Safety Situation and Analysis of Safety Measures for Electric Railway Construction Sites: Case Study of a Suburban Red Line Project, Bang Sue-Rangsit Section

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Abstract

Proceeding from the policy of developing and promoting international railway networks with neighborhood countries has been an expansion of the national railway system. This expansion has necessitated the establishment of many railway route construction projects. In this circumstance, the construction workforce is critical to the success of these necessary projects. However, it is vital for the effectiveness of the projects' workforce to ensure a safe environment and mitigate risks related to the construction process during the projects. Therefore, this study focused on an investigation of project construction safety in various situations, related analysis of safety measures, and construction risk mitigation of a specific metro train route construction project, the Red Line Bang Sue-Rangsit segment, Bangkok, Thailand. Near miss incidents were a significant part of our investigation. The study collected data from 108 samples and found that there were 200 cases of near miss incidents. The case subjects for the study were divided into 6 groups, which were: 1) personnel working at heights, 2) railway installation workers, 3) crane and forklift operators, 4) heavy machinery and transportation operators, 5) personnel working in obstructed areas, and 6) Other non-specific categories of railway construction workers. Following the group identification of railway safety work categories, risk assessment and evaluation of safety measures were performed. The research determined that the group of workers with the highest risk were the personnel working at heights, especially at the Bang Sue Grand Station construction site. After reviewing the near miss incidents, it was observed that the primary causal factor involved was human behavior at the worksite. The significant contributing factors were the safety conditions in the workplace environment and the safety of standard operating procedures. Safety and Risk mitigating factors were experience, training, and clear understanding of the safety procedures and enforced worksite safety policies/rules.

สถานการณ์ความปลอดภัยและการวิเคราะห์มาตรการเพื่อความปลอดภัยในการก่อสร้างทางรถไฟฟ้า: กรณีศึกษาโครงการระบบรถไฟชานเมืองสายสีแดง ช่วงบางซื่อ – รังสิต

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บ ท คั ด ย่ อ

นโยบายการพัฒนาและเชื่อมโยงเศรษฐกิจและเพื่อนบ้านด้วยระบบรางส่งผลให้เกิดการขยายตัวด้านโครงข่ายเส้นทางรถไฟและเกิดการสร้างงานด้านการก่อสร้างระบบรางขึ้นเป็นอย่างมาก โดยมีแรงงานเป็นส่วนสำคัญที่ช่วยขับเคลื่อนให้งานก่อสร้างระบบรางสำเร็จ ขณะเดียวกันจำนวนอุบัติเหตุในงานก่อสร้างระบบรางก็เพิ่มขึ้นตามจำนวนโครงการก่อสร้างที่เพิ่มมากขึ้น เพื่อศึกษาและหาแนวทางในการลดการเกิดอุบัติเหตุในงานก่อสร้างระบบราง งานวิจัยนี้ได้ทำการศึกษาสถานการณ์ความปลอดภัยในการก่อสร้างของโครงการระบบรถไฟชานเมืองสายสีแดง ช่วงบางซื่อ – รังสิต กรุงเทพมหานคร ประเทศไทย โดยให้ความสนใจกับเหตุการณ์เกือบเกิดอุบัติเหตุ ซึ่งอาจเป็นจุดเริ่มต้นของการพัฒนาไปสู่อุบัติเหตุได้ แล้วหามาตรการในการแก้ไขหรือป้องกัน จากการศึกษากับกลุ่มตัวอย่างจำนวน 108 ตัวอย่าง สามารถรวบรวมเหตุการณ์เกือบเกิดอุบัติเหตุได้จำนวน 200 เหตุการณ์ ซึ่งสามารถจัดกลุ่มเหตุการณ์ออกได้เป็น 6 กลุ่ม คือ 1) กลุ่มที่ทำงานบนที่สูง 2) กลุ่มที่ทำงานเกี่ยวกับการติดตั้งราง 3) กลุ่มที่ทำงานเกี่ยวกับเครนและโฟร์คลิฟท์ 4) กลุ่มที่ทำงานกับเครื่องจักรหนักและการขนส่ง 5) กลุ่มที่ทำงานในพื้นที่ที่มีสิ่งกีดขวางทางเดิน และ 6) กลุ่มอื่นๆ จากนั้นประเมินระดับความเสี่ยงของเหตุการณ์เพื่อให้ความสำคัญในการแก้ไขหรือป้องกันเป็นอันดับแรก ตลอดจนกำหนดมาตรการเพื่อป้องกัน กลุ่มที่มีความเสี่ยงในระดับสูงสุดคือกลุ่มที่ทำงานบนที่สูง โดยเฉพาะในส่วนของการก่อสร้างสถานีกลางบางซื่อ สำหรับสาเหตุของการเกิดอุบัติเหตุนั้น พบว่า มีองค์ประกอบหลักมาจากพฤติกรรมของผู้ปฏิบัติงานและสภาพแวดล้อมในการทำงาน ทั้งนี้ ประสบการณ์ การฝึกอบรม ความเข้าใจในขั้นตอนความปลอดภัย รวมทั้งนโยบายและกฎเกณฑ์ต่าง ๆ ด้านความปลอดภัยจะช่วยให้สถานการณ์ความปลอดภัยดีขึ้นได้

