Analysis of Human Error Risk with Human Reliability Methods in Construction Projects

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Abstract. Work injury rates in Indonesia are relatively high, resulting in an urgency to maintain the safety of workers whose numbers are increasing. The biggest sector contributing to work accidents in Indonesia is the construction area, including building construction and causing large physical and financial losses. Workplace accidents are usually caused by human error and are strongly related to human reliability. The use of Fuzzy Cognitive Reliability and Error Analysis Method (Fuzzy CREAM) method is aimed at research to analyze patterns of worker behavior that affect the risk of workplace accidents combined with Bayesian Network simulation. 176 construction workers in the Jakarta and surrounding areas became the object of research. The value of Human Error Probability (HEP) was successfully obtained and the solution was given based on the characteristics of workers in the Control Mode category.

1. Introduction

In 2013, The International Labour Organization (ILO) states that every 15 seconds 1 worker died in the world resulting from a work accident, and 160 other workers experienced the threat of workplace accidents in their working environment. In Indonesia, Based on the data of the Indonesian Central Statistics agency, it was found that there was an increase that occurred there were many workers and people working age in Indonesia from 2016 to 2018. In the year 2016, which was only 127.8 million has increased to 133.9 million people. Based on the data issued by the Social Security Administering Agency (BPJS) Indonesia employment, the number of labor accidents that occurred in Indonesia in 2017 reached 123,000 cases.

Work accidents that occur not only endanger the lives of workers but also inflict losses on the running project. Based on BPJS employment data Indonesia stated that in 2018 there was an increase in financial losses in all regions of Indonesia amounting to 971 billion, increasing as much as 179 billion compared to the previous year. The working sector that dominates the proportion of work accidents occurring in Indonesia is construction, by 32%. Indonesia also has a goal to accelerating the process of infrastructure development, this showed by the increase of the State budget and expenditure Indonesia which has increased in infrastructure category by 123.4%.

80% of work accidents that occur are caused by human error. This indicates that human reliability in the work environment, especially in the construction project environment, is still relatively low. Based on the situation and condition explain, it is found that the work accident in Indonesia needs to be taken seriously. It becomes an urgency to increase the reliability of human reliability in the
construction work environment. This research is conducted using the Human Reliability Assessment method.

2. Literature Study and Research Methodology
This research is based on several literature studies, this study comprise the discussion about ergonomics and also the discussion about methods of measuring human reliability

2.1. Ergonomics
Ergonomics are often also referred to as human factors, as they relate to humans and their interactions. Ergonomics are defined as a static branch of science to utilize information about the nature, ability, and limitation of human beings in designing a working system so that people can live and work on the system well, that is to achieve the desired objectives through the work, effectively, healthy, comfortable and efficient [1].

According to the International Ergonomics Association Organization (IEA), ergonomic or human factor is a scientific discipline that focuses on understanding the interaction between human beings and other elements in a system and ergonomics is the work that applies the theory, principles, data, and methods in designing to optimize human existence and overall performance in a system.

2.2. Human Error and Human Reliability
Human Error is Inappropriate human decisions or behaviors that may reduce or potentially reduce the effectiveness, safety, or performance of a system [2].

Human error is very related to human reliability, where human reliability is a procedure to perform quantitative analysis in predicting the possibility of human error, providing explanation of how human error occurred, as well as a measurement of human reliability to calculate the degree of truth from success of an activity or work done by man [3].

2.3. Cognitive Reliability & Error Analysis Method (CREAM)
Measurement of human reliability or commonly called human Reliability Assessment (HRA) is a qualitative and quantitative method for measuring human contributions to a risk [4]. There are 72 methods/tools of HRA with 35 including potential to be applied. Where from 45 The HRA method there are 17 that have been identified as relevant for use in human reliability measurements in the context of occupational health and safety [4].

The Cognitive Reliability and Error Analysis Method (CREAM) is a second generation HRA method that uses a relationship approach between the nature of cognition, context/purpose, and inseparable action (competence) [5].

The main purpose of CREAM is to offer practical two-way approaches to analysis and performance assessment [5]. The basic method of CREAM used to determine the control mode and the error rate interval under the screening stage, while the expanded method used for quantification of cognitive function errors.

