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Hazard and Risk Analysis of Driven Pile Foundation Works Using HIRARC Method

Stefani Liandar[1*], *Andi Bayu* Putra[1], and *Eduardi* Prahara[1]

[1]Civil Engineering Department, Faculty of Engineering, 11480 Bina Nusantara University, Indonesia

Abstract. One of the construction processes with high potential for danger is driven pile foundation work. Driven pile foundation work has a series of processes that are quite dangerous if not executed properly due complicated work process. This study aims to identify hazards and provide efforts to control hazards using the HIRARC method. Based on the results of the study, 42 potential hazards were identified, with 21 possible hazards at a low level, and 21 possible hazards at a moderate level. Risk controls are carried out by checking the equipment before use, checking the feasibility of SIA and SIO to ensure operator competence, clearing the work area from unauthorized workers other than the operator of heavy equipment and helper(s), providing barricades and warning signs in the work area, using essential PPE and additional PPE, and good coordination and communication with all workers involved in driven pile foundation work. Several suggestions are everyone that is in charge of work must be firm in penalties, all work tools must be checked carefully and periodically, and PPE providers must provide essential and additional PPE for specialized jobs. For future research we can suggest continue discussion regarding the operational control, cost budget plan, and evaluation and review of SHE performance.

1 Introduction

Infrastructure construction is one of the essentials throughout the country. In Indonesia itself, infrastructure construction begun to be developed, even tending to increase rapidly compared to previous years. Infrastructure construction in Indonesia is built with the hope to increase the growth and development of various other essential sectors, such as economic, cultural, social, and transportation sectors [1]. However, the construction sector cannot be separated from the risks and dangers of working accidents. Even the construction sector has a potential and a high level of risk related to work accidents. The number of work accidents that are quite high in the construction sector resulted in work accidents due to construction as one of the highest contributors to work accidents in Indonesia and even the world [2].

The larger the scale of the construction, the greater the security demands. Security in infrastructure development needs to be more echoed so that there are less parties who are ignorant of work security. Work accidents themselves occur due to the lack of fulfilment of requirements in carrying out occupational safety and health to avoid danger. An example of a work that has quite a lot of potential work accidents is the driven pile foundation works. Driven pile foundation works may not be as complicated as the work of the upper structure, but still needs to be considered the safety of the work, because the risk of the stake job is no less dangerous than other job risks [3]. Driven pile foundation works has a series of processes that are quite dangerous if not carried out properly because the work process is quite complicated [4].

To reduce the number of accidents, it is necessary to make efforts to identify the causes of these accidents that can occur through an assessment of the work process and the danger points in the work process so that prevention efforts can be made for the next period [5]. OHSAS 18001:2007 requires a HIRARC identification method, in which the process is divided into 3 (three) parts, namely Hazard Identification, Risk Assessment, and Risk Control.

From several hazard and risk analysis techniques, HIRARC method was decided appropriate to be used as a risk analysis technique in research because HIRARC method can describe in detail about hazard identification throughout the work process, provide risk assessment of hazards and risks identified with certain levels, and provide risk control needed to minimize the level of risk identified [6].

1.1 Objectives

- To know the steps in identifying potential risks and hazards in pile foundation erection work.
- To find out how to conduct a risk assessment based on the potential risks identified or arising in the implementation of work activities.
- To find out efforts to control risks, control measures from a potential hazard, and risks from pile foundation erection work.

* Corresponding author: stefani.liandar@binus.ac.id, andi.putra@binus.edu, eduardi@binus.ac.id

2 Literature review

2.1 Past research

There are several previous research used as sources for this research. Within this research their conclusions are:
- Based on this research, in the process of driven pile foundation, it can be identified that there are 8 sources of danger with 16 potential hazards in the work of driven pile foundation [7];
- Based on the analysis of this study, it can be concluded that the work of driven pile foundation has 12 forms of failure based on the potential hazards identified [8];
- Based on the analysis of this study, identified 42 hazards, where physical harm is the most potential danger among other types of danger [9];
- Based on the analysis of this study, there are 4 potential dangers and risks at low levels, 5 potential dangers and risks at medium-low levels, 13 potential dangers and risks at low-high levels, and 5 potential hazards and risks at high levels [10].

