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## ***Heavy Machinery Operators: Necessary Competencies to Reduce Construction Accidents***

**J K Bedi<sup>1</sup>, R A Rahman<sup>1,2</sup> and Z Din<sup>3</sup>**

1 Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Kuantan, Pahang, Malaysia

2 Earth Resources and Sustainability Centre, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Kuantan, Pahang, Malaysia

3 Department of Construction Management, University of Houston, 4734 Calhoun Rd, Houston, TX 77204, United States

E-mail: jasvin96@hotmail.com

**Abstract.** The construction industry has been consistently performing poorly in safety resulting in substantial human and economic losses globally. The hazard related to heavy machinery operations can lead to injury or fatality of operators, workers, or visitors. Thus, safety training of heavy machinery operators (HMOs) is crucial to perform their tasks safely on construction projects. HMOs face various risks due to complex work environments at a job site such as the presence of other workers, material flow, equipment motion, and temporary structures that limit the space for heavy machinery. This research identifies the causes of accidents and competencies required to eliminate these accidents associated with heavy machinery operators. To achieve that, interview data with fifteen construction project managers are analyzed. This study's findings suggest that the causes of heavy machinery accidents include insufficient maintenance, negligence of operators, inadequate training, human factor, and site condition. Conversely, the competencies to mitigate heavy machinery accidents are knowledge of safety incentives and penalties from safety training, the ability to conduct safety briefing, inspect heavy machinery and site conditions, and communication skills. Industry practitioners and researchers can use these findings to enhance construction productivity by creating a safe working environment at construction sites.

### **1. Introduction**

The construction industry is one of the most profitable sectors around the globe [1]. While the construction industry dramatically contributes to the growth of the economy as well as the development of infrastructures, heavy machinery is part of the vital assets for different soil and material handling activities in the construction industry [2]. However, the occurrence of accidents related to heavy machinery is often associated with its severe impact on the project flow in terms of cost and time [3]. These accidents can be mitigated by publicizing the safety issues and unsafe behavior among employees and including employee participation in the creation of safety programs, conducting safety audits, and identifying alternatives to improve safety at construction sites [4]. Also, these accidents occur due to construction companies fails to provide a safe working environment that increases the potential for tragedy to occur and impair the success of the construction industry. Thus, a better understanding of



appropriate strategies for minimizing heavy machinery accident rates is vital in the area of construction project management as it will benefit the industry at large [1].

From 2015 to 2017, several types of accidents have been run into in Malaysia, whereby risk related to heavy machinery marks the dominant incident [5]. Heavy machinery is a self-propelled vehicle designed to perform construction task that involves inherent hazard and result in more complexities at the site due to presence of operating crews, flow materials, equipment motion and temporary assembly that make the space to be constrained and confined by heavy machinery [6]. Heavy machinery could be a hazard and cause severe injuries due to physical contact with powered machinery without adequate safeguarding and control [7]. Accidents among heavy machinery operators are caused by backhoe accidents, rollover accidents, struck-by accidents, defective parts of the machine components, and electrocution [8]. For example, the type of cases in Malaysia is being pinned by heavy machinery (16 cases), electrocution (6 cases), and struck and hit by heavy equipment due to blind spots (38 cases) [5]. In addition to ensuring that the safety standards and minimum requirement in operating heavy machinery are met, these accidents can be prevented if additional safety measures are provided to address the causes that contribute to these accidents. Also, preparing heavy machinery operators with the competencies that are necessary for reducing heavy machinery accidents can contribute to the reduction of heavy machinery accidents. Therefore, understanding the causes of accidents and competencies required to avoid those accidents is crucial to reduce heavy machinery accidents.

This paper's objective is to identify the causes of heavy machinery accidents and competencies required among its operators to avoid those accidents. The authors address that objective by analyzing interview data with fifteen construction managers from different construction companies across Malaysia. The findings of this research will provide an insight into the causes and how the occurrence of accidents in the relationship between operators and machinery can be resolved. Reducing heavy machinery accidents can improve construction productivity of a hazard-free and rewarding working environment.

