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Systematic Approach to Crane-Related Near-Miss Analysis

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Abstract
The use of near-miss management systems in construction is relatively new and has not been fully explored or understood. Although the issue has drawn some research attention lately, no efforts appear to have been made to investigate near misses in a systematic perspective and to propose a model that enables to analyze a given set of reported incidents. The research effort reported here suggests a systematic approach to near-miss analysis, and concentrates on tower-crane-related near-miss events. This is due to the centrality of tower cranes in nowadays construction on the one hand, and the potential of tower cranes as hazard generators on construction sites on the other hand. The study began with an extensive effort to collect stories of safety events, including near misses and accidents. An exploratory research method was then implemented in developing a comprehensive database of crane-related accidents and near-miss events. The database classifies each event using a set of encoded variables that disclose event definition, crane status, activity, main incident factor, and more. The applicability of the database is demonstrated by providing qualified support to the notion of cause communality between accidents and near misses, an issue that has been studied in the context of other industries.

Keywords
Construction safety, Accidents, Near misses, Tower ceanes.

1. Introduction

The application of near-miss management systems has improved safety in various high-hazard industries such as the process industry (Jones *et al.*, 1999; Seveso II, 1997), civil aviation (ICAO, 2010), and railway transportation (Wright and van der Schaff, 2004). In construction, however, the application of near-miss systems is relatively new (Cambraia *et al.*, 2010) and a gross under-reporting hinders the efficient use of such systems (Shapira *et al.*, 2012). The study of near misses in construction in recent years has covered some aspects of the issue (Fullerton *et al.*, 2009; Cambraia *et al.*, 2010; Wu *et al.*, 2010; Hallowell *et al.*, 2013), yet no in-depth investigation of the technical aspects of near-miss reports to establish their basic terms has been made, presumably due to the variety of attributes and terms that appear in near-miss reports.

This study focused on analyzing near-miss reports in a systematic perspective adopting a two-step approach. The current paper reports on the first step, which concentrated on establishing a comprehensive near-miss database and validating its applicability for multi-case analyses. Further research efforts are in progress, utilizing the database features in the implementation of advanced statistical analysis methods for in-depth investigation of near-miss reports, regarding subjects such as risk potential analysis and accident type prediction. The study concentrated on the tower-crane environment, yet its methodology is applicable to other domains as well.

The study commenced with an extensive effort to collect near-miss as well as accident reports to serve as raw material for the database. The reports were analyzed to reveal the basic features of their subject matter, which were then organized under a set of categories and variables within the categories, namely the event definition (e.g., near miss, slight damage, major injury), crane status (e.g., routine work, idling time), crane activity during the incident (e.g., rigging, hoisting, jumping), failure mode (e.g., signaling error, inattention, fatigue), and several others. The resulting database also enables to identify future events as identical or similar to previous ones, and to draw due conclusions based on preset analyses.

The communality of causes between accidents and near misses, i.e. "common cause hypothesis", has been studied extensively in other industries (Wright and van der Schaff, 2004; Alamgir, 2009; Konstandinidou *et al.*, 2011) but not in construction. This paper demonstrates the applicability of the database definitions by utilizing them to provide support for the hypothesis concerning the tower-crane work environment. This result offers further support for the concept of near-miss analyses efficiency and applicability