2.2 Foundation pile

The foundation is one of the crucial parts of all construction development, whether in the construction of buildings, houses, or on toll roads. The foundation itself is known as part of the lowest structure in a construction (substructure). The foundation oversees receiving structural loads, which then the loads it supports are transmitted to the ground or can be referred to as a liaison between the infrastructure above and the ground. One of the foundations that is quite commonly used in infrastructure work is the pile foundation. Pile foundations are generally used in infrastructure with large loads, such as the use of high-rise buildings, flyovers, and so on [11].

2.3 Risk management

According to ISO 31000:2018, risk management is defined as a coordinated form of activity with a view to organizing and controlling work related to risk. Generally, risk management is defined as all matters relating to risk, including as a process to identify, measure, and ensure a risk, and how to plan a strategy to control that risk [12].

2.4 Hazard identification, risk assessment, and risk control (HIRARC)

In various fields of work, including in infrastructure construction projects, it is necessary to have protection measures by identifying, controlling, and preventing hazards and risks that can harm many parties, both workers and the companies that cover them. Therefore, it is necessary to have a work accident risk measurement method using the hazard identification method [13]. One of the uses of this method is the use of the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method.

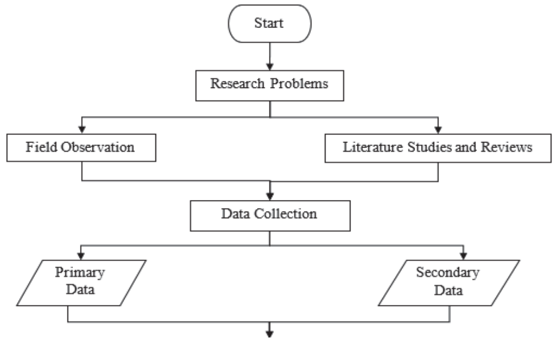
Hazard Identification, Risk Assessment, and Risk Control methods are risk management methods to identify risks that are likely to occur and the level of severity they cause [14]. The HIRARC method has several advantages compared to other methods, where the approach to the HIRARC method is easier to understand and can be applied to new jobs or jobs with work procedures changing over time [15].

The following are the objectives of the HIRARC method based on the Guidelines for Hazard Identification, Risk Assessment, and Risk Control [16]:
1. To identify all the factors that are likely to cause harm, both to the workers, company, and others.
2. To consider how likely a hazard or danger will be to all related parties and the possible severity caused by the risk.
3. To plan, introduce, and monitor preventive measures to ensure that risks are always controlled.

3 Methods

This research began by conducting field observations on the working procedures of driven pile foundation works and the collection of literature studies related to the driven pile foundation works, as well as reference risk analysis used. Furthermore, the collection of the required data, namely primary data, and secondary data. Primary data is data collected based on observations, in the form of questionnaires and interviews with expert sources, while secondary data in the form of stages of driven pile foundation works and literature studies used as references in this study. Furthermore, a research instrument test in the form of validation tests, reliability tests, and normality tests on questionnaires that have been disseminated, with a total of 38 respondents, with an early target of 30 respondents. According to [17] quoting [18] guidelines, a sample size greater than 30 and less than 500 is suitable for most behavioural studies.

The method starts with conducting a hazard and risk analysis using HIRARC method consisting of Hazard Identification, Risk Assessment, and Risk Control on the work of driven pile foundation. Furthermore, validation of research results with expert sources, namely SHE experts in construction projects. The conclusion of the research that has been done is to identify risk, to know the risk rating and know the countermeasures or controls that can be done from the risks identified in the driven pile foundation works. Figure 1 is the research flowchart for this paper.



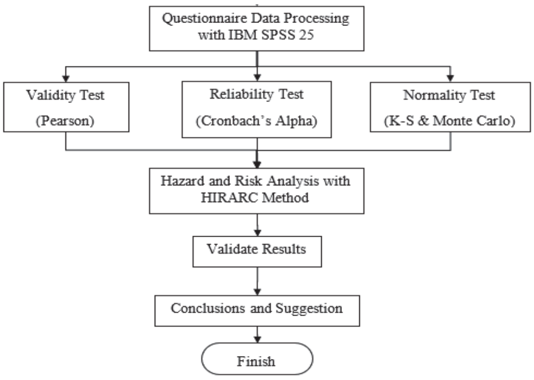


Fig. 1. Research flowchart.

