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Human error probability analysis using Success Likelihood Index Method (SLIM) approach in grinding activities

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Abstract. Grinding activities produced 31% accident cases that occurred repeatedly and had the same cause. Most of them were investigated and were proved to be caused by human error. The study aims to obtain the value of Human Error Probability (HEP), thus, it could be employed as prevention and controlling consideration. HEP value was obtained by finding the value of. Success Likelihood Index (SLI). SLI value could be obtained using questionnaires and Performance Shaping Factor (PSF) assessment which had been filled by expert judgment. The scenarios were developed to predict and reduce the occurrence of human error as applied to Success Likelihood Index Method (SLIM). This research illustrated the factors that affected errors in the grinding process were procedure, fatigue, complexity, training, and experience. The task that contained the highest error value was in the first task (use PPE following predetermined). While the task which included the lowest HEP was task 2 (prepare documents according to pre-defined). As part of efforts to reduce the error probability values grinding process, it recommended reducing the probability of error by increasing the value of PSF, ranging from improved procedures, reduction of fatigue of the workers, the reduction of the complexity of the job, increased training for workers, and increased workers' qualification through work experience history.

1. Introduction

The "human factor" plays an important role to predict the safe operation of a facility. Hence, the information about human capacities and behaviors should be applied precisely to improve the safety of a systematic process. Norman [1] and Reason [2] investigate an "error" arise in situations where an act is devoted both purposely and un-purposely; however, the error itself and the original purpose of the act are often described separately. Sanders and McCormick [3] illustrate human errors as inappropriate decisions that obtain a negative effect on the effectiveness of the safety system and performance. Providing a system classification may facilitate to organize human error data and provide insight into how errors can be prevented. Several studies have determined that such errors are a major cause of accidents in grinding [4–6].

Reduction in human errors will naturally lead to a reduction in costs [7]. Human error has been well known as the most contributing factor to accidents. Several factors contribute to human errors including personal characteristics, managerial or organizational aspects, the complexity of work methods, environmental conditions, machine design, training methods, supervision methods, presence, and/or absence of work instruction [8].

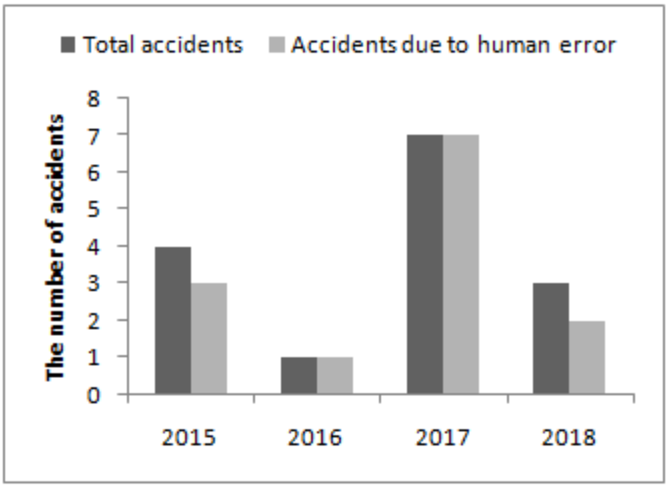

Figure 1. The number of accidents in grinding activities.

The previous studies are conducted to investigate the contribution of human factors into accidents. Heinrich concludes that unsafe acts (88%), unsafe conditions (10%), and unpredictable factors (2%) account for these accidents are analyzed in 7500 accidents [9]. In another study conducted in Australia, 83% of 2000 accidents are due to human error. A similar study is carried out at Berlin Technical University illustrates that the cause of 64% of all accidents is a human failure [10, 11]. It can be argued that human error is very complicated not only due to individual mistakes but also the conditions of human error.

Human Reliability Analysis (HRA) always has an essential concern of safety engineers and risk assessment analysts. The main reason for that is the subjectivity of the methods employed to estimate human reliability and the uncertainty of the data concerning human factors, along with the complexity of human behavior. For an HRA technique to be valid, the model specifies the likely human error modes and the process whereby numerical estimates of HEP are obtained must both be valid. A discussion of validity in the human-machine system context is available in Hollnagel [12], and Cronbach and Meehl [13] consider the validity issue within the context of psychological testing.