2. Literature Review

2.1 Approaches to Near-miss Management

Heinrich *et al.* (1980) defined an accident as "an unplanned and uncontrolled event, in which the action or reaction of an object, substance, person, or radiation result in personal injury or the probability thereof". This definition leads to the overall approach to accidents, including cases that ended merely "in the probability" of an injury. Heinrich *et al.* further stated that the "point of attack" in accident analyses should be the accident itself and not the injury that it caused. The injury is only the result of an accident and therefore the importance of the individual accident lies not in the fact that injury occurred but in the potentiality of the accident to create injury. Heinrich's point of view concentrates, therefore, on the benefit of near-miss investigation, as a comprehensive procedure along with accident investigation, to ensure that valuable data will not be overlooked and the statistical exposure will not be unnecessary limited. Jones *et al.* (1999) described the European Council's regulations (Seveso II, 1997) that recommended only voluntary reporting of near-miss events to the authorities. Nevertheless, they suggested that internal investigation of near misses should be an integral part of the safety management system, stating that near-miss reporting will eventually reduce the occurrences of near misses as well as full-scale accidents. Phimister *et al.* (2003) presented a seven-stage framework for the systematic analysis of near-miss incidents. The framework begins with the identification and report of near-miss occurrences, through prioritization, causal analysis, solution identification, dissemination, and resolution. They emphasized that although the identification of near misses is regarded as a vital step in the system to reduce site risk exposure, only the successful execution of each and every stage will reduce risk for a given near miss. Gnoni *et al.* (2013) challenged this structured approach, describing a near-miss management system as an integral part of the lean management approach in a global automotive supplier firm. This system suggests that the operational level supervisor should assess and resolve near-miss events, while the health and safety department shall become involved only when the supervisor asks for supportive action. This "bottom-up" approach aspires to optimize the information flow according to lean management principles. The aforementioned dissemination stage includes discussing the events in safety meetings as well as recording and analyzing event statistics.

The philosophy of near-miss analyses seems to rely on a basic assumption regarding the existence of some causal relations between near misses and full-scale accidents. Nevertheless, the hypothesis of similarity of causes for major and minor accidents, termed "the common cause hypothesis", is not straightforward, and numerous researches confronted this issue in order to evaluate the justification of implementing near-miss data systems as an accident-preventing mechanism. Wright and van der Schaaf (2004) claimed that Heinrich, in the first edition (1931) of his seminal book, did not intend to convince the reader as to the commonality of causes between different accident outcomes, but rather to illustrate the fact that prevention need not wait until an accident occurs and should not focus only on the most severe consequences but also on events at the lower levels of the outcome severity scale. Wright and van der Schaaf also stated that the similarities in the pathways leading to minor and major incidents are a vital argument that should be used to motivate employees to report near misses. Thus, they recommended studying the communality of causes between the different incident levels for different domains, and provided a qualified support for the common-cause hypothesis in the UK railways causal taxonomy. Alamgir *et al.* (2009) studied the causal pathways of near misses and minor occupational injuries and concluded that the relative distributions of causes and activities involved in musculoskeletal injuries were similar. Moreover, they claimed that their findings support the use of near-miss and minor injury data in injury prevention programs. These studies, including Davis (2000), Wright (2000), and Konstandinidou *et al.* (2011), support the usefulness of collecting, studying, and drawing conclusions from near-miss data as well as from data from actual accidents.

2.2 Near Misses in Construction

Cambraia *et al.* (2010) proposed the analysis of near misses according to four categories: (1) the quality of data obtained during the report, named "traceability"; (2) the nature of the event according to basic definitions of Brazilian regulations; (3) the type of feedback on the barriers that prevented it from becoming a full-scale accident; and (4) the assessment of risk associated with each event in terms of severity and probability. These researchers claimed that the use of near misses appeared to be a relatively recent practice in the construction industry. In order to substantiate their statement, they quoted Hinze (2002) as identifying the use of near misses in large construction companies, while Liska (1993) did not observe a similar practice. Hinze (2002) also concluded that, on average, 22 near-miss events were documented per project, yet Cambraia's (2010) findings regarding the quantity of incident occurrences outnumbered Hinze's (2002) as a result of encouraging workers to report them. Wu *et al.* (2010b) described an investigative tool designed to derive information from accident databases and suggested analyzing near-miss events using a database of "precursors and immediate factors (PaIfs)" derived from the analysis of historical records. They demonstrated the establishment of a database on the fall-from-scaffold event and identified 20 precursors by analyzing 50 cases. They also recommended future research on the quantitative analyses of the relationships between near misses and accidents based on the established database. In another paper, Wu *et al.* (2010a) described a real-time system for tracking near-miss accidents on construction sites, based on sensors for environmental surveillance for access control and storing the resulting safety information concerning hazardous situations and site-specific details. This system should able to manage the access control, environmental conditions, and real-time locations of both workers and equipment/vehicles. The purpose of the data is to detect the occurrences of near-miss accidents and prevent possible accidents. Similarly, Fullerton *et al.* (2009) suggested radio frequency technology to help recognize danger of collision between on-foot personnel and heavy equipment. Such automated detection can detect near misses as well as a vast number of unsafe actions and conditions that lack the component of "real event" or "loss of energy". Important as these warnings may be, these situations come in vast numbers (e.g., Heinrich *et al.*, 1980; Phimister *et al.*, 2003) and every system based on them is prone to be overflowed by data. Therefore, this study suggests a structured way of dealing with this information, based on an in-depth investigation of near-miss events that aims to categorize them and analyze multiple events according to category definitions.