To make the CREAM method more quantitative, some studies introduced the fuzzy logic theory into the original method commonly said as fuzzy CREAM. In Fuzzy CREAM, the measured variable for the Human Reliability Assessment is a continuous value varying from 0 to 100 or commonly called the Common Performance Condition (CPC).

In the human Reliability Assessment, fuzzy CREAM was used and will be simulated with the Bayesian network.

Table 1. Example of proportion impact of assessment on human reliability according to fuzzy theory

| Training Experience | Real | Fuzzy |
|---------------------|------|-------|
| Increase            | 69,29| 0,48  |
| Neutral             | 69,29| 0,52  |
| Decrease            | 69,29| 0     |
2.4. Bayes Theorem
The Bayesian theory is a theory in a condition of the degree of truth that considers the degree of truth of an event (hypothesis) depending on other events (evidence). Bayes theory Statement:

\[(A|B)P(B) = P(A,B) = P(B|A)P(A)\]  

where \(P(A/B)\) is a combined probability of Genesis \(A\) and \(B\). Dividing both sides by \(P(B)\), obtained:

\[P(A|B) = P(B|A)P(A)/P(B)\]  

In general Bayes theorems can be written in the form of:

\[P(A_i|B) = P(B|A_i)P(A_i)/P(B|A_i)P(A_i)\]  

If \(\{A_i\}\) forms the partition of the event space, for each \(A_i\) in the partition.

2.5. Bayesian Network
The Bayesian Network or Belief Network (BN) is a probabilistic graphic model that represents a set of variables and their probabilistic freedoms. This method is widely used to understand the relationship between variables because it learns the relationship of each variable in dependency and independence. The Bayesian Network has two main elements: the graph structure and the parameters \[7\]. The graph structure and parameters are used to predict the final outcome based on the causal relationship depicted in the form of a graph.

3. Data Collection and Data Processing
Scope of research carried out is on construction work. This is based on data that in the industrial sector in Indonesia, this sector has the greatest risk of work accidents at 32% of the total work accidents that occur. This fact creates an urgency to calculate and analyze the risk of work accidents due to human error, which is the biggest factor that causes work accident cases in the world.

The construction used in this study is the category of building construction. This is because this construction category is easier to access and reach in the research process. The site of the research was carried out on four building construction projects in the Jakarta area.

The object of research aimed at building construction field workers who are people who directly use heavy equipment on construction projects, this allows them to have a high risk of work accidents.

In the division of labour, based on the results of field observations made by researchers divided into three, namely

- Reinforcing Work, including the construction of structures under the building.
- Excavation and Casting Work, including the construction of structures under buildings.
- Work on Formwork, including the construction of structures on buildings.

3.1. Data Collecting
To be able to calculate human error and analyze the human reliability of an industrial environment requires data that can show the activities that occur in the environment, called as the measured variable or CPC, as well as supporting data regarding the level of influence of the variable strength of human reliability on activities in the environment.

3.2. Data Processing
Research on HRA is intended to measure the degree of truth of human error that will occur in an industrial environment through observing the related variable called the common performance condition (CPC). CPC in the CREAM method consists of 8 variables [5] consisting of Training and Experience [5], Physical Environment, Organizational Management, Work Characteristics, Available Time, Safety Procedures, Job Specifications, and Crew Collaboration Quality. To simplify the process of analysis and calculation of eight CPC variables are grouped into 3 main CPC groups [8], namely:

- Management Related Factor is a combination of CPC: Training and experience, organizational management, and crew collaboration.
• Environmental Factor is a continuation of the development of CPC: physical environment.
• Management Related Factor is a combination of CPC: Work Characteristics, available time, safety procedures, and job specifications.

All the CPCs mentioned above will be assessed based on questions on the questionnaire by building construction workers using an assessment with a scale of 0-100 on each question. All of these CPCs will then form groups of groups called control modes. There are four types of control modes that can occur during work [5], defined in Table 2:

| Control Mode | Description | Predictive interval of action failure |
|--------------|-------------|---------------------------------------|
| Strategic    | In strategic control, the person considers the global context, thus uses a wider time horizon and looks ahead at higher level goals. The strategic mode provides a more efficient and robust performance and may therefore seem the ideal to strive for | (0.000005, 0.01) |
| Tactical     | In tactical control, performance is based on planning, hence more or less follows a known procedure or rule. The planning is, however, of limited scope and the needs taken into account may sometimes be ad hoc | (0.001, 0.1) |
| Opportunic   | In opportune control, the next action is determined by the salient features of the current context rather than on more stable intentions or goals. The person does very little planning or anticipation, perhaps because the context is not clearly understood or because time is to constrained | (0.01, 0.5) |
| Scrambled    | In scrambled control, the choice of next action is in practice unpredictable or haphazard. Scrambled control characterises a situation where there is little or no thinking involved in choosing what to do | (0.1, 1.0) |