1. Introduction

With the expansion of railway networks for both long distance intercity train routes and metro commuter train routes including double track railway [1] of city trains and commuter trains, eleven routes [2] including high speed rail construction were planned in the future [3-4]. With this expansion, there would be a heightened risk of accidents occurring during the increased railway construction. These accidents are typically from human errors during work activities. Ineffective or poorly organized safety management is another factor in occurrence of accidents. Construction industry data from the Thailand National Statistical Office in the year 2014 reported that there are 355,598 people working in the national construction industry. Most workers are in building construction (223,114 people), which is approximately 66.5% of all construction industry workers. There are 27,691 people working in road and railway construction, which are estimated to be 8.3% of all workers in the construction industry [5]. The information from the Compensation Fund of the Thailand Social Security Office reported that the main causes of 21.3% of the annual accidents involving construction workers during the years 2012-2016 were from structure collapse and falling objects. The injuries from cutting and eye chemical/object injuries were 18.8% and 16.1% per year respectively [6]. These accidents lead to the loss of human resources, financial losses, and economic and social impacts to society. Additionally, these types of incidents and the resulting negative effects can have a profound impact on national development. Railway construction is one of the areas that causes many worksite accidents and receives media attention in the society when accidents occur [7]. Therefore, it is critically important to make safety a priority, perform risk assessments and develop safety measures to protect workers, as well as the public from the consequences of accidents. In fact, many accidents stemmed from and were often preceded by related near-miss incidents. Near-miss incidents rarely received enough attention to motivate the changes required to prevent serious accidents in the end. Therefore, near-miss reporting and collection is one of the necessary instruments used for recording unexpected incidents and identifying preventative methods and strategies [8-10]. Also risk assessment and risk management models are important in railway construction projects, especially in large projects that have many activities with high exposure to risk [11-13].

In this study, near-miss incidents from railway route construction were identified and investigated. To prevent unexpected serious accidents from occurring, appropriate and effective safety measures should be deployed. To accurately define the most suitable safety measures, what occurs prior to an accident or near miss as well as what happens after an event has occurred should be analyzed. There are several methods for hazard identification, Event Tree Analysis (ETA) is one of the techniques that can evaluate all the possible failure sequences and identify their respective consequences [14]. The ETA technique has been used for helping in design for safety and in preventing marine accidents [15], as well as analyzing for flood protection [16]. This has been used as a general model for railway system risk assessment [17]. In this research, the Metro train route construction of the Red Line Bang Sue-Rangsit was selected as the study model. And the ETA technique was aslo used.

2. Methodology

2.1 Data surveying and collecting

This research is focused on a current construction project with safety issues at an electric railway construction site in Bangkok, Thailand during a period of 4 months in 2018 - 2019. The suburban Red Line project, Bang Sue-Rangsit section was selected for this study. Near miss incidents were collected and categorized along with the frequency rate of incidents using onsite surveys covering the target stations and depot construction sites. Study data also gathered from interviews with onsite personnel and safety officers as well as researcher observations made during the onsite visits.

After collecting the data from observations, interviews, and surveys the accumulated information was classified as: the type of incidents, accidents, and the risk category of the workers. As mentioned before, near-miss incidents were the primary focus of this research, because these have the potential to evolve into serious accidents if the underlying factors are not mitigated. Therefore, appropriate, and effective safety measures for accident protection could be implemented after review of the incidents. Employee awareness of near miss incidences can contribute to the development of a safety culture and a mindset of alertness to risk. Identifying the type of work activity involved in the incidents will help in categorizing the risk group of the near-miss incidents. Information about the incidents from interviews will confirm the official incident/accident record of the construction companies.

2.2 Research instrument

In this research, two types of data were gathered. The first type of data was from the official safety reports that all contracting companies had submitted to the State Railway of Thailand (SRT). The second type of data was from the interviews with the sample groups. For effective interviews with several varied sample groups, the guideline questions for repetitive interviewing must be scoped out to fit with the research objectives. Therefore, the question guidelines for interviewing were defined in an interview form. In this investigation, the interview form was composed of three sections. The first section was to gather certain general information of the interviewee, such as gender, age, job position, etc. The second section was to capture specific information about incidents /accidents that the interviewees had witnessed themselves or could remember from their experience in the area that they worked up until the time of the interview. And the final section was just a blank form for the interviewers to record the incidents/accidents that they had observed themselves or which occurred during the surveying period, especially the near-miss incidents. However, an impediment to information collection using these methods was the participation of foreign language speaking workers active at the construction site. The researchers were faced with a language barrier problem when workers were not able to communicate in either Thai or English. Consequently, the interviews were conducted with Thai speaking workers only.

2.3 Hazard Identification and Risk Assessment

This research was focused on the near miss incidents. The occurrences of such events were used to identify the hazards and measures related to the railway construction by using the Event Tree Analysis (ETA)technique. The ETA technique is one of the hazard identification techniques that is preferred by the Department of Industrial Works. The ETA focuses on hazard identification method, risk assessment, and risk management planning, B.E. 2543 [18]. Our goal is to focus on near-miss incidents, and, subsequently, to find apposite safety measures for preventing accidents; therefore, when a near-miss incident is identified, it will be defined as an initiating event. After an initiating event, the necessary mitigating safety measures will be provided to prevent an accident. Proceeding from this concept, the general form of ETA technique used in this research has been adapted and formulated as in Figure 1.