3. Establishing the Basic Safety Event Record

Reason (1997) defined safety culture, among other things, as a "reporting culture", adding that persuading people to file reports may not be an easy task. Davis *et al.* (2000) emphasized the issue of confidential reporting as a vital concept in the near-miss management system, to prevent the system from falling into disuse due to the lack of reports. In construction, however, there is a limited ability to provide meaningful accident and near-miss statistics from reports due to gross underreporting (Shapira *et al.*, 2012). Yet Cambraia *et al.* (2010), who studied near-miss management on construction sites, achieved a dramatic increase in both number and quality of reports after systematically encouraging the workforce to report. The study reported here adopted this idea in an extensive effort to establish a comprehensive tower-crane-related accident and near-miss database.

Any qualitative or quantitative analysis of near-miss data must rely on a large database obtained from industry sources. It was clear from the onset of the study that this issue would be challenging due to the reluctance of construction companies to share such information. It also became clear that instructing construction companies to develop a more comprehensive near-miss reporting scheme would be part of the data collection phase, giving them the opportunity to benefit from their willingness to cooperate. Leading construction companies were approached with a proposal to take part in the study. The interaction with each construction company began with a brief introduction of the basic ideas of near-miss management, presented in a 40-minute lecture to the relevant stakeholders (safety officers, project managers, project engineers, and superintendents). The lectures included definitions of near-miss events, near-miss reporting and basic analyses, and the basic idea of encouraging workers to report in a non-punitive environment. After being introduced, the researcher acquired the existing near-miss data and the second step of site interviews began. The interviews were held at the construction sites, and the site managers were encouraged to speak freely and to tell about near misses that had occurred on their actual sites. The experience of managing this social dynamic process with a group of site managers was interesting and enlightening, and the research database was enriched with a large quantity of near-miss stories. Further stories were collected from the literature (King, 2012; Shapira and Lyachin, 2009) and from internet sites (Craneaccidents.com; Vertikal.net). The resulting database represents various context conditions such as different companies, methods of data collection, and levels of detail, and includes 241 tower-crane safety incidents, of which 162 are near misses and 79 are full-scale accidents.

4. Processing the Data – The Safety Event Database

The first step in investigating variables and trends in the event stories was the establishment of a basic set of definitions that was meant to support two main goals of the research: (1) the analysis of future events by identifying parallel events within the database according to a given set of variables; and (2) an automated multi-case analysis implementing cross checks according to the variables. The challenge of analyzing a large number of event stories to form a concise set of variables in a systematic manner was met by adopting the method of content analysis; the texts were searched for patterns, recurring topics, and expressions that ultimately formed a system of categories and variables within the categories. Fellows and Lieu (2008) recommended constructing an initial set of guidelines and then, while executing a first pass of the data, confirming or amending them; next, a second more consistent pass has to take place, using the final categorization. Thus, base variables were defined using literature sources (Häkkinen, 1978; Häkkinen, 1993; Suruda *et al.*, 1999; Shepherd *et al.*, 2000; Beavers *et al.*, 2006; Aneziris *et al.*, 2008) and as the procedure proceeded, additional definitions emerged to complete the final picture of tower-crane-related safety event definitions. The demand for the additional definitions arose since the existing nomenclature relates to all crane types without considering the special tower-crane context. The procedure of observation began with a few basic questions, such as, "What is the most concise way of describing an incident?" "What are the main elements that constitute an incident?" "What is the most

