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Classification scheme and prevention measures for caught-in-between occupational fatalities

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ABSTRACT

The current study analyzed 312 caught-in-between fatalities caused by machinery and vehicles. A comprehensive and mutually exclusive coding scheme was developed to analyze and code each caught-in-between fatality in terms of age, gender, experience of the victim, type of industry, source of injury, and causes for these accidents. Boolean algebra analysis was applied on these 312 caught-in-between fatalities to derive minimal cut set (MCS) causes associated with each source of injury. Eventually, contributing factors and common accident patterns associated with (1) special process machinery including textile, printing, packaging machinery, (2) metal, woodworking, and special material machinery, (3) conveyor, (4) vehicle, (5) crane, (6) construction machinery, and (7) elevator can be divided into three major groups through Boolean algebra and MCS analysis. The MCS causes associated with conveyor share the same primary causes as those of the special process machinery including textile, printing, packaging and metal, woodworking, and special material machinery. These fatalities can be eliminated by focusing on the prevention measures associated with lack of safeguards, working on a running machine or process, unintentional activation, unsafe posture or position, unsafe clothing, and defective safeguards. Other precise and effective intervention can be developed based on the identified groups of accident causes associated with each source of injury.

1. Introduction

According to the US Occupational Safety & Health Administration, a caught-in-between accident is defined as being caught between moving and stationary objects or parts of the machine, or being caught between the material and a moving part of the machine (OSHA Directorate of Training and Education, 2011). Between 2011 and 2015, in Taiwan, there were 121 caught-in-between fatal injuries, accounting for 4% of 3006 fatality cases (Bureau of Labor Insurance, 2015). However, in the same period, there were 6786 caught-in-between disabling injuries, accounting for 38.7% of 17,534 disabling injuries caused by all accident types. Caught-in-between has been the leading cause of disabling injuries in Taiwan and other countries such as Korea (Jeong, 1999) and Finland (Lind, 2008). Identifying how accidents occur can reveal factors and causes contributing to past incidents which in turn will help target preventive action to reduce the likelihood of future accidents (Olsen and Williamson, 2015). Thus, appropriate analysis of caught-in-between fatality scenarios can help to prevent a very significant proportion of disabling and fatal accidents.

Based on our previous review of thousands of fatality reports, we discovered that very few inspectors had enough training to include all potential causal factors. Nevertheless, the fatality case report is the most comprehensive source for collecting key facts, such as type of industry, age, gender, experience level of the victim; the source of injury; the accident type; and any other relevant factors. An in-depth analysis of the fatality reports had allowed us to identify specific dangerous working sites for fatal falls (Chi et al., 2005), certain sources of injury for electrocution (Chi et al., 2009), and high risk segments of the worker population (Chi and Chen, 2003). Since there is a great commonality in the potential causes between fatal and non-fatal caught-in-between accidents (Lind, 2008), and fatal accident reports provide a more detailed description of the accident process, the current study conducted an in-depth analysis of 312 caught-in-between occupational fatalities between 1996 and 2007 in order to prevent similar future accidents.

Ideally, the in-depth accident analysis should cover the immediate cause of injury, the movement and task performed preceding the injury, and characteristics of the victim, machine, and environment (Drury and Brill, 1983). A deceased victim, however, cannot be available for systematic data collection (Adams et al., 1981; Chi et al., 2006). Accident classification systems are important tools to provide a valid representation of what happened in the accident (Olsen and Williamson,

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2017). Our previous development of coding schemes for fatal fall (Chi et al., 2005) and fatal electrocution (Chi et al., 2009) was generalized and applied to the analysis of fatal accidents which had occurred in other countries. The current study adopted a similar approach to review previous studies of caught-in-between accidents to develop a uniform and comprehensive coding scheme to facilitate the categorization of accident cause, source of injury, individual factors, and the deriving of contributing factors and accident patterns. The coding scheme of accident cause was developed based on relevant researches including Lind (2008), Sorock et al. (2001), and Aird (2008), which will be explained in detail as follows.

Lind (2008) analyzed industrial maintenance accidents in terms of active failures and latent conditions. Active failures are unsafe acts committed by people in direct contact with the system while latent conditions are managerial influences and social pressures that make up the culture, influence the design of equipment or systems, and supervisory inadequacies (Health and Safety Executive, 2017; Reason, 1990). In Lind (2008), the unsafe acts (active failures) included dangerous working methods, defective hazard identification, non-use of personal protective equipment (PPE), and working at a running machine/process while the latent conditions included defective work instructions, defective safety equipment, insufficient experience, device failure, and defective walking or working surface. Dangerous working methods were the most frequently identified unsafe acts for fatal accidents while working at a running process occurred most often for severe non-fatal accidents (Lind, 2008). Defective work instructions and defective safety equipment are the most typical latent causes for both fatal and non-fatal accidents (Lind, 2008). A similar classification of accident conditions into unsafe acts and unsafe conditions was proposed in Aird (2008), except that Aird provided more detailed sub-categories and items, e.g. failure to secure, bypassing safety devices, and defective tools and equipment. Sorock et al. (2001) studied the unsafe conditions that lead to upper extremity injuries including in a hurry; not realizing hand was in hazardous area; misjudging time and distance to avoid injury; attention not fully on task or hand; co-worker did something to cause injury; tool, work material, or hand slipped or shifted; defective machine/tool; no safeguard on machinery/tool; or machinery accidentally activated. Chinniah (2015) summarized the causes related to moving parts of machinery, including easy access to moving parts of machinery, lack of safeguarding, absence of lockout procedures, inexperience of workers, bypassing safeguards, lack of risk assessment, lack of supervision, poor machinery design, unsafe working methods, no clear instructions to workers on how to intervene safely on machinery, and modifications to machinery and control systems. The above-mentioned research was reviewed and compared to derive a comprehensive and mutually exclusive coding scheme for accident causes. The coding scheme for other factors will be described in the materials and methods section.