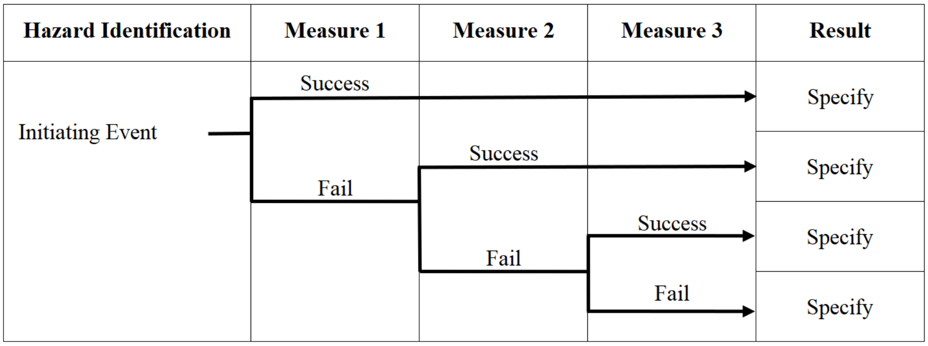

Figure 1 General form of Event Tree Analysis (ETA) technique adapted for this research.

Furthermore, to organize the collected data to perform the risk assessment, the near-miss incidents were categorized into 4 levels, as shown in Table 1 [18].

Table 1 Level of Probable Incident Occurrence.

Level	Details
1	Lowest occurrence, never happened within 10 years
2	Low occurrence, could only happen once within 5 - 10 years
3	Moderate occurrence, could happen once within 1 - 5 years
4	High occurrence, could happen once within a year

Next, the severity of the incidents was classified by their potential degree of impact to people, communities, property, and the environment. The severity levels were categorized into 4 levels as shown in Table 2 to Table 5 [18].

Table 2 Severity Levels of Incidents That Impact People.

Level	severity	Details
1	Low	Small injury at first aid
2	Moderate	Injury that needs medical treatment
3	High	Serious injury or sickness
4	Highest	Disability or fatality

Table 3 The Severity Levels of Incidents that Impact Local Communities.

Level	severity	Details
1	Low	Small or no impact to the community around the worksite
2	Moderate	Moderate impact to the local community, amendable quickly
3	High	Significant impact to community, need time for correction
4	Highest	Serious or widespread community impact, requiring government action with costs charged to contributing actors for remediation

Table 4 The Severity Levels of Incidents that Impact the Environment.

Level	severity	Details
1	Low	No impact to the environment, or can be controlled or corrected
2	Moderate	Moderate impact to the environment, remediated quickly
3	High	Significant impact to the environment, need time for correction
4	Highest	Serious,widespread long -term damage to environment, need significant resources and long period to remediate

Table 5 The Severity Levels of Incidents that Impact Property.

Level	severity	Details
1	Low	None or Lowest impact to property
2	Moderate	Moderate property damage, construction can be continued
3	High	Significant property damage, some construction must be stopped
4	Highest	Severe property damage, all construction must be stopped

The levels of risk were the results of the probability of incident occurrence multiplied by the severity level of incidents that impact people, communities, property, and the environment. If there were difference or variance among them, the highest level of severity in each category will be used for analysis. The levels of risk were categorized into 4 levels as shown in Table 6 [18].

Table 6 The Levels of Risk.

Risk level	Result	Meaning
1	1 - 2	Low risk
2	3 - 6	Acceptable risk, measures and controls must be rechecked
3	8 - 9	High risk, require process adjustment or implementation of essential process to reduce risk
4	12 - 16	Unacceptable risk, must stop and revise process to reduce risk immediately

The levels of risks can calculate from,

$$R = C \times \{ Lp, Ls, Lr, La \} \quad (1)$$

Where R is levels of risks.

C is the level of probability occurrence of incident.

Lp is the severity level of incidents that impact to person.

Ls is the severity level of incidents that impact to communities.

Lr is the severity level of incidents that impact to properties.

La is the severity level of incidents that impact to environment.

Lp, Ls, Lr, and La are selected using only the factor that has the highest level of severity.

3. Results

3.1 The project costs and the accident statistic

The suburban Red Line project, Bang Sue-Rangsit Section, is one of several projects under the blueprint for Bangkok Mass Rapid Transit Master Plan for Bangkok Metropolitan (M-MAP). On 22 May 2007, the cabinet approved the funding for the project in the amount of 59,888 MB. with the cooperation of the Japanese government by the Japan International Cooperation Agency (JICA) [19]. The budget was increased to 93,950 MB. and the construction process was launched on 4 March, 2013 and was expected to be completed in October 2020. The construction cost of the project through 2018 was shown in Figure 2. The accident cases, including property damage, injuries and deaths and the estimated compensation cost [20] were also shown in Figure 3.