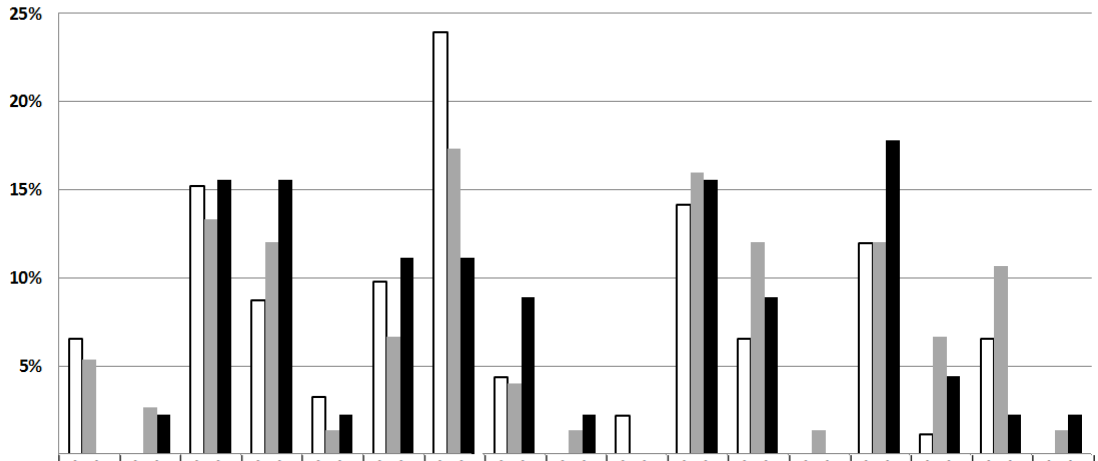
proper way to define the triggering activity or situation of the incident?" Consequently, a set of categories and variables within the categories were defined as the main database structure. During the second run, all event stories were examined thoroughly and each was related to the existing definitions. After processing about 200 event stories, a state of saturation was reached and the database structure was considered final. It is important to note, however, that the database structure is modular and further variables and categories may emerge on demand. The final database consists of several categories, some of which are strictly contextual information, such as date, day of the week, and crane work status. Another category measures the severity of the incident using a six-point scale (1 = near miss with no injury or property damage to 6 = fatal injury). The three most important categories that reveal substantial information about the incident answer three questions: (1) "when?" – the type of activity the crane was performing when the incident occurred; (2) "what?" – the definition of the incident; and (3) "why?" – a description of the failure mode that caused the incident.

5. Demonstrating Applicability of the Systematic Approach

The structured way of relating to crane-related safety incidents opens the possibility of simultaneously analyzing a large number of incidents according to the variable definitions, trends, and causal analyses. Raviv *et al*. (2015) demonstrated the potential of analyzing numerous near misses by comparing two sets of events obtained from two large construction companies in Israel. It was evident that one company suffered from a main drawback regarding crane safety, as turned out from the recurring incidents involving crane technical failures that attest to the poor technical state of their tower crane fleet as well as to maintenance problems. On the other hand, it became clear that the other company suffered from a noticeable flaw concerning the training of their ground crew (riggers and signalers), as was evident also by the significant portion of load problems. This comparison emphasized the efficiency of relating the various near-miss stories to a set of simple codes that enable various crosschecks that lead to the drawing of initial conclusions from the raw data. The following paragraphs will elaborate on another analysis type as a demonstration of the database system's potential. The analysis addresses the aforementioned "common cause hypothesis" and aims to investigate its applicability to the tower-crane-related context.

The approach to investigating the common cause hypothesis requires an initial definition of what a *cause of accident* really means. Numerous accident causation models exist and the decision which one to implement depends on the research goal. This issue was well described by Lundberg *et al.* (2009), who coined the abbreviation 'WYLFIWIF' (What-You-Look-For-Is-What-You-Find), meaning that the accident investigation often focuses on issues that the investigator deems important. Consequently, the common cause "research question" depends on a preset question of what to look for, namely, causal variables and category definitions. Wright and van der Schaaf (2004) studied the causation of accidents and near misses on two different levels with regard to the causal taxonomy implemented in the UK railways' confidential incident reporting system (CIRAS). The higher level, or "macro" codes, are four top-level categories each of which comprises a set of individual "micro" codes. Wright and van der Schaaf found support for the common cause hypothesis on the macro level, and further analysis of the micro level showed support for 21 of 24 causal factors. They explained the lack of support for the remaining three causes and concluded that they had found qualified support for the hypothesis within the railway domain. Similarly, the crane-related safety event database can serve as a tool for studying the common cause hypothesis in construction, according to its causal taxonomy, specifically in the context of tower cranes.