3.3. Data Processing
This study requires data on the assessment of building construction workers for variables related to HRA. Data search was performed by conducting interviews and filling out questionnaires consisting of 8 CPC variables. Determination of the number of respondents based on the Cochran formula, 1977, and found that the minimum number of samples needed was 139 people. The research questionnaire was divided into four predetermined building construction sites. Researchers managed to get as many as 176 respondents in this study, respondents had come from three work divisions that exist in building construction projects. Based on the results of the validity and reliability test, it was found that 6 out of a total of 8 variables were declared valid. The test results also found that all questionnaire questions have a high level of validity. In the reliability test, it was found that all the questions that had been said were reliable.

3.3.1. Fuzzy Value Calculation, after the data obtained is said to be valid and reliable, the data is continued in data processing to find out the variables that affect human error. The results of the questionnaire assessment were calculated in the form of fuzzy values for each CPC and became an illustration of the effect of each CPC on human reliability (Increase / Neutral / Decrease).

• CPC with a value of 0 - 50, categorized as the influence of low category CPC (Inadequate/Unsatisfied) and gives effect decrease on human reliability.
• CPC with a value of 10 - 90, categorized as the influence of CPC is moderate (Acceptable) and provides a neutral influence on human reliability.
• CPC with a value of 90-100, categorized as the influence of high category CPC (Adequate/Satisfied) and gives an increased effect on human reliability.

The value obtained at each CPC is converted into fuzzy form, to be able to show the fuzzy logic attached to table 3.
Table 3. Value calculation results for fuzzy each CPC based on overall activity

|     | CPC 1   | CPC 2   | CPC 3   | CPC 4   | CPC 5   | CPC 6   | CPC 7   | CPC 8   |
|-----|---------|---------|---------|---------|---------|---------|---------|---------|
|     | Increase| 0.482   | 0.712   | 0.712   | 0.623   | 0.623   | 0.663   | 0.663   |
| Total| Neutral | 0.518   | 0.288   | 0.288   | 0.377   | 0.377   | 0.337   | 0.337   |
|     | Decrease| 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   |

The value obtained for 3 CPC Category is converted into fuzzy value form, for 3 CPC category fuzzy value attached on table 4.

Table 4. Value calculation results for fuzzy each CPC based on category

|     | Management Factor | Environmental Factor | Work Related Factor |
|-----|-------------------|----------------------|---------------------|
|     | Real              | Fuzzy                | Real                | Fuzzy         |
| Increase| 0.59375           | 0.59375              | 0.8125              |
| Neutral | 73.75             | 0.40625              | 82.5                | 0.1875        |
| Decrease| 0                  | 0                    | 0                   | 0              |

The calculation is then continued by calculating the fuzzy value of each CPC for each job category, enclosed in table 5.

Table 5. Result value calculation fuzzy each CPC based on job category

|     | CPC 1   | CPC 2   | CPC 3   | CPC 4   | CPC 5   | CPC 6   | CPC 7   | CPC 8   |
|-----|---------|---------|---------|---------|---------|---------|---------|---------|
| Reinforcing| Increase | 0.670   | 0.627   | 0.655   | 0.655   | 0.744   | 0.744   | 0.715   | 0.715   |
|       | Neutral | 0.330   | 0.373   | 0.345   | 0.345   | 0.256   | 0.256   | 0.285   | 0.285   |
|       | Decrease| 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   |
| Excavation and Casting| Increase | 0.238   | 0.817   | 0.616   | 0.616   | 0.640   | 0.640   | 0.671   | 0.671   |
|       | Neutral | 0.762   | 0.183   | 0.384   | 0.384   | 0.360   | 0.360   | 0.329   | 0.329   |
|       | Decrease| 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   |
| Formwork| Increase | 0.539   | 0.690   | 0.597   | 0.597   | 0.605   | 0.605   | 0.604   | 0.604   |
|       | Neutral | 0.461   | 0.310   | 0.403   | 0.403   | 0.395   | 0.395   | 0.396   | 0.396   |
|       | Decrease| 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   | 0.000   |

3.3.2. Conditional Probability Calculation. In order to be able to process fuzzy values on the Bayesian network, it is necessary to calculate the latest degree of truth value for the three CPC groupings, because these three factors can only occur when other CPC factors that affect them have already occurred.