Figure 3 shows that the early stage of the project, 2014 (2nd year of the project), had the highest number of accidents that caused property damage. After that period, the rate of such accidents steadily declined. This implied that safety measures were effectively improving construction worksite safety levels. These safety levels related to the injury rate that can be seen only during the first three years of the project. For the case of fatal accidents occur during 2015-2017, with 7 deaths (average 2 deaths per year), the year 2015 has the highest compensation cost due to many accidents involving injury, fatalities, and property damage. As observed in Figure 4, the monthly accident rate, the first year of the project had the highest rate and it dropped dramatically from 2014. All these charts demonstrate that the safety management system seems to be improving accident and incident rates steadily. Also, when comparing the compensation to the total project value, the estimated compensation is a relatively small amount and insignificant (less than 0.001% of the project value). However, the loss of human resources and the loss of a family's member is difficult to quantify in strictly financial terms. Every project tried to prevent all losses and injuries, especially the loss of human life and serious injuries. Note that the compensation cost was estimated based upon the standard compensation defined by the Social Security Office [20]. Because the exact com-

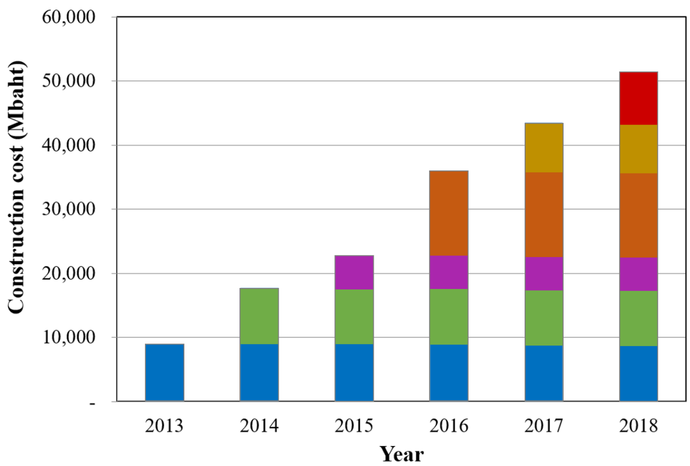

Figure 2 Accumulated value of the project.

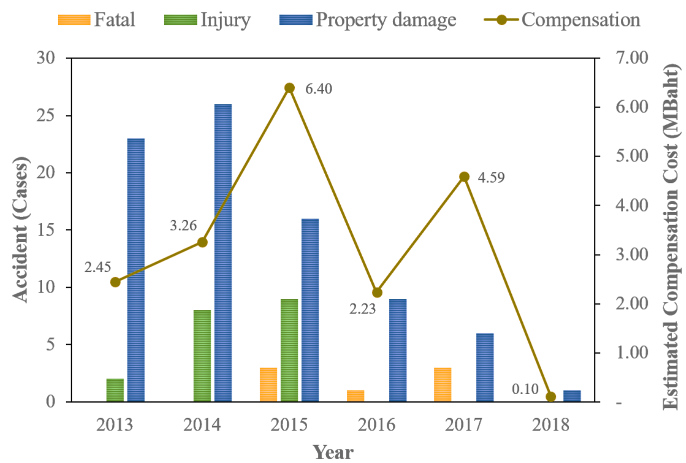

Figure 3 Accident statistic and compensation cost estimation.

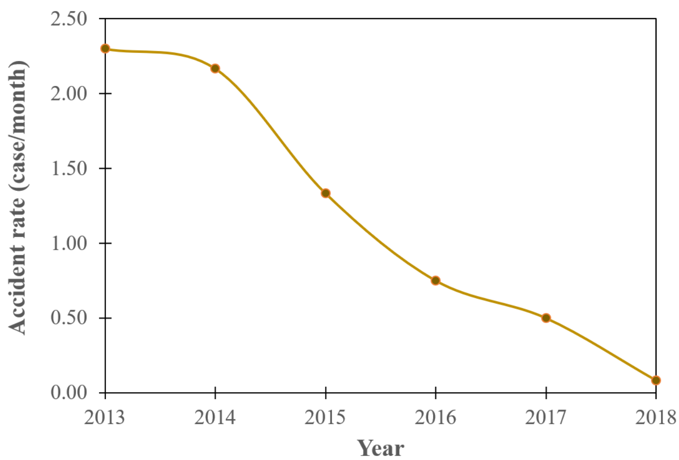

Figure 4 Monthly rate of accidents that damaged properties.