4 Data collection

4.1 Respondents

The characteristics of the respondents in this study were divided into several parts, among others, based on the gender of the respondent, the age of the respondent, the last education of the respondent, the part of the construction party of the respondent, the position of the respondent, and the year of the respondent's work experience in the construction sector. In the research conducted by the author, there were 38 respondents from 4 (four) projects with various characteristics. Below figures are the descriptions for the respondents.

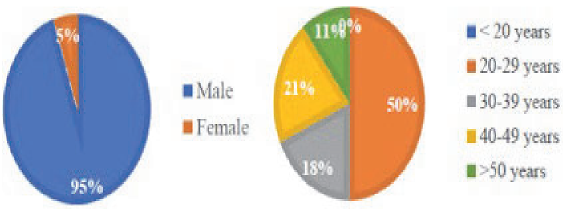


Fig. 2. Respondents characteristics (left: gender; right: age range).

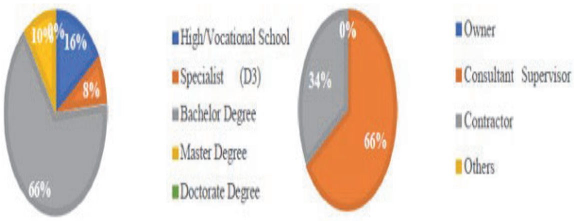


Fig. 3. Respondents characteristics (left: education; right: construction roles).

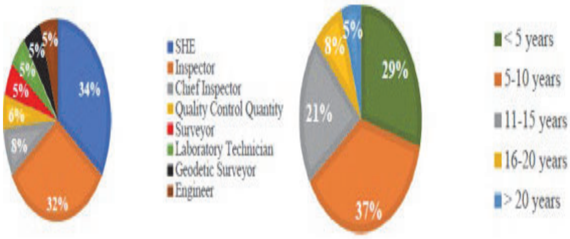


Fig. 4. Respondents characteristics (left: job title; right: working experience).

Figure 2, figure 3, and figure 4 above shows the description for the respondents used in this research.

4.2 Research variables

On table 1 below are the variables used for the questions in the questionnaire.

Table 1. Variables used for the questionnaire.

No.	Potential Danger and Risks	Sources
X1	**Preparation of driven pile foundation works**	Observation
X1.1	Pile driver condition is not good	(Wiguna 2018)
X1.2	Steel *sling* conditions are not good	(Wiguna 2018)
X1.3	Landslide due to lack of soil compaction for pile driving tools	(Wiguna 2018)
X1.4	Workers are dehydrated and decreased focus during the determination and installation of staking point because of the influence of weather.	(Erba 2018)
X1.5	Worker scratched by iron during installation of staking point	(Erba 2018)
X1.6	Worker's hand hit by hammer during installation of staking point	(Erba 2018)
X1.7	Weather that does not allow to continue the determination and installation of the staking point	(Erba 2018)
X2	**Transfer of pile from stock yard to driving location with crane service and pile driver**	Observation
X2.1	Crane service is not in a good condition	(Wiguna 2018)
X2.2	Crane service operator is less competent	(Erba 2018)
X2.3	*Crane service is not working in the middle of work*	(Erba 2018)
X2.4	The pile fell because the installation of slings on the pile lacked/ not tight	(Iman 2018)
X2.5	*Sling of crane service broken during lifting operation*	(Erba 2018)
X2.6	*Crane service collapsed due to overloaded*	(Wiguna 2018)
X2.7	Heavy equipment derailed due to non-water-free location	(Iman 2018)
X2.8	Worker hit by crane service during lifting operation	(Erba 2018)
X2.9	Worker hit by pile during lifting operation	(Erba 2018)
X2.10	Worker struck down by pile during lifting operation	(Erba 2018)
X2.11	Workers unfocused during pile driving briefing due to weather influence	(Erba 2018)
X2.12	Worker falls while giving instructions on the placement of driven pile	(Erba 2018)
X3	**Pile driving using pile drivers**	Observation
X3.1	Worker is wedged during the installation of helmets on the head of the pile	(Erba 2018)
X3.2	Worker is scratched during the installation of helmet on the head of the pile	(Erba 2018)
X3.3	Pile driver is not working in the middle of work	(Erba 2018)
X3.4	Pile driver operator is less competent	(Erba 2018)
X3.5	The pile broke during a hammering	(Indrayani 2017)
X3.6	Hammer detaches and struck down the workers	(Moniaga and Rompis 2019)
X3.7	Workers injured from working in the dark	(Erba 2018)
X3.8	Worker suffers hearing loss due to noise of generator engine	(Wiguna 2018)
X3.9	Worker suffers hearing loss due to noise of hammer	(Fuad et al. 2019)
X3.10	Workers poisoned by carbon monoxide from generator engine fumes	(Wiguna 2018)
X4	**Splicing work for the bottom pile and the middle pile with welding**	Observation
X4.1	The pile fell because the installation of slings on the stake lacked/ not tight	(Iman 2018)
X4.2	*Sling of crane service broken during lifting operation*	(Wiguna 2018)
X4.3	Worker hit by pile during lifting operation	(Erba 2018)
X4.4	Worker struck down by stake during lifting operation	(Erba 2018)
X4.5	Welding tool is not working in the middle of welding work	(Erba 2018)
X4.6	Workers electrocuted by a wet welding work area (shorted)	(Iman 2018)
X4.7	Worker suffers burns from sparks during welding	(Erba 2018)
X4.8	Worker scratched/injured by welding equipment	(Iman 2018)
X4.9	Welding causes fires in the area around the work area	(Erba 2018)
X4.10	Worker suffers hearing loss/deafness due to welding work	(Wiguna 2018)
X4.11	Worker experiences respiratory distress due to welding work	(Fuad et al. 2019)
X4.12	Worker experiences visual impairment due to sparks/radiation during welding	(Erba 2018)
X4.13	Worker slips while applying anti-rust epoxy paint on pile joint	(Erba 2018)