Several methods are developed as the teamwork of engineers and psychologists, to assist the analysis of human error and human reliability. Most of them require expert judgment, statistical data, and simulation proofs including Success Likelihood Index Methods (SLIM) approach.

The SLIM approach is a technique applied in the Human Reliability Analysis (HRA) and aims to analyze the possibility of human error that occurs when conducting a job. A likely basis for the evaluation of the results from the SLIM test is convergent validity. SLIM is also an HRA approach with an approach that considers various PSF value recommendations and sociotechnical factors using a mathematical formula that produces a Human Error Probability (HEP) value, as long as the weight and rating of the PSF are known. Therefore the results of the analysis can be employed to provide recommendations to reduce the occurrence of errors, with the expectation that the same accident will not be repeated [14]. Excess SLIM compared to other methods in HRA analysis among others is the errors can be measured at any level of job, sub-work, even on any each task of sub-work, thus it can be known which task has the highest risk. Moreover, SLIM uses a mathematical formula to generate HEP value, as long as the weighting and the rating of PSF are known. Consequently, the parameters that affect an individual's ability to perform a given job can be recognized [15].

Grinding is an activity to produce a smooth surface and can achieve high accuracy. Grinding can also be employed to create workpieces such as tidying the results of cutting, smoothing out welds, curves on angled workpieces, preparing workpiece surfaces to be welded, refine, and make accurate measurements on the surface of the workpiece (finishing), and others. On a grinding machine, the sharpening stone rotation at workpiece slicing requires a very high rotation speed. Grinding activities can be dangerous, among others, if there is a lack of operator expertise, operations are not following SOPs and tools are not checked before the operation. 31% of accidents occur in international companies in Surabaya engaged in manufacturing steam boiler manufacturing are accidents in the grinding process (Figure 1). Grinding is the type of work that produces the most accident cases, and 66.67% - 100% in the last five years due to human error. Therefore, it is necessary to have an in-depth study of the SLIM approach as one of the techniques of human reliability analysis to study human error in grinding activities.

2. Material and Methods

2.1. Selection of Expert Judgment

Expert judgment consisted of a group leader, Environmental Health and Safety (EHS) inspector and supervisor. The criteria for determining expert judgment referred to Skjong and Wentworth's [16] included participating in the design or evaluation of a grinding process security system, having participated in a risk assessment in the grinding field, having experience in the grinding field, not filling in the questionnaire simultaneously with other judges, willing to spend time during working hours to be asked for information related to grinding work, had a lot of knowledge about grinding work, and also contained a good reputation in the company, neutral, honest, and confident.

2.2. The Determining of Task Analysis

The task analysis was identified as the working step of the job in the details of grinding. Task analysis on the work of portable grinding machines prepared based on the work instructions grinding work, then developed in more detail. Task analysis verified by EHS manager, a grinding operator, and expert judgment. The task was determined to produce a questionnaire of Performance Shaping Factors (PSF) weighting and an assessment questionnaire of PSF. Error probabilities were calculated for each task and subtask.

2.3. The Determining of Suitable Performance Shaping Factors (PSF)

The PSF was the factors that affect the probability of an error occurrence. It served to produce the PSF weighting questionnaire, the PSF assessment questionnaire, and also to calculate the Success Likelihood Index (SLI). PSF determined based on accident data and the factors that cause errors to be identified and verified by expert judgment.

2.4. The Development of A Weighting Questionnaire

The questionnaire was filled out by expert judgment, which aimed to find out how much influence in each PSF generated errors in the grinding work by providing a weight for each PSF in each task. Weights are given on a range of 1 to 10. Weight 10 had the greatest effect and 1 contained the least effect. It meant that the greater the number of PSF showed the increasingly influential in the emergence of errors in grinding work. Inversely, the smaller the number of PSF had a small influence on the incidence of errors in grinding work compared to other PSFs.