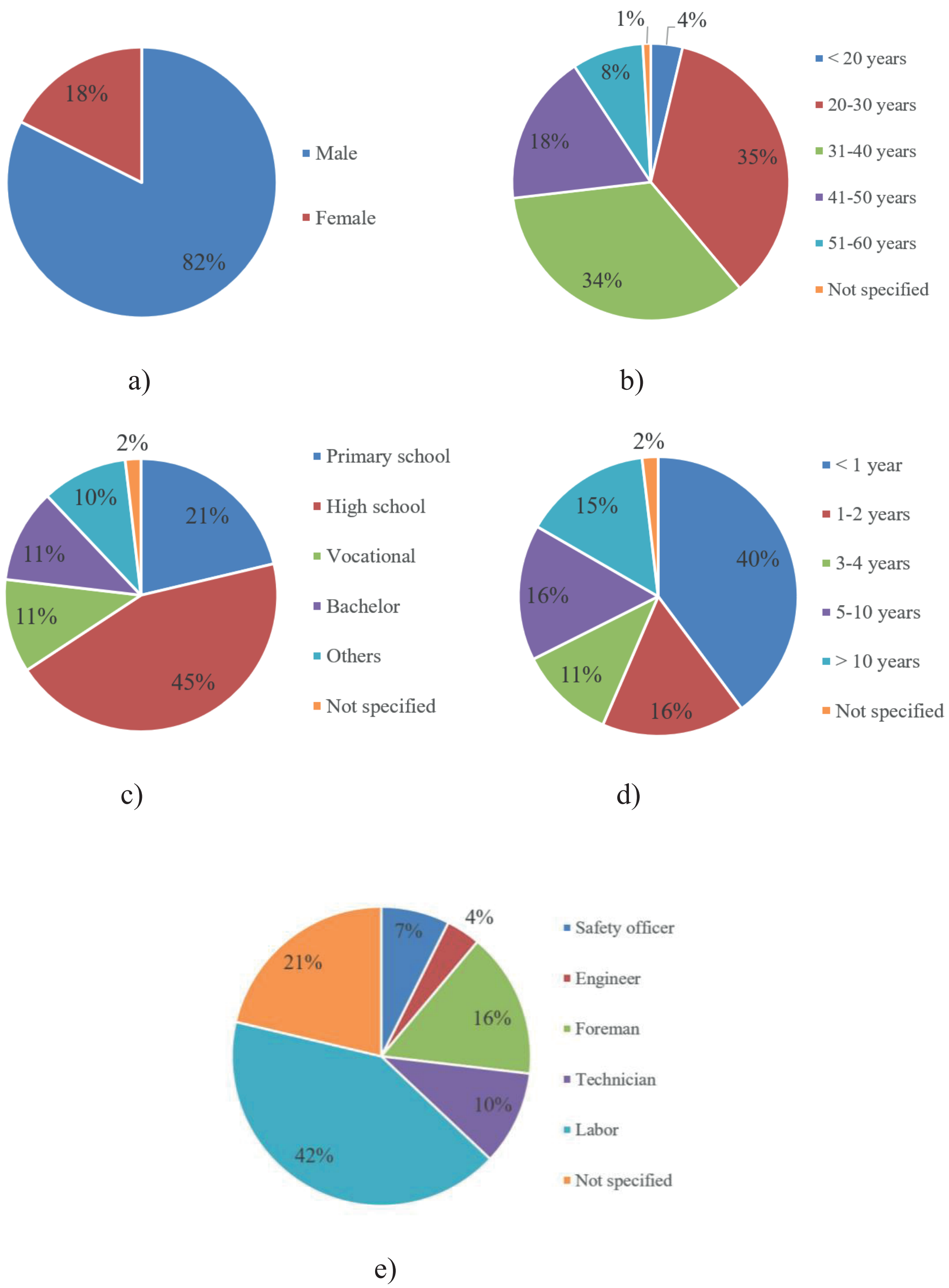

Figure 5 a) gender, b) age, c) education, d) experience and e) job position.

pensation cost couldn’t be declared, there were other indemnities included.

3.2 General Information About Sample Data

The data was collected onsite at Bang Sue Grand station, nearby stations, and at the depot. Approximately 108 data points related to 200 near-miss incidents were gathered.

The data show that most of the participants are male (82%) and 70% of the participants have a range in age from 20-40 years old.

Some 90% of participants have an education level lower than a Bachelors’ degree and 21% have completed only a primary school education. This should be a matter of concern regarding communication to participants of important information such as safety rules, procedures, and regulations. The communication of safety information should be clear and easily understood, for even the participants with the lowest levels of education. This is necessary so all personnel can easily follow safety requirements and directions.

The project is already 5 years old. Most of the participants, approximately 60%, have under 5 years of experience and around 40% have less than 1 year of experience. These statistics indicate a major need for the inexperienced workers to develop both skills applying best practices for safety, and a safety mindset that is strong enough to affect their behavior in avoiding risks.

3.3 Identification and Classification of Near-Miss Incidents or Potential Accidents

There were 200 relevant activities inside the construction site that this study observed, over 4 months, and collected as a matter of interest related to safety. Figure 6 shows a sample of such an activity of interest related to a so called “near miss accident”. Hanging material has struck an object or surface on the floor, and the glass almost drops. Another serious unplanned event risk was that it is unpredictable when the lifting cables may break, or a problem may occur with the vacuum device holding the heavy materials during the lifting process. Therefore, to reduce risk of injury from a falling object, the workers should not remain located under the heavy glass material as shown in the figure.

Figure 6 Sample Activity at a Worksite Pertinent to a Near-Miss Incident.

The data were collected onsite at Bang Sue Grand station, nearby stations, and depot, gathering around 108 data and 200 near-miss incidents. The data were classified into 6 groups of work as described in the list below:

1. Working at heights
2. Working with rail installation
3. Working with crane and forklift
4. Working with heavy machine and transportation

5. Working in obstructed areas
6. Other general cases

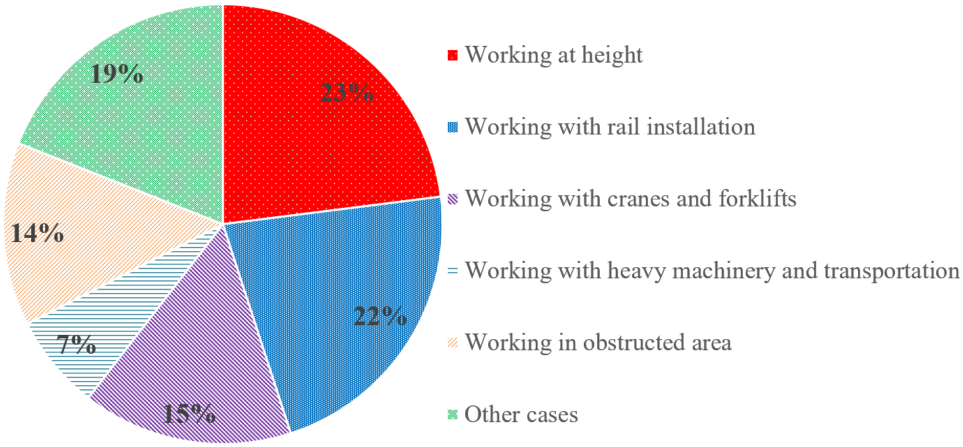

Figure 7 The ratio of incidents.