## **2. Literature Review**

### *2.1. Heavy Machinery Accidents*

While heavy machinery accidents are often caused by natural disasters such as thunderstorms, earthquakes, and strong winds that cannot be forecasted, heavy machinery operators can minimize the injuries or fatalities from these incidents [9]. Therefore, to reduce heavy machinery accidents, numerous studies have identified the causes of heavy machinery accidents through the dissemination of questionnaire surveys [10; 11; 12]. One of those studies suggests that the cause of heavy machinery accidents are due to vision-related death such as blind spots and obstruction due to confined and compact working space whereby operators fail to locate on-foot employees or a fixed object that is close to the working area [10]. On the other hand, another study suggests that the failure of identifying and assessing the perception of risk of heavy machinery operators could initiate the occurrence of casualty such as the workers being caught between two heavy machineries or between a heavy machinery and a fixed object and operators being struck by swinging equipment attachments or crushed under overturned heavy machinery that develops new risk as well as increasing the existing risk while carrying out heavy-duty construction equipment activities [11]. Furthermore, in Canada, mishaps allied with heavy machinery also occur due to lack of safeguards, lack of lockout procedures, inexperienced operator, lack of risk evaluation, and lack of supervision, unsafe working practices, and no clear instructions to operators on approaches to engage safely in machinery [12]. Therefore, identifying the underlying causes contributing to the calamity of heavy machinery accidents is crucial and must be comprehended as every construction project phases and process levels.

### *2.2. Heavy Machinery Operators*

In conjunction with reducing the accident rates related to heavy machinery in the construction industry, one of the approaches includes having heavy machinery operators with the appropriate competencies. These competencies involve having operators that know methods for monitoring blind areas to avoid accidents such as collision with workers or other objects [13]. This competency is essential to ensure that nobody is either behind or in the blind spots of the operators when operating the heavy machinery, including getting off and checking the machine. That competency also includes having heavy machinery operators that know utilizing cameras to view blind areas and using available sensors and warning systems to avoid collision between heavy equipment and other object or person [10]. Also, teamwork and communication skills are crucial among heavy machinery operators in collaborating with other individuals at the site, including flaggers, to avoid and reduce hazards that are generated while carrying out heavy-duty construction equipment operations [14]. Furthermore, it is emphasized that the operator needs to abide by safe working practices, having the ability to detect hazards, monitoring the heavy machinery's condition and enduring to the instructions and orders is a key to promote a safe construction [15]. In general, different studies suggest that heavy machinery operators require different competencies to avert the likelihood of casualty. Therefore, having an in-depth understanding of the necessary competencies among heavy machinery operators is crucial to reduce heavy machinery accidents.

### *2.3. Positioning of this study*

Various studies have shown the causes that contribute to heavy machinery accidents that may lead to lethal and impact the successful implementation of project output. Hence, the root of casualty must be recognized to rectify and refine the construction project's productivity deficiency because a successful project is defined when it is completed within the allocated cost, quality, and time [16]. To further improve the safety performance of the construction industry, some approaches are required in preventing accidents that are correlated with the operator and heavy machinery. However, the study may not capture the additional causes of accidents and competencies needed by an operator to reduce these accidents because the data is collected by a questionnaire survey that is standardized and inflexible to changes. Therefore, this study will address this gap through individual interviews with industry practitioners to provide additional insights into the causes of heavy machinery accidents and competencies required among its operators to reduce those accidents.

## **3. Methods**

The collection of data involves acquiring data from individual interviews with construction managers from various construction companies. Qualitative approaches used to analyze the collected data. The subsequent subsections describe this study's data collection and data analysis approach.

### *3.1. Data Collection*

This study's data collection aims to elicit information on the causes that lead to accidents among heavy machinery operators and the competencies required to reduce the occurrence of these accidents through open-ended interviews with construction managers. The target population of this study is construction managers from grade G7 construction companies in Malaysia. According to Malaysia's Construction Industry Development Board (CIDB), only G7 licensed companies are eligible to conduct any construction projects without any restrictions. Thus, this research emphasizes on construction managers from grade G7 contractors due to their rich experience in safety implementation among heavy machinery operators in construction projects. This study uses open-ended interviews because it allows participants to give their viewpoints and be more flexible with their statements [17]. In other words, this method enables construction managers to answer the interview question based on their personal experiences on what are the causes of accidents and the necessary competencies among heavy machinery operators in mitigating these accidents. The interview questions are: (1) What are the causes that lead to the occurrence of heavy machinery accidents? (2) What are the competencies required among heavy machinery operators to reduce heavy machinery accidents? Further questions will be asked to obtain sufficient information before the research being conducted based on the responses received from the

interviewers. After each interview, the conversations held between the interviewer and respondents are summarised and sent to the respondent for validation.