As explained earlier, the extensive effort of collecting crane-related safety incidents yielded 241 incidents, most of which were collected in Israel and the rest (29 incidents) were extracted from sources abroad. The common cause hypothesis analysis was applied only to local incidents (212 incidents) in order to maintain high consistency of contextual or cultural conditions. Figure 1 depicts the ratio



	(01) Failure of lifting accessories	(02) Overriding of limiters	(03) Improper rigging	(04) Error of signal person	(05) Limited visibility	(06) Failure in communication	(07) Inattention	(08) Strong wind	(09) Rail failure	(10) Fatigue of operator	(11) Technical failure in crane	(12) Load mishap	(13) Wrong location of crane	(14) Operator error	(15) Other technical failure	(16) Horizontal pull of load	(17) No signal person
Near miss	7%	0%	15%	9%	3%	10%	24%	4%	0%	2%	14%	7%	0%	12%	1%	7%	0%
Damage	5%	3%	13%	12%	1%	7%	17%	4%	1%	0%	16%	12%	1%	12%	7%	11%	1%
Injury and Fatality	0%	2%	16%	16%	2%	11%	11%	9%	2%	0%	16%	9%	0%	18%	4%	2%	2%

Figure 1: Causal Factor Ratio for Severity Levels

relationships of the different causal factors for the three incident severity levels, namely "near miss", "damage", and "injury and fatality". It is worth noting that the total sum of each severity level is not necessarily 100% due to the possibility of attributing more than one causal factor to any single incident. Some causal factors show no significant difference in their proportions (01, 02, 03, 05, 06, 09, 10, 11, 13, and 17), while considerable differences were noticed in others (04, 07, 08, 12, 14, 15, and 16). These findings support the common cause hypothesis for only 10 of 17 causal factors. However, the initial rejection of the hypothesis for other causal factors yields some enlightening insights, as follows:

1. The proportion of causal codes relating to operator errors (signal person for No. 04 and crane operator for No. 14) is significantly higher as the severity increases. This could be stem from the fact that many human-factor-related near misses are not reported due to their actual or perceived association with disciplinary action (Davis *et al.*, 2000).
2. On the other hand, the causal factor inattention (07) diminishes with the increase in severity. Since inattention can be unveiled almost only if admitted, it is obvious that as the severity rises, people have a lower tendency to admit inattention.
3. All three above-mentioned factors [error of signal person (04), inattention (07), and error of crane operator (14)] deal with strict human factor causal codes. The cumulative proportions of severity for these factors (45% for near miss, 41% for damage, and 45% for injury and fatality) are almost identical and, therefore, firmly support the common cause hypothesis for the human-factor-related causes. The shift between these human-error related causal factors could be attributed, as above mentioned, to tendencies in attitude towards near-miss reporting and accident investigation.

The findings therefore provide qualitative support for the common cause hypothesis for 14 of the 17 causal factors related to the tower-crane work environment. This adds significant value to safety research, as the hypothesis was tested and supported earlier for other domains, and the current research provides

additional evidence of the applicability of the theory, as recommended by Wright and van der Schaaf (2004).

6. Conclusion

The systematic approach to the technical investigation of tower-crane-related safety incidents described in this paper established a set of encoded variables that disclose the event definition, and eventually constructed a comprehensive tower-crane-related safety incident database. The applicability of the database was demonstrated by an analysis of 212 cases within the Israeli construction industry, providing qualified support for the commonality of causes for near misses, damages, and injuries and fatalities in that context. Further quantitative analyses of multi-case data according to the set of basic standard definitions will enable to draw conclusions directly from the data without the need for complicated investigations. An ongoing phase of the study investigates the application of statistical analyses that will help improve the profound understanding of tower-crane-related near-miss and accident occurrences on construction sites. These analysis methods will provide construction companies with the means of implementing preventive steps according to their findings and conclusions. Although the study focuses on tower-crane-related incidents, the suggested methods can produce similar results in other domains or be implemented with respect to safety incidents on construction sites in general.

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