The frequency rate of incidents was analyzed and showed in Figure 7:

From the 200 near-miss incidents, the highest percentage of near-miss incidents was the group working at height and it has been observed that this type of work is normally higher risk than the others. The working with railway installation group, working with cranes and forklifts group, and working in an obstructed area group have a similar ratio of 14-22%. The working with heavy machinery and transportation operators group has only 7%. However, the other general case group cannot be classified with the five other groups since there are different kinds of incidents involved. So, this research will focus on only the first 5 groups.

3.4 Risk Assessment of Hazard Identification

To classify the risk level of each hazard identification, risk assessment (1) is very important to analyze priorities and the importance of safety measures. The assessment shows classified risks relating to working groups and hazard identifications shown in Table 7.

Table 7 Risk Assessment of Hazard Identification for each working groups.

No.	Event	Risk evaluation			
		Probability	severity	Result	Risk level
1. Working at height					
1	Worker falls from height	4	4	16	4
2	Equipment/parts fall during installation at height	4	4	16	4

Table 7 Risk Assessment of Hazard Identification for each working groups. (Continue)

No.	Event	Risk evaluation			
		Probability	severity	Result	Risk level
3	Scaffolding overloaded	4	3	12	4
4	Incomplete scaffolding installation	4	3	12	4
5	Workers careless/play while working at height	4	3	12	4
6	Glass falls because of electric crane power interruption	3	3	9	3
7	Unsecured or mislaid hand tools fall from height	4	2	8	3
8	Incomplete or unstable scaffolding components	4	2	8	3
9	Scaffolding collapse because of vibration or strong wind	4	2	8	3
10	Workers' risk of falling from high scaffolding	4	2	8	3
11	Workers throw or leave materials that may fall from height	4	1	4	2
12	Sparks from cutting or welding fall from height	4	1	4	2
13	Small metal objects or materials fall from height	4	1	4	2
14	Broken scaffolding may move or fall unpredictably	4	1	4	2
15	Insufficient ground support for scaffolding	4	1	4	2
2. Working with rail installation					
1	Concrete sleepers fall from crane during lifting	4	3	12	4
2	Missed rail clip installation by improper hammering	4	2	8	3
3	Materials fall from elevated track	4	2	8	3
4	Steel cutting blade broken and bouncing off of materials	4	2	8	3
5	Sparks from cutting or welding bouncing off of objects	4	1	4	2
6	Rail support collapse	4	1	4	2
7	Trolley derails or crashes into workers or materials	4	1	4	2
8	Ballast bouncing off of machinery	4	1	4	2
3. Working with Crane and Forklift					
3.1 Tower crane					
1	Crane is overloaded	3	4	12	4
2	Crane damaged or operation interrupted during lifting	4	3	12	4
3	Human error of crane driver	4	2	8	3
4	Insufficient support of crane's base	2	4	8	3

Table 7 Risk Assessment of Hazard Identification for each working groups. (Continue)

No.	Event	Risk evaluation			
		Probability	severity	Result	Risk level
3.2 Mobile crane					
1	Insufficient strength for crane's support base	4	4	16	4
2	Crane operation close to grid or electrical wires/component	3	4	12	4
3	Crane is overloaded	3	3	9	3
4	Crane operation close to buildings	4	2	8	3
5	Crane damage/interrupt during lifting	4	2	8	3
6	Error of crane operator	4	2	8	3
3.3 Forklift					
1	Forklift overloaded or unbalanced	4	2	8	3
2	Error of forklift driver	4	2	8	3
3	Materials, machinery, or vehicles impact buildings/workers	4	1	4	2
4	Materials fall during lifting or moving	4	1	4	2
5	Forklift damage/interrupt during lifting	4	1	4	2
6	Unsafe or obstructed path/route	4	1	4	2
4. Working with heavy machine and transportation					
1	Freight train approach when workers are close to track	4	4	16	4
2	Backhoe rotating and hitting nearby workers	4	3	12	4
3	Forklift or carried materials strike workers	4	2	8	3
4	Truck crashes into other vehicle or workers	4	2	8	3
5	Machine interruption during operation	4	2	8	3
5. Working in obstructed area					
1	Worker stumbles onto earthing bar emerging from elevated track floor	4	2	8	3
2	Falling drain port on the elevated track floor	4	2	8	3
3	Worker stumble on obstacles on the floor at night	4	1	4	2

From Table 7, the highest risk working groups were the personnel working at heights, railway installation workers, crane and forklift operators, and the heavy machinery and transportation operators. While the personnel working in obstructed areas, and other non-specific categories of railway construction workers have some risk, they are the groups with the least risk exposure since there are not any dangers from machinery or transport vehicles; they have less risks and less effects on others. The results show that most of the hazard identifications have a risk level of 3 and 4. These have a high probability of occurrence and agreed well with the high probability occurrence level condition in Table 1.