2.5. The Assessment of PSF

The determining of the value of PSF determined the quality of each PSF in each task. It could be utilized to calculate the Success Likelihood Index (SLI). Ratings were verified through the results of the PSF assessment questionnaire that had been filled out by expert judgment.

2.6. The Rating of Performance Shaping Factors (PSF) on Each Task

This questionnaire aims to determine the quality of each PSF in each task. The quality is described in the form of weight. The rating scale starts on a scale of 0 to 100. The range of PSF rating scale in Table 1 referred to DiMattia [17].

Table 1. Description of the PSF rating scale for each task.

PSF (*Performance Shaping Factors*	**Scoring Scale**		
	100	**50**	**0**
Procedure	The procedure in this task is almost perfect	Rather perfect procedure	No procedure
Fatigue	Workers are not tired of this task	Rather tired	Very tired
Complexity	Not a complicated task	A bit tricky	Very complicated
Training	A lot of training so workers are highly trained in this task	There is some training	No training
Experience	Experienced in this task	Rather experienced	inexperienced

2.7. The Calculating of Success Likelihood Index (SLI) value

The SLI value is used to calculate Human Error Probability (HEP). SLI could be applied as a performance indicator and could be employed as an aspect of monitoring the Occupational Health and Safety (OHS) management system as well. SLI values were calculated using Equation 1, referred to Embrey and Humpreys [18].

$$SLI_j = \sum R_{ij} W_i \tag{1}$$

SLI_j = SLI value of $task_j$
R_{ij} = PSF_i rating of $task_j$
W_i = PSF_iNormalization Weight ($\sum W_i = 1$)

The SLI value in each task was determined by the rating values and normalization weights obtained.

2.8. The Converting of SLI to Human Error Probability (HEP)

The SLI value was converted to HEP value to obtain the probability of human error in grinding work. It referred to Embrey and Kontogiannis [19] using Equation 2.

$$\log(\text{HEP}) = a\ \text{SLI} + b \tag{2}$$

a = Constant
SLI = Success Likelihood Index
b = Constant

The Probability of Success (POS) value was acquired from the SLI value referred to Embrey and Kontogiannis [19] using Equation 3.

$$\text{POS} = 1 - \text{HEP} \tag{3}$$

a and b value was determined by identifying the error probability minimum in 2 tasks. The error probability value could be recognized from the accident data in task 1 and task 4. These tasks were selected because there were the highest accident cases compared to other tasks. 5 accidents occurred for

5 years in task 1 (task A) due to lack of presence of task 1. While the absence of task 4 (task B) produced 2 accidents for 5 years, referred to Equation 4.

$$Task\text{ A or Task B} = \frac{Total\ accidents\ for\ 5\ years}{\frac{hours}{days}\ x\ \frac{days}{weeks}\ x\ \frac{weeks}{years}\ x\ years} \quad (4)$$

3. Result and Discussion

3.1. The Determining of Performance Shaping Factors (PSF)

The PSF identified as influencing the occurrence of errors was the procedure, fatigue, illumination, complexity, and work shift. verification results from the judges found that from the 5 PSFs determined. The term of PSF was used to denote both of human traits and conditions of work settings that were perceived by judges to have a predominant influence on success likelihood in the scenario being evaluated [18]. It turned out that lighting had no probability of meaningful consequences regarding the expert suggestion. Subsequently, there were 2 additional PSFs suggested by the judges, namely training and the experience factor. Hence, there were 5 PSFs that affected the grinding work namely procedure, fatigue, complexity, training, and experience.

3.2. The Weighing of Performance Shaping Factors (PSF)

The weight of the PSF was determined through a questionnaire by expert judgment. The weighted results of the judges were averaged. The weight was then normalized through each value divided by the total value overall. The total normalized weight should be 1.00. The weighting results showed a comparison of the level of importance of the PSFs to the grinding work (Figure 2).

Table 2. Weighting the weighting of performance shaping factors (PSF) questionnaire results.