**Table 1.** List of Interviewee.

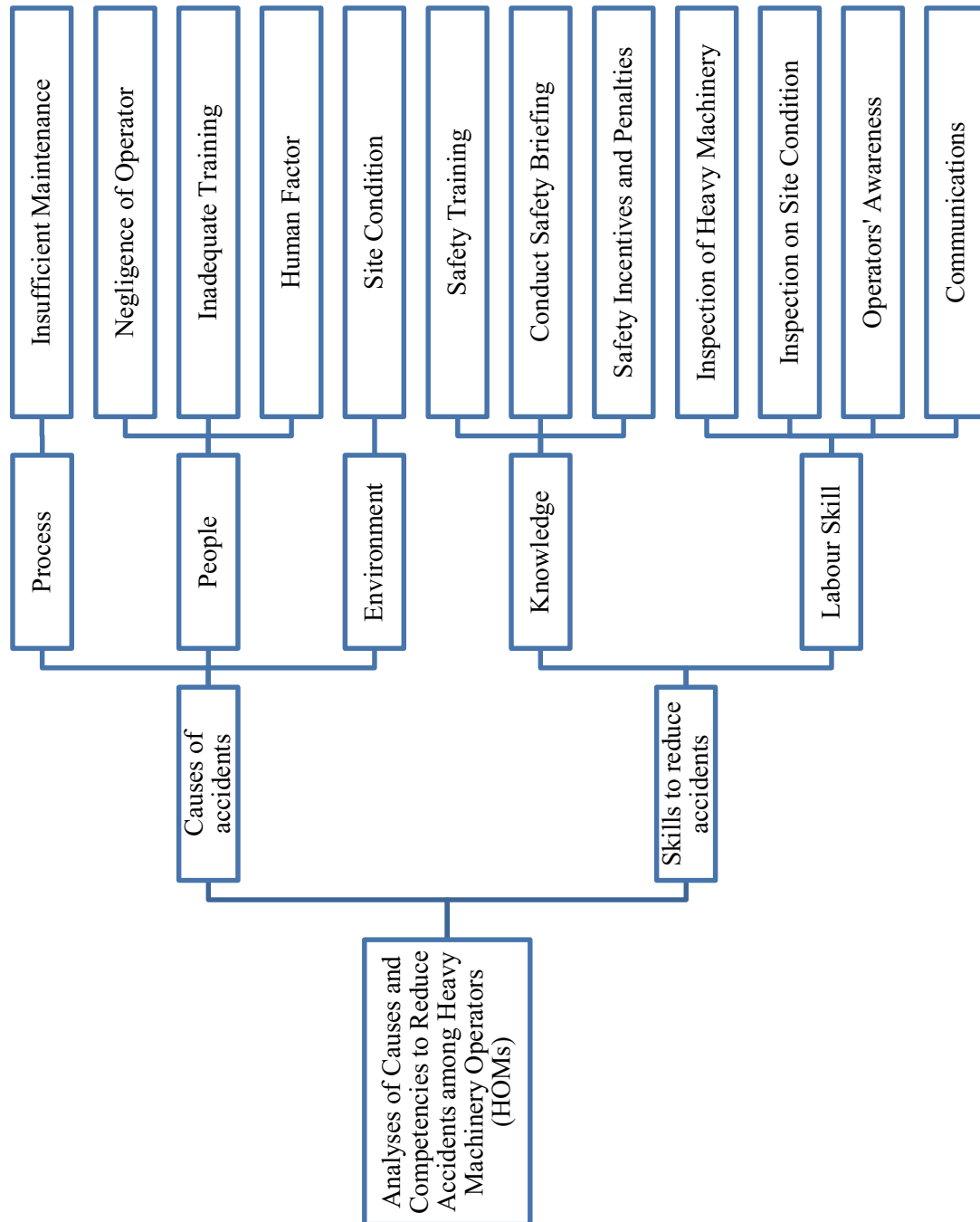
ID	Position	Organization
1	Site Engineer	Contractor A
2	Site Engineer	Contractor B
3	Site Supervisor	Contractor C
4	Site Supervisor	Contractor D
5	Site Engineer	Contractor E
6	Site Engineer	Contractor F
7	Project Engineer	Contractor G
8	Site Engineer	Contractor H
9	Site Engineer	Contractor I
10	Site Engineer	Contractor J
11	Site Engineer	Contractor K
12	Site Engineer	Contractor L
13	Site Engineer	Contractor M
14	Site Engineer	Contractor N
15	Site Engineer	Contractor O

