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Mobile crane safe operation approach to prevent electrocution using fuzzy-set logic models

H.M. Al-Humaidi [a,*], F. Hadipriono Tan [b]

[a] Dept. of CE, Kuwait Univ., P.O. Box 5969, Safat 13060, Kuwait
[b] Dept. of CE, The Ohio State Univ., Columbus, OH 43210, USA

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ABSTRACT

Mobile cranes are involved in over 90% of crane accidents because their mobility increases risks over those faced by stationary cranes. Contact between crane and power lines is the most common cause of fatalities, with approximately 40% of all fatalities attributable to electrocution. Clear distance between cranes and energized power lines is a major factor in determining the likelihood of electrocution. Subjective judgment is commonly used to establish the relation between the clear distance and likelihood of fatal contacts. Hence, fuzzy modus ponens deduction techniques incorporating rotational and angular fuzzy-set models, which approximate subjective judgment, are introduced in this paper.

1. Introduction

Crane accidents result in many serious injuries and fatalities each year. Several causes contribute to crane-related accidents. The need for an analysis of causes of crane accidents is paramount. In an earlier study, causes of crane-related accidents were compiled and represented graphically through the use of a fault-tree model that illustrates the graphical interrelationship among these causes [1]. The fuzzy-set concept was then employed to determine the likelihood of mobile crane contact with overhead power lines. The study recommended further analysis of contact between mobile cranes and energized power lines.

According to data kept by the Occupational Health and Safety Administration (OSHA), crane contact with power lines is the most common cause of fatalities in crane accidents, (with about 40% of all fatalities are attributable to electrocution). The other major causes of crane accidents include mishaps during assembly and dismantling of the crane (about 12%), boom buckling (8%), rigging failure (7%), and crane upset and overturning (7%). More than 90% of crane accidents involve mobile cranes, as these cranes face higher risks than stationary cranes [1].

This study is limited to accidents involving mobile crane contact with overhead power lines. The study was limited to these specific kinds of accidents for two reasons. First, due to on-site mobility, mobile cranes are riskier than other types of cranes. Second, data obtained by OSHA suggests that most accidents are related to contact between overhead power lines and mobile cranes. Accidents involving the overturn of a mobile crane have a variety of causes, such crane overload, improper support of the crane rig, and so on. This type of accident is not considered in this study unless overturning the crane results in overhead power line contact.

According to the Bureau of Labor Statistics (2007), the United States construction industry has the highest rate of injury of any major industry. Successful accident-control practices that have been adopted by other industries become questionable when applied to construction projects. This limitation arises from the following reasons.

First, organizational work involves either operations or projects. Operations are ongoing and repetitive, whereas many construction projects are unique and temporary [2]. In addition, project completions are limited by time and resources. Therefore, manufacturing industry control practices cannot always be implemented in construction projects.

Second, unlike manufacturing industries, projects operate in a non-controllable environment. In the manufacturing industry, the environment can be controlled, and similar quality products can be achieved. In construction projects, the environment is often non-controllable; weather can easily affect the output or product. Unforeseen occurrences such as underground soil condition can also impact the output of the project.

* Corresponding author.
E-mail address: hanoufalhumaidi@usa.com (H.M. Al-Humaidi).

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Third, the use of historical data in planning, analyzing, and managing future events is limited in projects. Since many construction projects are unique and non-repetitive, the implementation of probabilistic data analysis using a probability distribution function can become impractical.

Safety control and construction risk-management processes are imposed on construction sites by recruiting a person whose responsibility is on-site safety. Construction risk management in the United States is different from that in Europe. In the United States, a "Competent Person" is assigned to control construction risk. According to OSHA, a competent person is "an individual who, by way of training and/or experience, is knowledgeable of applicable standards, is capable of identifying workplace hazards relating to the specific operation, is designated by the employer, and has authority to take appropriate actions" (OSHA 29 CFR 1926.32) [3]. In the UK, the Construction Design and Management Regulations (CDM) enforce risk-planning and -management practices. These regulations assign health and safety regulations to all parties. CDM regulations also require a planning supervisor to co-ordinate health and safety starting from the project-planning phase. Furthermore, CDM regulations require involvement of all construction parties in safety planning during the design stage and require a safety plan to be implemented during bidding, construction, and post-construction stages. In the UK, CDM regulations stipulate a responsible person who must authorize erection plans. Prior to any erection task using mobile cranes, the responsible person must submit erection plans to minimize risks involved in the erection process [4].