The questionnaire used a 1 to 5 (1 is lowest, 5 is highest) scale to determine the Likelihood and Severtiy of a risk, for example is the table 2 below:

Table 2. Example of questionnaire question.

<table>
<tr><th>No.</th><th rowspan="2">Potential Danger and Risks</th><th colspan="2">Scale (1-5)</th></tr>
<tr><th>X1</th><th>Likelihood</th><th>Severity</th></tr>
<tr><td></td><td colspan="3">Preparation of driven pile foundation works</td></tr>
<tr><td>X1.1</td><td>Pile driver condition is not good</td><td></td><td></td></tr>
<tr><td>etc.</td><td>etc.</td><td>etc.</td><td>etc.</td></tr>
</table>

5 Results and discussion

5.1 Validity test

Testing the validity of a research variable is an index that shows whether a measuring instrument is correctly measure something or not [19]. Required value r of the table used as a valid reference for the absence of Pearson's Product value, where to get the table value is to calculate the value df with the formula df = n-2 and reference critical value or significance level of 5% [20]. Based on the results of the questionnaire, it is known that the number of respondents involved is 38 respondents, who the value of df = 38-2 = 36. Then, the value of df = 36 is used in the r table with a significance level of 5%, then the value of r table obtained is 0.329 [21]. Based on the value of the r table and the value of Pearson's Correlation can be concluded valid, or the questionnaire of the study is valid. It should be known if the value of r calculates > r table, then it is declared valid, and vice versa if r calculates the < r of the table, then the item is declared invalid.

Based on the results of validity test analysis that has been conducted using computerized IBM SPSS Statistics 25, each test item has a r calculates value greater than the value of the r table (0.329), which that the data from the test item that has been done is declared valid.

5.2 Reliability test

Reliability testing on a research variable is how far a measurement can be believed [22]. The study used Cronbach's Alpha standard. The standard use of Cronbach's Alpha is that if Cronbach's Alpha value is greater than 0.7, then the data can be said to be reliable [23].

Based on the results of reliability test analysis that has been conducted using computerized IBM SPSS Statistics 25, each test item has a value of Cronbach's Alpha greater than 0.7, which the data from the test item that has been done is declared reliable.

5.3 Normality test

The normality test is a method used to see if a data is in a normal distribution or distributed normally [24]. The normality test on this study used Kolmogorov-Smirnov. A data can be said to be distributed normally if the significance value is more than 5%, and vice versa if the significance value is less than 5%, then the data is otherwise not distributed normally. In this study the value of significance will refer to the exact value of Monte Carlo because the value of significance by Asymptotic; the value p is estimated based on the assumption of the data, where if the research data is small or small, the data becomes unbalanced and likely not to distribute normally to give inaccurate results [25].