No	Task	PSF Value				
		Procedure	Fatigue	Complexity	Training	Experience
1	Use PPE following requirement	8.75	6,50	7	7.25	8.50
2	Prepare a document following requirement	5.50	3,25	5	5.25	5.75
3	Perform autonomous maintenance	5.75	4,50	4	5.50	5.25
4	Select the grinding stone according to the type of material would be grinded and the work should be conducted	5.75	4	4.75	6	6.75
5	Install grinding stones	5.75	3.25	3.25	5.50	5
6	Turn on the grinding machine	5.50	5.50	5.50	5.50	4.75
7	Grinding the material	6.50	5.75	6.25	6	7.75
8	Turn off the grinding machine	5.50	5.50	5.50	5.50	4.75
9	Check the results of the grinding whether following the document	7	3.75	4.50	5	5.75
10	Perform autonomous maintenance	5.75	5	3.50	4.75	4.75
11	Return the grinder to its original place	3.75	4	2.75	2.75	3.25
12	Carry out 5S	5.25	5.25	5.25	6.25	5
	Total	70.75	56.25	57.25	65.25	67.25
	Average (Weight)	5.90	4.69	4.77	5.44	5.60

The level of importance of PSFs in order from the largest was procedure, experience, training, complexity, and fatigue. The procedure was one of PSF on grinding work if it was not carried out properly would be produced the most initiating errors. Therefore, it was followed by work experience factors that were less possibility of generating an error to the experienced worker. The lack of training could affect as well to the level of accidents. The complexity in the grinding process also influenced the occurrence of errors. The complex workpiece or the difficulty of grinding positions increased the probability to generate an error. The fatigue decreased worker concentration, which did not infrequently produce sleepy, and other signs of exhausted. There have been many cases of accidents that have occurred due to this factor. These five factors are the most influential in grinding work.

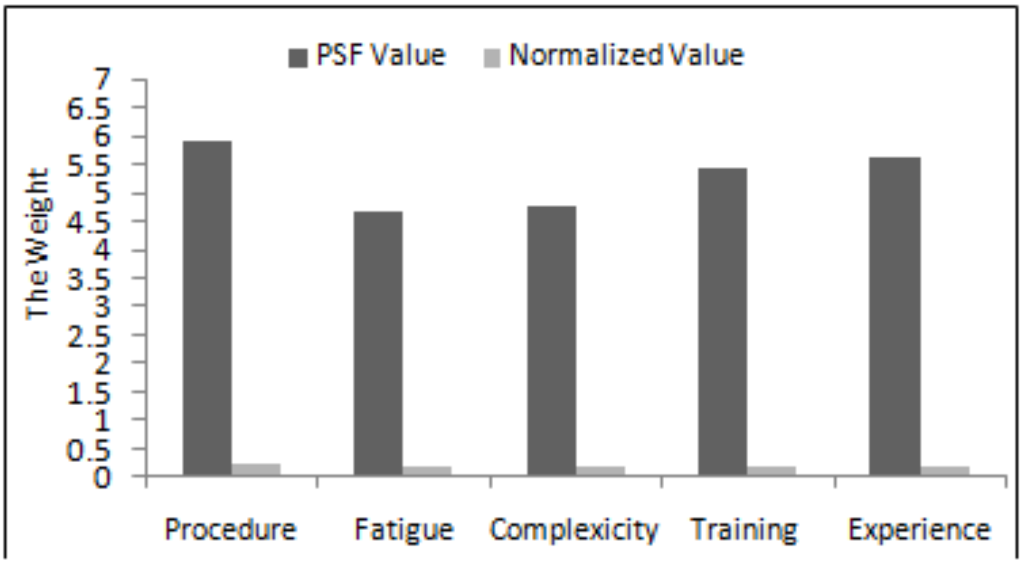

Figure 2. The PSF and normalized value. Data presented in mean of PSF and normalized value.

3.3. The Determining of Performance Shaping Factors (PSFs) Value for Each Task
Ratings were determined through the results of the PSF assessment questionnaire that had been filled out by expert judgment. Afterward, the rating results of the judges were averaged. The quality of procedures on grinding work that had been made by the company was 92.5. It meant that the quality of procedures in this task was almost perfect because it was closed to a rating of 100. While the fatigue factor in the first task was 80, meaning that the task of using PPE as specified, the workers did not feel tired of this task. For complexity, the first task was not a complicated task to execute. The quality of training in the first task was 100, meaning that there was a lot of training in the task. Hence, workers were already highly trained in the task. The experience factor of the first task was 92.5. It meant that the workers were very experienced.

