HUMAN RELIABILITY ANALYSIS IN NUCLEAR POWER PLANTS

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ABSTRACT

HUMAN RELIABILITY ANALYSIS IN NUCLEAR POWER PLANTS. Reliability is a major requirement in socio-technical systems such as nuclear power plants. Studies have confirmed that human errors are the most contributors to accidents or incidents in such systems. Human reliability analysis (HRA) can be applied to systematically identify and analyze human error – related events. It offers opportunities to correctly improve human-machine interfaces, reliability and safety. Three main objectives of HRA are human error and contributor identification, human error modeling, and human error probability quantification. There are various approaches, which have been implemented for HRA in socio-technical systems. They are different in scopes, types, task decomposition levels, and factors influencing error probabilities. The purpose of this study is to investigate five HRA approaches, which have been widely implemented to assess human errors influencing the safety operation of NPPs. Strengths and weaknesses of each approach are reviewed and discussed. Published articles on human errors and HRA are gathered to achieve this study objective.

Keyword: Human reliability analysis, human error, nuclear power plant.

ANALISIS KEANDALAN MANUSIA PADA PEMBANGKIT LISTRIK TENAGA NUKLIR.


Kata kunci: Analisis keandalan manusia, kesalahan manusia, pembangkit listrik tenaga nuklir.
INTRODUCTION
Considering energy resource availability, climate change and air quality, nuclear power plants (NPPs) become more and more important for future energy resources [1]. To gain public support and confidence, NPP designs and technologies are continually developed to mainly improve their safety and reliability. Over the past year, safety and technological concept, such as passive safety systems, have been developed to reduce technical equipment failures [2, 3]. However, it is impossible to describe system reliability without considering the failure of humans to perform their tasks. Studies confirm that incorrect human actions are the most contributors to accidents and incidents in socio-technical systems [4, 5]. For example, over 90% accidents in nuclear industry are caused by human errors [6, 7]. Institute of Nuclear Power Operation (INPO) recorded that 48% of the total events in NPPs during the period of 2010-2011 are caused by human errors [8]. Human errors are also reported as the cause of TMI-2 and Chernobyl accidents [9, 10].

Human performance is highly affected by task characteristics and working environment [11]. There are three factors that can affect humans to properly complete their tasks, i.e. technical factors, organizational factors and personal factors [11]. In order to systematically identify and analyze human error – related events, human reliability analysis (HRA) can be applied [12]. HRA offers opportunities to correctly improve human-machine interfaces, reliability and safety in socio-technical systems [13]. It has been proven to be particularly useful to mitigate human errors in nuclear industry [14].

HRA aims to predict the probabilities of humans to commence to errors due to their performance degradation [15, 16]. It has three main objectives, i.e. to identify possible human error and contributors, to model human error, and to quantify human error probabilities [17, 18]. There are various approaches that have been implemented to investigate human performance in socio-technical systems [18]. They are different in scopes, types, task decomposition levels, and various factors initiating human errors. There is no one HRA approach, which is universally approved and accepted for identifying and analyzing human error – related events [16]. We can also encounter from literatures that Technique for Human Error Rate Prediction, Standardized Plant Analysis Risk Human Reliability Assessment, A Technique for Human Event Analysis, Cognitive Reliability and Error Analysis Method, and Success Likelihood Index Method using Multi-Attribute Utility Decomposition are five HRA approaches, which have been widely implemented in NPPs. In order to success, it is necessary to choose the most appropriate HRA approach for a certain problem characteristic. The purpose of this study is to investigate the applications of those five HRA approaches. Strengths and weaknesses of each approach are reviewed and discussed. Published articles on human errors and HRA approaches are gathered to achieve the objective of this study.

THEORY
Human factors are critical to system availability and reliability. Human errors can be defined as human incapability to properly accomplish a task under specific condition at a given time [14, 15]. Human error refers to common mistakes, which are easily identified and diagnosed. Various sources of human errors are lack of training, poor equipment design, inadequate lighting, loud noise, inadequate work layout, improper tools, and poor operating procedures [19].

Human errors can be classified into three types, i.e. omission error, commission error, and intentional error. Omission error is triggered by lapse or misperception. Meanwhile, commission error is triggered by performing incorrect actions. This type of error can also be caused by mistakenly selecting procedure sequences. Furthermore, intentional error can be caused by not following procedure sequences without consequence awareness [20].

Human errors can be evaluated by understanding human performance factors (HPFs) and human behavior. HPFs can be categorized into internal factors and external factors. Internal HPFs are induced by psychological and physiological aspects. Psychological aspects include stress, over workload, depression, demotivation and loss of concentration. Physiological aspects include health conditions and deceases. Meanwhile, external HPFs are induced by technological aspects and social aspects. Technological aspects include procedures, equipment, and work conditions. Social aspects include poor social acceptance and conditions [20].
Human behavior can also considerably damage system performance and safety [21]. Human behavior can be characterized by and based on procedure, skill and knowledge. Procedure – based human behavior is very effective when employees do not have enough expertise to do a specific task. Furthermore, skill – based human behavior is very effective when employees have enough expertise on a specific task and can perform it within a specific time framework. Meanwhile, knowledge – based human behavior is highly influenced by time and task complexity. Employees should have enough time to process and implement information obtained [20].

METHODOLOGY

The main objective of human reliability analysis (HRA) is to assess operator contribution to the failure of a system. It collects information on human characteristics and behaviors prior to improving the reliability of human – machine systems. In general, HRA focuses on predicting human error probability, understanding cognitive process of human error, and understanding human performance factors that can initiate human error. There are various approaches that have been implemented for HRA.