3.5 Hazard Identification using Event Tree Analysis

After the near-miss incidents were classified, the incidents were analyzed with correlating implemented safety measures and outcomes for hypothetical incidents where some or all safety measures were implemented as shown in Figure 8. The relationships of incidents, safety measures and resulting outcomes could be associated with each other to demonstrate reduced risks. Many of these safety measures could work in concert to produce a safer working environment. However, use of too many safety factors could lead to incompatibilities and unforeseen conflicting effects that could compromise safety and interfere with worker or process productivity. Therefore, one area of potential accidents should have at most three or four evaluated and tested safety measures.

From Event Tree Analysis, measures for near-miss incidents of 6 categories of worker groups are summarized as shown in Table 8.

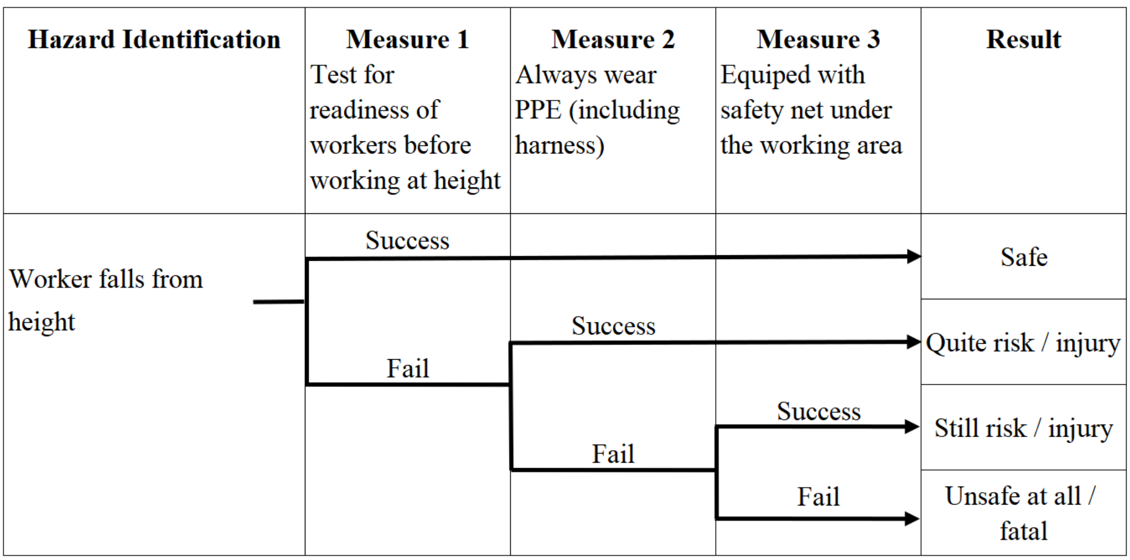

Figure 8 The example of hazard identification and results for the case of working at height groups using Event Tree Analysis technique.

Table 8 Summary of measures for near-miss incidents of 6 personnel categories.

Category Group	Measure 1	Measure 2	Measure 3	Measure 4	Suggestion
Working at height	Test for readiness of workers before working at height	Always wear personal protective equipment, including harness	Setting safety area with a large enough safety perimeter	Training cover rules and safety for working at height	Serious enforcement. Diligent follow up. Continuous improvement PDCA
Working with rail installation	Inspect for readiness and safety of machines and equipment before using every time	Wear personal protective equipment every time	Lifting concrete sleepers with care and always having signal provider	Training to educate personnel on safety rules safety operating procedures	Serious enforcement. Diligent follow up. Continuous improvement PDCA
Working with Crane and Forklift	Crane installation and operation with standard, inspections, and legal certification	Crane and forklift operations performed by authorized personnel	Inspections for readiness and safety of crane and forklift before use at all times	Training on laws and safety standards for Crane & Forklift operation	Serious enforcement. Diligent follow up. Continuous improvement PDCA
Working with heavy machine and transportation	Machine operations by authorized personnel	Having enough lighting, signals and traffic signs for transportation safety	Inspect for readiness and safety of crane and forklift before operation	Training on laws and safety for working with heavy machine and transportation	Serious enforcement. Diligent follow up. Continuous improvement PDCA
Working in obstructed areas	Attaching soft material on the unmovable obstacles	Using color and signs to warn workers, and use enough lighting for night-time	Area management, separate walkway, and obstacles as feasible	Training covering safety rules and safety operating procedures for work tasks	Serious enforcement. Diligent follow up. Continuous improvement PDCA
Other cases	Inspect for readiness and safety of machines and equipment before using every time	Wear personal protective equipment at all times	Working while conscientiously following safety rules and taking safety risks seriously	Training on safety rules and education about safety operating procedures for work tasks	Serious enforcement. Diligent fo llow up. Continuous improvement PDCA

4. Discussion

There are some limitations for this research such as a four-month time frame for collecting and studying the data. The project was launched in 2013 and expected to finish in 2021, but this study collected data during October 2018 to January 2019. Therefore, the collected data can reflect only the situation during that period, it could not represent the whole project timeline. Many activities had already been in process for many years (i.e., foundation works), so it was impossible to collect and analyze complete project data during such a constricted study timeframe.