3.4. The Calculation of Success Likelihood Index (SLI)
The rating values and normalization weights were determined, hence SLI value could be identified in each task, shows in table 3.

3.5. Converting the value of Success Likelihood Index (SLI) to Human Error Probability (HEP) Value
After the SLI value was identified, the next step was to find the error probability (Equation 2).To find out the values of a and b (Equation 2) at least the probability of error in 2 tasks should be recognized.

The error probability value could be identified from the accident data in task 1 and task 4. These 2 tasks were selected because there were the highest accident cases compared to other tasks. In task 1 (task A), the number of accidents that occurred due to lack of task 1 fulfillment was 5 accidents for 5 years. While the number of accidents that occurred due to ignore task 4 (task B) was 2 accidents for 5 years. The probability of error is calculated according to Equation 2.

Hence that the equation was obtained as follows:

log (HEP) = a SLI + b

log (HEP) = 0,0066323 SLI – 3,831614

While the POS value was obtained from Equation 3. Table 4 illustrates the calculations of the SLI, HEP, and POS.

Table 3. The weight of PSF and the value of SLI.

Task	PSF Value					SLI Value
	Procedure	Fatigue	Complexity	Training	Experience	
Use PPE following requirement	92.50	80	82.50	100	92.50	90.03
Prepare a document following requirement	75	40	50	72.5	70	62.63
Perform autonomous maintenance	95	85	72.50	87.50	80	84.43
Select the grinding stone according to the type of material would be grinded and the work should be conducted	97.50	87.50	82.50	97.50	82.50	89.85
Install grinding stones	100	62.50	72.50	80	75	78.85
Turn on the grinding machine	87.50	75	77.50	87.50	77.50	81.35
Grinding the material	92.50	75	77,50	82.50	92.50	84.55
Turn off the grinding machine	95	77.50	77.50	77.50	75	80.83
Check the results of the grinding whether following the document	90	70	67.50	80	67.50	75.53
Perform autonomous maintenance	92.50	57.50	70	92.50	90	81.63
Return the grinder to its original place	77.50	77.50	77.50	65	87.50	76.98
Carry out 5S	60	85	85	70	90	77.40
The normalized weight	0.22	0.18	0.18	0.21	0.21	∑SLI = 964.06

Table 4 illustrates that the increase of SLI value would be followed by the increase of HEP value. Even though the POS value was inversely proportional to HEP value. The HEP value increased would be followed by a decrease in the POS value and vice versa.

Table 4. The value of SLI, HEP, and POS.

No	Task	SLI	HEP	POS
1	Use PPE following requirement	90.03	0.0005828	0.9994172
2	Prepare a document following requirement	62.63	0.0003835	0.9996165
3	Perform autonomous maintenance	84.43	0.000535	0.999465
4	Select the grinding stone according to the type of material would be grinded and the work should be conducted	89.85	0.0005812	0.9994188
5	Install grinding stones	78.85	0.0004913	0.9995087
6	Turn on the grinding machine	81.35	0.0005104	0.9994896
7	Grinding the material	84.55	0.000536	0.999464
8	Turn off the grinding machine	80.83	0.0005064	0.9994936
9	Check the results of the grinding whether following the document	75.53	0.000467	0.999533
10	Perform autonomous maintenance	81.63	0.0005126	0.9994874
11	Return the grinder to its original place	76.98	0.0004805	0.9995195
12	Carry out 5S	77.40	0.0004775	0.9995225

Table 4 shows that the task with the highest error probability was task 1 (use PPE following requirement). Giving evidence that task 1 had the largest accident occurrence with the highest frequency and severity according to accident records. This data illustrates that these accidents occurred due to there was a lack of protection from the proper use of PPE. Balkhyour *et al.* [20] investigated that PPEs are very effective in minimizing occupational injuries, accidents, and other hazards which otherwise result in substantial manpower and financial losses in 37 small-scale industries situated in urban premises of Jeddah. This research illustrates that education correlated with the use of PPE only for safety mats, face masks, and safety glasses. Besides these three types of PPE, education was not related to the use of PPE. Setyaningrumand Saputra [21] studied the correlation between the use of PPE with the occupational accident. This research concluded that PPE was one of the risk management control accidents. The use of PPE can reduce the risk of accidents, moreover for the work with large potential hazards, and high risk.