### 3.2. Data Analysis

The data are analyzed using the thematic analysis whereby all sets of data are brief despite elucidate various aspects of the study, and the method used to recognize, examine, and data is being described in patterns [18]. The thematic analysis comprises of six-phases. The first phase is to be conversant with the data. Data are gathered through interviews with participants, and records are taken through notes. The second phase is to lead to initial codes whereby coding is used to simplify the data into tiny pieces of significance to make it simpler. Furthermore, Microsoft Excel can be utilized to code and recognize the subject matter [19]. The third phase is to search for themes. This phase is when all data is accumulated applicable to each prospective. The fourth phase is to evaluate the theme whereby the thematic map for the analysis is generated. The fifth is the defining and naming themes phase, whereby the codes are used to generate the sub-themes and themes. The final phase is when the results and findings are reported based on the analysis. Therefore, analysis is a repeated process that is evolved over time.

## 4. Results and Discussion

Figure 1 illustrates the causes of heavy machinery accidents and competencies required among heavy machinery operators to reduce those accidents that are identified through analyzing this study's interview data with fifteen construction managers. In this study, the causes of accidents are themed into the process, people, and environment. On the other hand, the competencies to reduce accidents are further themed into knowledge and labor skill. The details of each theme are also described in the subsequent subsections.



**Figure 1.** Overview of causes of heavy machinery accidents and competencies required among its operators to avoid those accidents.

**Table 2.** The total number of hits for causes of heavy machinery accidents and competencies required among its operators to avoid those accidents.

	Contractor A	Contractor B	Contractor C	Contractor D	Contractor E	Contractor F	Contractor G	Contractor H	Contractor I	Contractor J	Contractor K	Contractor L	Contractor M	Contractor N	Contractor O	Total no of hits
<b>Causes of Accidents</b>																
<b>Process</b>																
Insufficient maintenance	✓	✓	✓	✓			✓		✓	✓		✓		✓	✓	10
<b>People</b>																
Negligence of operator		✓	✓	✓	✓		✓					✓			✓	7
Inadequate training	✓		✓						✓	✓			✓	✓	✓	7
Human factor	✓					✓	✓	✓	✓				✓	✓	✓	7
<b>Environment</b>																
Site condition	✓	✓	✓		✓	✓	✓		✓		✓	✓	✓		✓	11
<b>Competencies to Reduce Accidents</b>																
<b>Knowledge</b>																
Safety training	✓		✓		✓	✓		✓	✓	✓		✓		✓	✓	10
Conduct safety briefing	✓					✓								✓	✓	3
Safety incentives and penalties	✓															1
<b>Labour Skill</b>																
Inspection of heavy machinery		✓	✓	✓	✓				✓	✓		✓	✓		✓	9
Inspection on site condition		✓					✓	✓		✓				✓		5
Operators' awareness				✓			✓	✓				✓	✓		✓	6
Communications							✓				✓					2

#### 4.1. Causes of Heavy Machinery Accidents

##### 4.1.1. Process

###### 4.1.1.1. Insufficient Maintenance

According to several participants, lack of maintenance of the heavy machinery may cause long term mechanical defects that can lead to severe injury to operators due to its poor performance. According to [20], most of the injuries and fatalities are due to poor maintenance of the machinery spare parts that are not being maintained over a long period of time. Furthermore, heavy machinery accidents occur due to hydraulic problems that lead to abnormal noise, high fluid temperature, and slow operations due to inadequate maintenance. The hydraulic problem may damage the pump and motor, thus reducing the efficiency of machinery operations. Therefore, it is important to daily inspect the machinery such as replacing the fuel filters, checking the chain and gearbox as well as greasing all the lube points for better performance. Maintenance of heavy machinery tends to increase the reliability of components and hence the level of safety.

#### 4.1.2. People

##### 4.1.2.1. Negligence of Operator

Different machinery has a different load-carrying capacity. Based on the participants' view, overloading of the machinery can lead to the failure of structural components of the machinery that cause inadequacy of the machinery to carry the load. For instance, in one of the participant's projects, an unexpected death occurs due to the crane's hoist rope broke, and the hydraulic jack fails to control the movement of the hoist rope that causes heavy materials to fall on the operator. Conversely, excessive load carrying capacity can cause the overturning of the crane due to its counterweight effect where the crane can overturn if the counterweight is too heavy for the boom configurations. This means that the operator is required to adhere to the weight limit of machinery being operated and ensure that the loads are secured with proper rigging attachments.