Most of the time, the knowledge and experience of a competent person or planning supervisor are brought to bear on site through the use of subjective judgment. The use of linguistic values to express this judgment is paramount. For example, if an overhead power line is energized, a competent person may state: "While operating a crane, the operator may *very likely* be unaware of the fact that the overhead power line is still energized; therefore, the best safety procedure would *likely* be to de-energize the line prior to any crane operations." Another competent person might argue that "while operating a crane, the operator may *fairly likely* be unaware of the fact that the overhead power line is still energized; therefore, the best safety procedure would *likely* be to de-energize the line prior to any crane operations." To be more useful and consistent, the terms *very likely, fairly likely,* and *likely* can be transformed and manipulated using quantifiable measures.

Data that includes linguistic terms is best analyzed through the use of the fuzzy-set concept. Fuzzy sets can be employed to transform linguistic expressions such as *unlikely, likely* and *very likely* into quantitative terms. Fuzzy-set analysis has been widely used in civil engineering [5–7], but its application in the area of crane accidents is still limited. Understanding the causes of these accidents is essential prior to implementing this concept [9].

2. Crane accidents

Each year, contact between energized power lines and derrick cranes results in the deaths of crane operators or persons working on or around construction cranes. According OSHA statistics, crane accidents claim 50 lives in the United States each year. Approximately 500 construction workers died in crane accidents between 1984 and 1994, according to an OSHA study [1].

Contact between a crane and an energized power line is the most common cause of fatal accidents; roughly 40% of all fatalities are attributable to electrocution. The other major causes of crane accidents include crane assembly and disassembly (about 12%), boom buckling (8%), rigging failure (7%), and overturning of crane (7%). Mobile cranes are involved in more than 90% of crane accidents as they are inherently more risk-prone than stationary cranes. Detailed analysis of data is shown in Table 1.

The different types of cranes used in construction projects include mobile cranes, bridge cranes, gantry cranes, tower cranes, and ship cranes. In a study of crane-related construction accidents from 1997 to 1999, the OSHA Office Management Data Services (OMDS) found that more than 90% of the accidents involved mobile cranes. Fig. 1 represents the findings of the study and shows the statistics related to the number of accidents by type of crane.

Accident or failure causes are classified in three categories: enabling, triggering, and procedural. Enabling causes are defined as those contributing to deficiencies in design, construction, or maintenance, while triggering causes are external events that may initiate failure [8]. Procedural causes are indirect; they produce both enabling and triggering events and arise from the interrelationship of the various parties involved in the project.

Among the various procedures for analyzing the causes of crane-related electrocution are (1) deterministic, (2) nondeterministic probabilistic, and (3) non-deterministic fuzzy methods.

The deterministic approach analyses the historical data involving technical and procedural problems. Hence, in a project that involves operation of mobile cranes, preventive acts and procedures are taken to minimize or eliminate any source of hazard. The nature of construction projects sometimes involves temporary and unprecedented activities, and the availability of historical data about similar scenarios becomes questionable. Accordingly, this approach may overlook the many uncertainties that may be encountered on construction sites.

Nondeterministic probabilistic approaches examine the reliability of a system based on quantitative/statistical data. Since crane-related accidents are often unique and involve numerous variables, the probability approach to assessing the likelihood of an electrocution as a result of crane contact with overhead power line may require historical data that are currently unavailable.

On the other hand, the non-deterministic fuzzy-set approach for crane safety requires primarily the subjective judgment of domain experts. For example, with respect to electrocution accidents, a clear distance between the overhead power line and components of the crane may involve linguistic terms such as "clear distance is *very short, short*, or *fairly short*." The fuzzy-set approach can be implemented to transform such linguistic terms into quantitative mathematical representations.

Table 1
Percentage of fatalities in crane accidents according to cause of accident [1].

Circumstances of injury	Number of deaths	Percentage
Electrocution	198	39.44
Crane assembly/dismantling	58	11.55
Boom buckling/collapse	41	8.17
Crane upset/overturn	37	7.37
Rigging failure	36	7.17
Other	24	4.78
Overloading	22	4.38
Struck by moving load	22	4.38
Accidents related to manlifts	21	4.18
Working within swing radius of counterweight	17	3.39
Two-blocking	11	2.19
Hoist limitations	7	1.39
Killer hooks	3	0.60
Access/egress	2	0.40
Control confusion	1	0.20
Insufficient information	2	0.40
Total	502	100