Table 4 describes the lowest HEP was task 2 (prepare a document following requirement) in which these tasks had the lowest risk both of the accident frequency and severity, thus, they had a lower probability to generate accidents.

As efforts to reduce the error probability value in grinding work, the following recommendations were provided to decrease the error probability value by increased PSF value. It was ranging from improving procedures, reducing fatigue of workers, reducing the complexity of work, developing training and socialization on workers to improve worker knowledge [22], and improving worker qualifications through a history of work experience. Wachter and Yorio [23] found that the effectiveness of a safety management system and its practices in reducing accident rates depended on the levels of safety-focused cognitive and emotional worker engagement.

1. Procedure
   a. Tasks and task descriptions in the work instruction should be more detailed
   The procedure classified into work instruction and presented as job safety analysis (JSA). Job safety analysis conducted individually or as a group. Unsafe conditions prior to and while jobs were being carried out should be eliminated before work began [24]. Work instruction of grinding work using a portable grinding machine that lacked detailed contents, work instructions only contained points that were already common in grinding work. Therefore, it was necessary to create a task analysis for grinding work using a portable grinding machine.
   b. Providing work instruction socialization
   Work instruction socialization was required to provide detailed explanations related to work instruction and to provide a common perception of each workforce, since all this time, work instruction was only at some point in the workshop. The work instruction should be applied at every bay (workplace) thorough the routine company program for improving worker knowledge such as safety briefing, safety talks, safety training, and seminars. Hamdani *et al.* [22] found that the socialization of PPE could significantly improve the worker's knowledge and attitude to frequently use of PPE at any task of work.
2. Increased supervision
   The essential for supervision here by the supervisor or group leader to ensure the implementation of procedures and work instructions. Supervisors had to ensure the control programs arranged by management and the investigation team were employed [24].
3. Arrange work time and rest time for workers
   One of the PSFs that has a high weight to cause errors was fatigue, it was necessary to study to regulate work time and rest periods of workers. The management of working time and rest periods were necessary to ensure the worker obtained the workload regarding their capabilities. The regulation of worker workload referred to the threshold value of the work climate in Standard Nasional Indonesia (SNI) [25].
4. Complexity
   The level of complexity of the work which was one of the PSFs could be minimized by compiling more detailed work instructions and conducting training and re-training. The training was conducted to increase the knowledge and expertise of workers in grinding activities. It was essential as well to refreshing back the workers who had already received the previous training.
5. Experience
   One important PSF that produced errors was experienced with grinding work. Hence, it was important to recruit workers who had qualified skills as a good base for safety behavior. Safety management practices were designed to influence employee knowledge, skills, motivation, decision-making, attitudes, and perceptions [23].

4. Conclusion

Grinding activities contain high risks for potential hazards. Accident analysis data illustrate that the frequent accident due to human errors. The factors that influenced the occurrence of errors in grinding work are the procedure, fatigue, complexity, raining, and experience factors. The task that has the highest error probability value is the usage of the specified PPE with the HEP value is 0.0005828, which means the probability of success (no error) is the lowest compared to other tasks. This result shows that this task most often results in accidents caused by human error. These accidents occur due to there is a lack of protection from the proper use of PPE. While the lowest error probability value is the task of preparing documents under what has been determined with the HEP value of 0.0003835. Recommendations given to reduce the value of error probability are by compiling detailed work instructions as job safety analysis. Moreover, employee knowledge has to be improved through training or socialization programs for accident prevention. The supervision should be increased to ensure the procedures and work instruction in job safety analysis is implemented. The management of work time and rest periods of workers should be conducted to certify the worker obtains the workload according to their capabilities. The worker recruitment is applied to find an appropriate worker who has qualified skills.

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