##### 4.1.2.2. Inadequate Training

Other causes of accidents include inadequate training of operators in operating the heavy machinery. There is a need to align the training requirements to produce a competent operator that would improve the operators' current and future performance by establishment sets of standards. Based on the analysis of individual interviews with construction managers, untrained and inexperienced operators are the main reason that causes the occurrence of accidents. In most of the case, the company tends to save the cost of a project by hiring incompetent operator at a very nominal price. This results in construction projects having an uncertified operator do not possess the skill and knowledge in handling the machinery when an emergency is encountered and eventually leads to loss of control. Therefore, safety training is crucial to provide operators with the competency to operate the machinery effectively with optimal performance and reliability [21].

##### 4.1.2.3. Human Factor

The human factor in this study involves negligence and unsafe acts that could trigger the occurrence of accidents. Based on participant perspective, lack of commitment, carelessness of the operator, reckless operation, excessive working hours, poor information flow, and operators' low safety awareness is the major contribution to accidents that reduce the effectiveness of the workflow. Specifically, operators' behavior of not adhering to safety policies is an unsafe action that leads to negative consequences that could influence the performance of the project. For instance, the carelessness of operators such as playing mobile phones or two-way radios tends to leave the steering of machinery unattended and divert their attention that could result in running off the road and hitting other personnel on the ground. Furthermore, operators tend to ignore the restraint devices that are equipped by the machinery such as seat belts and thus prone to the severity of injury such as falling off when rollover incidents occur. As a result, the implementation of appropriate actions such as penalties on irresponsible operators' could be taken to effect a permanent improvement.

#### 4.1.3. Environment

##### 4.1.4. Site Condition

Poor housekeeping and lack of site inspection can conduce poor management of waste that may cause a significant impact. Therefore, creating a good and tidy work environment to keep the construction site clean and free from obstructions [22]. Besides, construction managers believe that unstable ground conditions due to inclement weather cause the soil condition to be saturated and thus reduce the bearing capacity of soil to support the load from heavy machinery. Accidents such as slip, trip, and fall of heavy machinery can occur during inclement weather due to instability of ground. Furthermore, numerous activities on-site with limited access can cause accidents due to blind spots as the working area is too confined. Blind spots are prevalent around the heavy machinery, and the operator often fails to identify on-foot-workers or objects near the work area [13]. For example, the operators need to be aware of their swing radius when operating the heavy machinery in confined or compact space to avoid hitting other



personnel or vehicle that could reduce work productivity. In conclusion, continuous monitoring of on-site conditions is vital to improving overall safety quality.

#### *4.2. Competencies to Reduce Heavy Machinery Accidents*

##### *4.2.1. Knowledge*

###### *4.2.1.1. Safety Training*

Safety training is a sequence of step that can be taken by every operator to be a competent personnel that has the acquired skills and knowledge in operating the machinery in any possible situation. It is a necessary step for construction managers to ensure that a comprehensive safety training program is essential to obstruct any significant contribution to dangerous activities and conditions. For instance, the company should hire a competent operator that has attended an induction on Green Card Course by CIDB. CIDB is a Green Card scheme that is widely recognized by the construction industry in recognition of skills, knowledge, understanding, competence and qualifications of the heavy machinery operators. Moreover, the operators' skills should be merely evaluated based on their experience, education, expertise, and potential. Implementation of safety and health program is the indicator of the reduction of severe injuries and fatalities. Therefore, safety training is one of the most effective ways of identifying and mitigating the occupational risk that is experienced when dealing with heavy machinery and ensures that the operator is competent in operating the high-tech machinery.

###### *4.2.1.2. Conduct Safety Briefing*

Participants suggested that the safety briefing with the site supervisor is a key element in improving the safety performance of a certain project. Ideally, operators should understand the ramifications of inadequate safety implementation when dealing with heavy machinery to prevent any risk of injury. For instance, attending the morning briefing or weekly induction guide the operators for familiarizing themselves with the safety term that is often being utilized by site supervisor during their supervision. Participants believe that operators that are not local citizens face the challenge of having language barriers, thus not having the ability to follow instructions conducted by the site supervisor. As expressed, having a short briefing every morning is necessary to ensure the operators are well equipped with the knowledge, ability, and capability in enforcing the safety standards during the operation of the heavy machinery.