Following our previous construction of a fault tree for fatal falls, fault tree and Boolean algebra were applied to the analysis of caught-in-between fatal fatalities (Chi et al., 2014). The construction of a fault tree diagram begins with the top event and proceeds in a top-down manner (Harms-Ringdahl, 2001). The AND- and OR-gates are used to provide logical connections between the basic events. The AND-gate, which is equivalent to the Boolean symbol "•", represents the intersection of the events attached to the gate while the OR-gate, which is equivalent to the Boolean symbol "+", represents the union of the events attached to the gate (Vesely et al., 1981). Given that fatal accidents can be caused by more than one cause combination, the integration of all possible cause combinations can be regarded as the union of these cause combinations. Since these cause combinations have redundancies, when the same event appeared more than once, minimal cut set (MCS) was applied to reduce the redundancy of basic events. For the MCS simplification process, all accident causes were divided into primary or secondary, depending on whether the cause had resulted in any fatality by itself or simultaneously with other cause(s), respectively. In other words, any single cause which contributed to the occurrence of a fatal accident was regarded as primary while all other accident causes were regarded as secondary (Chi et al., 2014). By letting the primary causes absorb the secondary causes, based on fundamental laws of Boolean algebra (Whitesitt, 1995), all possible cause combinations can be reduced to the "smallest"cut set (Vesely et al., 1981) that is necessary and sufficient to cause the caught-in-between fatality.

Reducing the accident causes with Boolean algebra into MCSs allowed us to focus directly on a smaller number of critical accident causes and their corresponding prevention measures. By examining the MCS, the smallest combination of root causes, an analyst can prioritize their prevention measures to prevent the top event from occurring (Doytchev and Szwillus, 2009; Zhang et al., 2014). Thus, the current study applied fault tree analysis to illustrate the causal relationships among events and causes, in terms of MCS, that contributed to 312 caught-in-between fatal accidents.

2. Materials and methods

The current study analyzed 312 work-related caught-in-between fatalities recorded by the Council of Labor Affairs in Taiwan between 1996 and 2007. A summarized version of each fatality case is available online. A complete version of the report can only be accessed through an application process to ensure confidentiality of the personal data. For each fatality report, age, gender, worker's experience, type of industry, source of injury, and accident cause were classified into several useful categories for further analysis. Since all caught-in-between accidents involved an obvious source of injury, e.g. machinery or vehicles, each caught-in-between accident was analyzed in terms of the different source of injury.

The fault tree analysis was applied to present the causal relationships among events and causes that contributed to the caught-in-between fatalities associated with different sources of injuries in terms of MCS (Chi et al., 2014). Given that fatal accidents can be caused by more than one cause combination, the integration of all possible cause combinations can be regarded as the union of these combinations. When the same event appeared more than once, MCS analysis was applied to reduce the redundancy of basic events.

2.1. Classification scheme

Age was divided into five categories of ≤24, 25–34, 35–44, 45–54, and ≥55, as in our previous study (Chi and Wu, 1997). Worker's experience was classified into six different levels of > 0 to ≤1, > 1 to ≤5, > 5 to ≤10, > 10 to ≤15, > 15 to ≤20, and > 20 years (Butani, 1988) to compare the relative risk of injuries by experience. Industry was classified into manufacturing, construction, transport and storage, commerce, service and administration, mining and quarrying, utility service, farming and fishing (Chi et al., 2004). Source of injuries was classified into machinery and vehicles, and further divided into subcategories and items as necessary according to the 2.3 Source of Injury Classification in the Occupational Injury and Illness Classification Manual (2017) (Boyle et al., 2000). For example, machinery was divided into (1) special process machinery including textile, printing, packaging machinery (code 37); (2) metal, woodworking, and special material machinery (code 35); (3) construction, logging, and mining machinery (code 32); and (4) material and personnel handling machinery (code 34). The subcategory of material handling machinery was further divided into conveyor, elevator, cranes, and vehicles, as necessary (see Table 1). Twenty-seven caught-in-between fatalities associated with other sources of injury, such as parts and materials (10 cases); heating, cooling, and cleaning machinery and appliances (6 cases); structures and surfaces (6 cases); wrapping machine on fishing vessel (3 cases); and other special purpose machines (2 cases) were eliminated from the current study to make our study's scope more focused and feasible.