeed was first published in the early 1930s by Heinrich et al. (1980) stated, in the fifth edition of their seminal book, that focusing only on the causes that lead to a major injury stems from a basic misunderstanding of what an accident really is. According to their definition, an accident is "an event that results in a personal injury *or the probability thereof*", meaning that the injury is not part of the accident but merely its result. They further added that, "when the causes of lost-time or so-called major accidents only are selected for study as a basis for record and for guidance in prevention work, efforts are often misdirected, valuable data are ignored, and the statistical exposure is unnecessarily limited." Adopting this perception, the study reported in the present paper adhered to the approach that the entire spectrum of safety incidents should be treated so as to learn lessons and take corrective action. Because near misses are defined in the existing literature in an ambiguous manner, the following review focuses first on the definitions of near misses and then continues to address safety terms in general and specifically those relating to tower cranes, leading to the philosophy that defines the current study's path.

2.1. Definitions of accidents and near misses

Phimister et al. (2003) stated that near misses are "an opportunity to improve environmental, health and safety practice based on a condition, or an incident with potential for more serious consequence". Moreover, their study describes a spectrum of incidents and conditions that define near misses, beginning with unsafe conditions, up to events with the potential for environmental damage on the highest severity level. They also defined two restrictions for near-miss events: (1) near misses must entail an "event", and (2) near misses must involve a "last safety barrier challenged".

Contrary to the range of definitions offered by Phimister et al. (2003), Cambraia et al. (2010) emphasized the need to differentiate near misses from other situations such as unsafe acts and unsafe conditions. They therefore defined near misses as instantaneous events that involve a sudden release of energy and have the potential to generate accidents, but that do not result in injury or material damage. Unlike other studies that referred only to the question of whether an injury occurred or not (e.g., Heinrich et al., 1980), Cambraia et al. (2010) raised the question of relating near misses also to accidents with material damage. Gnoni et al. (2013) identified the first problem in capturing and sharing information within the near-miss management system as the lack of a standardized and shared definition of a near miss. They differentiated between unsafe acts, unsafe conditions, and near misses, and defined a near miss as an event closest to an accident that has potential to cause injury or damage to health. Raviv et al. (2015a) differentiated between two levels of near misses: (1) no injury and no damage; and (2) slight property damage only.

The question of analyzing near-miss risk potential was discussed by Reason (1997), according to whom near misses range from "benign" events, in which some of the defenses prevented the incident from escalating, to events that "missed being catastrophic by only a hair's breadth". This differentiation provides the opportunity to learn two lessons: (1) benign events provide useful information about the system's resilience; and (2) near misses that were close to becoming catastrophic can serve as warning that reactive actions should be taken. Similarly, Jones et al. (1999) defined "major near misses" as incidents that could have reasonably led to "major accidents", whereas "near misses" can lead to "accidents". Such categorization of near misses according to their risk potential leads the quantitative analysis of risk to invest effort primarily in estimating the risk entailed in "top events" rather than in less severe events. The question of grading near misses according to their risk potential is worth studying, particularly considering that no efforts have yet been made in this direction with reference to the construction industry.

2.2. Classification of safety terms

Since the current study relies on the classification of incident stories, we reviewed the literature for classification methods that use various sets of categories and variables that describe incident attributes. Wang et al. (2011) proposed an ontology-based framework to support job hazard analysis. They suggested using ontologies to structure knowledge about activities, job steps, and hazards. By identifying a formal syntactic structure and modeling rules, they represented the diversified hazard concepts to allow easy management of safety rules. Similarly, El-Gohary and El-Diraby (2010) developed an ontology for infrastructure and construction processes to offer a rich conceptualization of domain-wide knowledge and thus provide an unambiguous formalized representation of knowledge. They further stated that a new ontology could be developed by adding new definitions to an existing ontology. Cambraia et al. (2010) found the classification of events to be useful mostly for building databases and for identifying long-term trends in near-miss investigation, similar to the method implemented in accident investigation. They also found, however, that relying on an existing set of definitions (in their case, the Brazilian regulations) was insufficient for their study's context and, therefore, made some adjustments to make up for missing definitions, in order to cover the context of near misses as well. Hale et al. (2012) used several existing frameworks to study the analysis of a small sample of fatal construction-related accidents to understand their underlying causes. The classification method these researchers finally implemented was originally developed for aviation, and thus several modifications had to be made.

Esmaeili et al. (2015) established a model for the assessment of attribute-based safety risks and claimed that while there are an infinite number of potential tasks and construction objects, the hazards created on construction sites are generated from a relatively small number of attributes. They began their research with a content analysis to identify the required attributes and recurring patterns within the event reports. When addressing their research limitations, Esmaeili et al. (2015) stated that the fact that their accident database relied on OSHA recordable incidents can be problematic for predictive models, because OSHA incidents deal mainly with fatalities and severe accidents, and so further research should be conducted to investigate the attributes of low-severity incidents and near misses.

2.3. Evaluating site hazards relating to tower cranes

The challenge of analyzing the safety risk level of a given construction site was addressed by Shapira and others in a multiphase study that identified risk factors and analyzed them to obtain a risk-level rating. In the first paper that reported on that study (Shapira and Lyachin, 2009), 21 risk factors were identified through expert knowledge elicitation and then grouped into four categories: project conditions, the environment, the human factor, and safety management. Based on these factors, Shapira and Simcha (2009) conducted a study aimed at formalizing expert knowledge into a set of weighted safety factors. Implementing