###### *4.2.1.3. Safety Incentive and Penalties*

Respondents suggest that safety rewards can heavily influence the operator's actions to promote and reward better workplace efficiency. Besides, safety incentives are mainly to strengthen the desired behavior positively. The company can merely emphasize to enforce the operator with penalty and deduction of salary if a proper workforce is not being implemented when dealing with heavy machinery. This is an initiative to influence the operator to be more effective in performing their task, operating the heavy machinery with appropriate skills to avoid any accidents that may seek reimbursement for injuries suffered. In general, programs that involve safety rewards are commonly implemented by companies to improve the operators' safety.

##### *4.2.2. Labour Skill*

###### *4.2.2.1. Inspection of Heavy Machinery*

Maintenance plays a key role in reducing cost, minimizing downtime of machinery, improving quality as well as increasing work productivity in achieving the goals and objectives of organizations. Several participants suggested that pre-season check and visual inspection of the heavy machinery is vital before executing the operation of heavy machinery on site. For instance, keeping track of the engine oil, hydraulic fluid, hydraulic hoses, lifting gears, buckets, and the boom is required to ensure the heavy machinery is being operated in good condition. Mishap associated with heavy machinery occurs due to poor maintenance and regular inspection that results in machinery breakdown and has a substantial

impact on the efficiency of machinery and the overall organizational performance. Machinery breakdown may occur due to unanticipated factors. Therefore machinery obsolescence can be prevented by construction managers by ensuring proper operation and continuously monitoring the machinery [23]. As a result, it is crucial to constantly evaluate heavy machinery conditions and detect signs of potential failure.

#### *4.2.2.2. Inspection on Site Condition*

Inspection of site condition is crucial to ensure the working area is free from obstruction and the platform is leveled. Participants believe that the challenges that are often associated with construction sites are the possible hazards or obstacles that are encountered, such as overhead power lines and underground utilities that make it less accessible for the heavy machinery to be operated in such areas. Also, regardless of obstruction, the operator needs to acquire the ability to make sure the ground level is capable of sustaining the load of the heavy machinery to avoid any settlement and instability. Therefore, scrutiny on the site is necessary to avoid the occurrence of misfortune that may result in idling in projects.

#### *4.2.2.3. Operators' Awareness*

Efforts to raise the operators' perception of the need for a safe, health-free workplace require concerted efforts and multiple parties' participation. Based on the participant's point of view, different approaches are needed to implement these efforts and should be enacted in a comprehensive and integrated manner to be as effective as possible. For example, the operator is not required to work exceeding the working hours and avoid distractions such as mobile phones when operating the heavy machinery. Companies should comply with local laws on the hour of work as the operator may utilize rest breaks to recover from fatigue and prepare for unprecedented productive work. As expressed, the operator should remain focused when operating the heavy machinery to prevent any accidents that could be detrimental.

#### *4.2.2.4. Communications*

Communications is important to ensure that the operator is properly operating the heavy machinery. Participants suggest that communication between operator and supervisor becomes an instrument for ensuring that operators stay away from potential hazards that can cause accidents. Besides, safety communications also aid in influencing the actions and attitude of the operator towards safety. For instance, the operator and site supervisor should have instant communication through two-way radio to ensure that their blind spots are kept clear. Breakdown in communications has eventually reduced the capability of an operator to take appropriate action during a critical situation, thus reducing the safety performance. For this reason, communication is essential in enhancing the safety of heavy machinery operators in reducing the rate of accidents in large-scale projects.

## **5. Conclusion**

To reduce accidents at construction sites, this study identifies the causes of heavy machinery accidents and competencies required by its operators by analyzing interview data from fifteen construction managers using the thematic analysis. The main findings from the analysis include:

- The causes of heavy machinery accidents include insufficient maintenance, negligence of operators, inadequate training, human factor, and site condition.
- These causes can be grouped into three categories: process, people, and environment.
- The competencies to mitigate heavy machinery accidents are: knowledge on safety incentives and penalties from safety training, ability to conduct safety briefing, inspect heavy machinery and site conditions, and communication skills.
- These competencies can be clustered into two categories: knowledge and skills.

In addition to providing additional insights to the construction safety body of knowledge, researchers and industry practitioners can use this study's findings to visualize the relationship between causes and necessary competencies associated with heavy machinery accidents and develop learning modules to prepare heavy machinery operators with the necessary competencies to reduce heavy machinery accidents. Thus, the lessons from this study would help the industry reduce the likelihood of heavy machinery mishaps that results in better workplace safety and higher project quality. The key theoretical

contribution of this study is by conveying a better understanding of heavy machinery accidents and the competencies required to enhance its operation.

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