Based on the results of the normality test analysis that has been conducted using computerized IBM SPSS Statistics 25, each test item has a Monte Carlo significance value greater than 5%, so that the data from the test item that has been done is declared normally distributed.

5.4 Hazard and risk analysis with HIRARC method

Hazard and Risk Analysis using HIRARC method consists of 3 (three) processes, namely Hazard Identification, Risk Assessment, and Risk Control.

5.4.1 Hazard identification according to HIRARC

To meet the HIRARC method, the first step that needs to be done is to identify hazards and risks in the work of driven pile foundation. At this stage, a collection of literature studies is needed to find out the dangers and risks that can occur at the time of driven pile foundation works (as a research variable), as well as conducting interviews with sources, among others, workers who involved in driven pile foundation works for the completion of unwritten data in the hazard and risk variables of stake work studied by the author. Table 3 is an example of HIRARC's hazard and risk identification results in the driven pile foundation work in this study:

Table 3. Hazard identification in driven pile foundation work.

Hazard Identification					
Stages of Work	Description	Potential Danger	Source of Danger	Causal Factors	Risk Classification
Preparation of driven pile foundation works	Heavy Equipment Preparation	Pile driver condition is not good	Mechanical Hazards	Equipment	Safety
		Steel sling conditions are not good	Mechanical Hazards	Equipment	Safety
		Landslide due to lack of soil compaction for pile driving tools	Mechanical Hazards	Environment	Safety

5.4.2 Risk assessment according to HIRARC

Risk assessment can be done based on the results of research questionnaires that have passed the instrument test, in the sense that the questionnaire is valid, reliable, and distributed normally. The selection of likelihood and severity (severity) used for the determination of risk ratings using the mode value or the most value of the representation of the respondents [26]. The risk value is obtained based on the multiplication of likelihood with severity, which is then carried out risk rating referring to Australia/New Zealand Standard AS/NZ 4360:2004 [27]. Table 4 is an example of the results of risk assessment on the work of driven pile foundation in this study:

Table 4. Risk assessment on erection girder work.

Risk Assessment						
Stages of Work	Description	Potential Danger	Risk Analysis			
			L	S	R	*Risk Rating*
Preparation of driven pile foundation works	Heavy Equipment Preparation	Pile driver condition is not good	2	4	8	*Moderate*
		Steel sling conditions are not good	2	1	2	*Low*
		Landslide due to lack of soil compaction for pile driving tools	1	4	4	*Low*

5.4.3 Risk control according to HIRARC based on interview results

After getting the results from risk assessment according to HIRARC, the next step is to find the control element of said risks. These risk controls were determined using interview methods. The people interviewed are: SHE Engineer, SHE Inspector, and a Chief Inspector. The questions all related to the results gathered above, such as: the process on how to avoid high and/or extreme risks, how to mediate the moderate risks, the impact of the risks, the steps to control risks, who or which party controls the risk from the identified hazards, and when is risk control from identified hazards implemented.

Hazard and risk control also have the goal of creating safe work activities, achieving more effective and productive work processes [28]. Based on OHSAS 18001:2007, risk control can be done by eliminating, substitution, technical control, administrative control, and use of PPE (Personal Protective Equipment). Table 5 below shows an example of the results of controls as a risk-management measure in the work of driven pile foundation:

Table 5. HIRARC form (AS/NZ 4360:2004 standards).

Hazard Identification			*Risk Assessment*				Risk Control	
Stages of Work	Description	Potential Danger	Risk Analysis				Control Recommendations	*PIC*
			L	S	R	RR		
Preparation of driven pile foundation works	Heavy Equipment Preparation	Pile driver condition is not good	2	4	8	*M*	**Elimination:** - Reject damaged/unfit equipment outside the work area. **Administrative Control**: - Inspection of heavy equipment during preparation, and shortly before the start of driving work; - Checking the feasibility of a Tool Permit (SIA);	SHE, Main Executor, Mechanical Team
		Steel sling conditions are not good	2	1	2	*L*	**Elimination:** - Reject *slings* that are not suitable for use **Administrative control:** - Inspection of the sling conditions used before work begins.	SHE, Main Executor, Mechanical Team
		Landslide due to lack of soil compaction for pile driving tools	1	4	4	*L*	**Technical control**: - Checking the density of footing soil; - Providing steel plates (steel plates) in the work area as access to heavy equipment and minimizing the potential of landslide; - Installation of barricades in the work area. **Administrative Control:** - Coordination with workers before work begins regarding the stages of work. **APD:** - Workers must use essential PPE (project helmets, vests, and *safety shoes*).	SHE, Main Executor, Mechanical Team