3.3.3. Fuzzy Bayesian Network Simulation. The results of the fuzzy values that have been obtained are input for the parent node in the Bayesian network. Bayesian networks are arranged based on predetermined CPC variables and their related relationships. The first nine CPC will be the first parent node, three groups of CPC will be the second parent node as nodes affected by the first node. The control mode group will be the child node or node to be reviewed for the final result. Bayesian network is done by using Netica software, the results obtained from the simulation results on overall activity shown on table 6.
Table 6. Simulation results bayesian network based on overall activity

| CPC Category       | Increase | Neutral | Decrease | Control Mode |
|--------------------|----------|---------|----------|--------------|
| Management Factor  | 0,758    | 0,242   | 0,000    | Strategic Mode 66,60% |
| Environmental Factor | 0,589    | 0,411   | 0,000    | Opportunistic Mode 27,20% |
| Work Related Factor | 0,806    | 0,294   | 0,000    | Tactical Mode 5,86% |

For the simulation results for the reinforcing work shown on table 7.

Table 7. Simulation results bayesian network based on reinforcing work categories

| CPC Category       | Increase | Neutral | Decrease | Control Mode |
|--------------------|----------|---------|----------|--------------|
| Management Factor  | 0,678    | 0,322   | 0,000    | Strategic Mode 60,20% |
| Environmental Factor | 0,618    | 0,382   | 0,000    | Opportunistic Mode 30,20% |
| Work Related Factor | 0,801    | 0,199   | 0,000    | Tactical Mode 7,55% |

The next, the results of simulation for casting work shown on table 8.

Table 8. Simulation results in bayesian network based on excavation and casting work categories

| CPC Category       | Increase | Neutral | Decrease | Control Mode |
|--------------------|----------|---------|----------|--------------|
| Management Factor  | 0,722    | 0,228   | 0,000    | Strategic Mode 65,60% |
| Environmental Factor | 0,458    | 0,542   | 0,000    | Opportunistic Mode 27,90% |
| Work Related Factor | 0,806    | 0,194   | 0,000    | Tactical Mode 6,43% |

The last simulation for formwork categories shown on table 9.

Table 9. Simulation results bayesian network based on formwork work categories

| CPC Category       | Increase | Neutral | Decrease | Control Mode |
|--------------------|----------|---------|----------|--------------|
| Management Factor  | 0,796    | 0,204   | 0,000    | Strategic Mode 71,50% |
| Environmental Factor | 0,655    | 0,345   | 0,000    | Opportunistic Mode 24,00% |
| Work Related Factor | 0,806    | 0,194   | 0,000    | Tactical Mode 4,55% |

3.3.4. Validity Test of Bayesian Network Simulation Results, the next step taken is to ensure the accuracy of the results from the data obtained, by comparing the deviation between the actual situation with the prediction of the model results [9]. The error rate value is obtained by comparing the simulation model with actual results. Given on table 10 the result of validation error rate for CPC management factor.
### Table 10. Results of validation error rate between model results and actual results for cpc management factor

|                      | Original | Model | Error rate |
|----------------------|----------|-------|------------|
| Increase             | 0.549    | 0.758 | 28%        |
| Neutral              | 0.406    | 0.242 | 40%        |
| Decrease             | 0.000    | 0.000 | 0%         |

Validation Rate for CPC environmental factor given on table 11.

### Table 11. Results of validation error rate between model results and actual results for cpc environmental factor

|                      | Original | Model | Error rate |
|----------------------|----------|-------|------------|
| Increase             | 0.594    | 0.589 | 1%         |
| Neutral              | 0.406    | 0.411 | 1%         |
| Decrease             | 0.000    | 0.000 | 0%         |

Last, for CPC work related factor validation error results rate given on table 12.