During the interview process, of varied levels of project participants, useful information was acquired regarding the causes of safety related incidents which are summarized as follows:

1. The suburban Red Line project, Bang Sue-Rangsit section is a Mega project, consisting of huge worksite areas, a variety of activities and different types of personnel involved. The safety system is of critical importance, but it is also extremely difficult and challenging to apply completely to such a complex project.

2. Effective and meaningful communication with foreigner workers is one of the primary problems; especially communicating safety regulations and standard operating procedures.

3. Less than optimal discipline and motivation of workers and safety officers to follow the safety regulations and procedures is a factor impeding the effectiveness risk mitigation procedures.

4. The project is working on an active railway system in operation. So, workers and supervisory management personnel need to maintain alertness to safety risks and procedures which apply to the active railway area. Negligence, even momentary, can increase risks.

5. Playfulness, sports, teasing or pranks or any other non-work-related activities must be prohibited and enforced while working or present for any reason within the project work areas.

6. Working with an awareness of risks and mindfulness of safety best practices is required. Distraction or a lack of safety focus is an impediment to maintaining a safe work environment.

7. Working without being conscious of the primary importance of safety results in negligence, injuries and causes project delays and increased costs.

8. Ignorance of and unwillingness to follow safety policies, procedures, and regulations.

These lists are some of the most important causative factors in accidents and near-miss events. The project made strenuous efforts to improve the safety system management and implement improved safety measures to the entire construction work area as was feasible. This resulted in a decline of the number of accidents during the period of the project. One strategic incentive was that the State Railway of Thailand (SRT) gave an ultimatum to the contracting companies to reduce the number of serious accidents and a ‘red card’ violation reporting rule that could stop work consequently. After this rule was applied, the accidents decreased significantly over time as shown in Figure 4. This is an example of application of the suggestions in Table 8. Notably at the construction site there were policies, rules, and operating procedures in effect. Despite this, the necessary rules enforcement and follow up due diligence maybe were not performed rigorously according to international industry best practice. Therefore, the key to successful safety risk management and mitigation is not only issuing safety policies and publishing procedures. Serious and diligent application of safety guidelines/rules with supervision, tracking, incentives and follow through enforcement to ensure execution of the safety management system operation are also crucial.

However, considering how accidents occur, it has been determined that the main factors are related to human behavior, and a contributing factor is the workplace environment. This is an object example of the structure of accidents which was proposed by Abdul Raouf [21] which postulated a combination of immediate causes (unsafe acts) and contributing causes (unsafe conditions) underlying most problems. The components of these structural factors for creating accidents occurs at railway construction project worksites as is assembled and described in Figure 9.

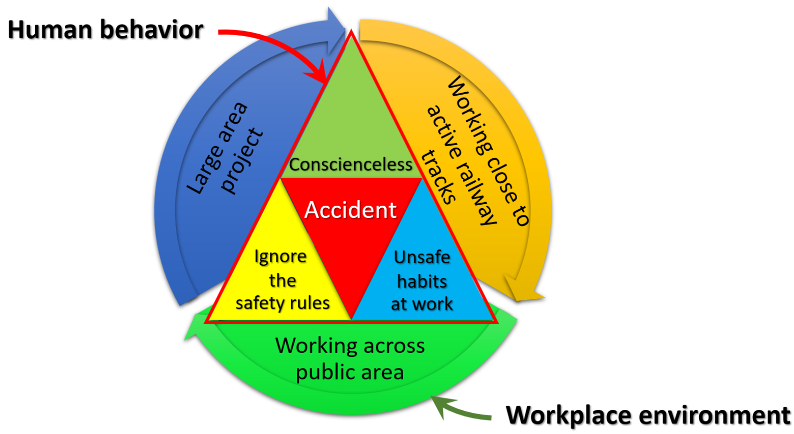

Figure 9 The components of accident occurring at railway construction workplace.

5. Conclusion

From the data collected from documents and the onsite survey process, the results show that the suburban Red Line project, Bang Sue-Rangsit section consists of a complex variety of activities and related processes which complicate safety risk management and mitigation. Nonetheless, the implementation of effective safety system management is of critical importance to control safety risks during all construction project activities to ensure productive working conditions and reduce costly accidents.

This study found that the highest risk level is among the group of workers who are performing tasks at heights above 2-3 meters. The risks entail the personnel accidently falling from an elevated area or accidents caused by objects fallingfrom height onto workers or equipment/materials. The results from accidents of this type are serious injuries or death from either falling or being hit from above by falling equipment or materials. Both personnel falling from a height and those on the ground level or lower levels are at risk for injury or death. To prevent such costly events and especially, loss of human life, standard operation procedures in accordance with international construction industry best practices for working at heights should be developed and become documented policy. The safety standards documentation should then be utilized in mandatory worker training. These safety standards should be prioritized, implemented, and enforced, always, at all project work site areas, by project managers and supervisors. The risk assessment demonstrates the significant risk levels to personnel and the benefits of reducing risks for project costs and productivity. Also of consideration is the corporation reputation for responsibility and integrity of management in taking care of their personnel.

Also of considerable significance is the positive attitude of workers toward safety and their alertness to safety risks. All worksite personnel need to be diligent in learning and observing safe operating procedures which are the key factors to prevent incidents resulting from safety standards violations. Both workers and supervisors should be conscientious of safety risks and following safety regulations diligently. Thus, developing safety conscious and disciplined personnel is essential for every type of construction project, not only railway construction.

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