5.4.4 Validation interview results

Based on the results of validation interviews, according to the sources, the risks identified in this study are in accordance with the circumstances in the field. However, there are differences in the outcome of the level of risk in the field, whereas the risk level results of some identified hazards in the field are at high and even extreme levels, while HIRARC results from this study show the absence of high and extreme levels of risk-HIRARC result from this study show that hazard and risk are low and moderate. The difference from the results of the study with the field is due to the results of risk assessments obtained based on the results of questionnaires that have been distributed, where there are many inputs from various respondents based on work experience on a particular project.

The collecting of probable values and severity values for risk assessment in the field in driven pile foundation works is taken based on assumptions and mutual agreements (which still refers to the risk matrix in accordance with AS/NZ standard 4360:2004) before work can begin, resulting in high and extreme levels of risk in some identified hazards. This aims to remind awareness about the potential dangers to all workers involved in the driven pile foundation works. And according to expert sources, the use of HIRARC methods in the field is adjusted to PUPR directives, because the HIRARC method is considered complete and can describe well (both the work process, identification of potential hazards, risk assessment, to risk control).

6 Conclusions and suggestions

6.1 Conclusions

Based on the results of the study and the discussions that have been done by the author in the previous chapter, the conclusion of this study can be drawn, shown as follows:

- In the hazard identification process, of the 4 (four) stages of driven pile foundation work, there are 42 possible hazards and risks identified, including:
    - In Stage 1: Preparation of driven pile foundation, there are 7 possible hazards and risks identified.
    - In Stage 2: Transfer of stake from stock yard to driving location with crane service and pile driver, there are 12 possible hazards and risks identified.
    - In Stage 3: Pile driving using pile drivers, there are 10 possible hazards and identified risks.
    - In Stage 4: Splicing work for the bottom pile and the middle pile with welding, there are 13 possible hazards and risks identified.
- In the risk assessment process, of the 42 possible hazards and risks identified in the stages of the foundation work, there are 21 possible hazards with a low risk assessment, and 21 possible hazards with moderate risk assessments, indicated as follows:
    - In Stage 1: Preparation of driven pile foundation, there are 4 possible hazards and risks at low levels and 3 possible hazards and risks at moderate levels.
    - In Stage 2: Transfer of stake from stock yard to driving location with crane service and pile driver, there are 5 possible hazards and risks at low levels and 7 possible hazards and risks at moderate levels.
    - In Stage 3: Pile driving using pile drivers, there are 6 possible hazards and risks at low levels and 4 possible hazards and risks at moderate levels.
    - In Stage 4: Splicing work for the bottom pile and the middle pile with welding, there are 6 possible hazards and risks at low levels and 7 possible hazards and risks at moderate levels.
- In the process of risk control, in the work of driven pile foundation, 5 forms of risk control are applied, shown as follows:
    - Elimination
    - Substitution
    - Technical Control
    - Administrative Control
    - Use of Personal Protective Equipment (PPE)
    - Administrative Control
    - Use of Personal Protective Equipment (PPE)

6.2 Suggestions

Based on the results of the research and discussions that have been done by the author in the previous chapter, the suggestion that can be given by the author is as follows:

- Suggestion for construction projects with driven pile foundation works
  - All persons in charge of work, both from the main executor, field supervisor, and SHE section must be firm in the provision of strict sanctions (in the form of reprimands or fines) if the workers do not use complete PPE while working.
  - All work tools must be checked carefully and periodically, where it must still be tested tools that will be used before being checked list or marked as fit for use.
  - The party responsible for providing PPE workers must provide essential PPE and additional PPE for specialized jobs.
- Suggestion for further research
  - This research does not conduct discussions up to operational control, Cost Budget Plan and evaluation and review of SHE/OHS performance, which it needs planning and further discussion on these matters.
  - More research is needed on the causes of differences with research results (theories) with actual circumstances in the field.

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