### Table 12. Validation results error rate between model results and actual results for cpc work related factor

|                      | Original | Model | Error rate |
|----------------------|----------|-------|------------|
| Increase             | 0.813    | 0.806 | 1%         |
| Neutral              | 0.188    | 0.194 | 3%         |
| Decrease             | 0.000    | 0.000 | 0%         |

3.3.5. Calculation of Human Error Probability, the Bayesian network simulation results are the basis for calculating human error probability (HEP), in building construction activities. The value that comes out in control mode will be multiplied by a special variable that converts the fuzzy value into a whole value or is called the defuzzification process [10]. The HEP value for all construction project activities, the category of reinforcing work, the category of excavation and casting work, and the category of Formwork work are 0.007, 0.009, 0.007, and 0.006, respectively.

### 3.4. Analysis and Results

3.4.1. HEP Calculation Analysis, based on the value of HEP, it can be stated that workers in the construction field are classified as reliable and belong to the control mode category that has the lowest HEP namely Strategic Mode. This shows that field workers have done their jobs well so that they have the inclination to provide an assessment of the questionnaire that has been distributed values above 70, with an average value of 76.81.

The building construction environment has been classified as reliable which is the impact of the complete work safety equipment and procedures for use by all workers. Directed job desks and good supervision by site engineering management or safety health environment that always conducts periodic inspections every morning and evening, also support a reliable building construction environment.

Based on HEP calculations, it was found that there was 1 CPC that had impact neutral on human reliability, namely Training Experience which was given by the lowest rating of all CPCs which was valued at 69.29. Construction workers were found to feel that the work training they received could still be increased in terms of quantity and quality. To be able to increase the effectiveness of human reliability on CPC training experience and change it from neutral to increase. This illustrates that the
contractor must ensure that each worker has received job training and understands the job desk provided through job training.

3.4.2. Analysis of Respondent Characteristics, based on the characteristics of the respondents, it was found that there was a linear relationship between the length of work and the amount of job training. Reinforcing workers are workers from the occupational category with the longest average duration of work in a construction project and receive the most work training when compared to workers from other occupational categories.

If the further analysis of the relationship exists between the duration of work time, the amount of work training, and the value of HEP, it is found that:

- The duration of work is directly proportional to the chance of work accident risk.
- The amount of job training is not inversely proportional to the risk of the work accident.

Meanwhile, job training is actually intended to reduce the risk of work accidents. This illustrates that the level of risk of work accidents in accordance with the long duration of work. While the amount of work training has not been able to reduce the risk of work accidents. The solution that can be given is to always maintain the comfort and safety of workers on the duration of work, which can be done by providing adequate rest periods. The reference that can be done is to use the Minister of Manpower and Transmigration Regulation No. Per-15 / Men / VII / 2005 concerning Working Hours and Rest Hours in the Indonesian General Mining Business Sector.

The HEP value obtained depicts construction workers in Jakarta and surrounding areas belonging to the group Strategic Mode. This group is classified as the most reliable group compared to other groups or has the lowest risk of work accidents.

4. Conclusion and Suggestion
The results obtained from this study were found the factors that influence human reliability for building construction workers in Jakarta and its surrounding areas are as follows:

- The aspects of K3 completeness and the running of work desk well become a factor causing the increase in the value of building construction workers reliability.
- Factors Training have the smallest impact on human reliability because there are still Workers who have not felt/are not satisfied with the existing work training Work duration has more relationship with human error than work training.
- Factors Management affect the group more Control Mode than Environmental Factors & Work-Related.
- Factors Crew Collaboration Quality Factors affect factors more Management than Training Experience & Organizational Management.
- Job Specification influences factors more Work-Related than factors Work Characteristics, Available Time & Safety Procedure.

Recommendations that can be given to improve reliability the activity of building construction workers in order to reduce the risk of work accidents in the Jakarta and surrounding areas is to improve the quality and quantity of interaction between workers, with detailed implementation steps as follows requiring lunch and dinner together for all workers, requiring workers to join together for workers accommodation and always do direct interaction through increased labor supervision time for mobile workers to three times a day and conduct joint activities outside working hours as a recreational activity together or so.

To be able to perfect further research related to human error using the method of human reliability in building construction projects is to select the appropriate research respondents and convince
respondents to provide an objective assessment, compare the fuzzy CREAM method with other methods on the same research object, and examine other types of construction projects to get a comparison of the reliability of workers between types of construction projects.

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