In this study, five HRA approaches that have been widely implemented for assessing human errors in the operation of NPPs are investigated. Those are Technique for Human Error Rate Prediction (THERP), Standardized Plant Analysis Risk Human Reliability Assessment (SPAR-H), A Technique for Human Event Analysis (ATHEANA), Cognitive Reliability and Error Analysis Method (CREAM), and Success Likelihood Index Method using Multi-Attribute Utility Decomposition (SLIM-MAUD). To discuss the strengths and weaknesses of each approach, a wide range of literatures on human errors and HRA approaches are gathered and reviewed.

RESULT AND DISCUSSION

Reliability is a major requirement for safety operation of nuclear power plants (NPPs), which can be affected by both technical equipment and human performance [22]. Human reliability analysis (HRA) aims to evaluate contribution of operators to the reliability of a system. HRA can identify what could go wrong in a system, what consequences could be raised by a human failure, what human performance factor could degrade human reliability, and what human reliability improvement could be needed to prevent human error [20].

In order to success, it is necessary to choose the most appropriate HRA approach. Approach selection can be done based on the objective of the analysis and problem characteristics. Three critical points, which need to be considered prior to approach selection, are human analysis objectives, human failure data availability, and analysis time period. Furthermore, it is also necessary to understand the objectives and limitations of each approach [20]. When it is possible to perform two or more approaches, it is advisable to apply those approaches and compare their results to ensure which human performance factor induces human error. This section reviews and investigates five HRA approaches, which have been commonly applied for assessing human performance in the operation of NPPs. Strengths and weaknesses of each approach are discussed.

Technique for Human Error Rate Prediction

Technique for Human Error Rate Prediction (THERP) deals with task analyses, error representation and identification, and quantification of human error. This approach is a hybrid model, which utilizes probability trees and dependency model for human error modeling [23]. It can be implemented to analyze human performance in maintenance, operational and incident conditions [20]. In order to calculate the probability of successful performance, THERP needs human error probabilities (HEPs), which should be available on a large human reliability database [6]. HEP database was established using tables, human reliability models, or expert judgment [24].

THERP is known as the best first generation HRA approach whose focuses are on human error probability quantification and operational human errors without considering too much on the cause and reason of observable human behaviour [24]. It offers two advantageous, i.e. event modeling and event quantification [6]. Furthermore, Dhillon [25] reported THERP is a powerful approach, which can be easily audited, and can be applied at all stages of design. It is suited very well for proceduralised and structured assessments. However, it still fails to capture the underlying causes of human error in dynamic and
complex actions [26]. It requires considerable training and cannot be completed under strict
time and resource constraint [27]. Moreover, it still has limitation on the scheme and model
classification [6]. Furthermore, It also fails to properly model scenarios and to assess the
impact of the performance shaping factors (PSFs) on human performance [25].

Even though, THERP was firstly designed and developed for nuclear industry
applications, it has also been implemented for risk assessment in other sectors [6].

**Simplified Plant Analysis Risk Human Reliability Assessment**

Simplified Plant Analysis Risk Human Reliability Assessment (SPAR-H) is the most
common HRA approach applied in nuclear industry to compute human error probabilities
(HEPs). SPAR-H is a further simplification and generalization of THERP. It removes the
THERP basic scenarios and concentrate only on two types of activities, i.e.
processing/diagnosis and response/action [27].

SPAR-H defines HEP using human performance influences [28]. Those HEPs are
quantified based on eight performance shaping factors (PSFs), i.e. available time,
stress/stressor, complexity, experience/training, procedures, ergonomics/human-machine
interface, fitness for duty, and work processes [17]. This approach is easy to be used,
straightforward and traceable [20]. It can indicate which problem corresponding to a high
HEP [27]. Moreover, those eight PSFs have covered many conditions to enable analysts
performing more detailed analysis [25].

The weakness of SPAR-H approach is that this approach does not provide enough
guidance and, hence, relies too much on justification given by analysts [27]. When more
detailed and realistic analysis is required, this approach is not suitable for diagnosing errors.
Moreover, the resolution degree of PSFs may not be sufficient for a detailed analysis [25].

**A Technique for Human Event Analysis**

A Technique for Human Event Analysis (ATHEANA) is a retrospective and prospective
approach for generating qualitative and quantitative HRA results. It can assess the failure of
cognitive human process such as detection, understanding, decision, and action [20]. This
approach offers a detailed search process as a powerful psychological framework to
diagnose performance shaping factors (PSFs) prior to identifying human actions [23].

The advantage of using this approach for HRA is that this approach provides more
holistic understanding of human factor context causing the incident [6]. Furthermore, it
considers a much wider PSF range and these factors do not need to be independently
treated. It is possible to estimate HEPs by considering various factors and combinations [25].

The limitation of the approach is that ATHEANA is cumbersome and requires a large
team [6]. Due to the involvement of expert justification, this method is difficult to be
implemented by an HRA analysts, who does not have enough training and experience [11]. It
also fails to describe the detailed causal relationships amongst human factors corresponding
to a certain incident [25].

**Cognitive Reliability and Error Analysis Method**

Cognitive Reliability and Error Analysis Method (CREAM) is a bidirectional approach
for both accident analysis and performance prediction with emphasis on human cognitive
activities [25]. It was designed and developed for nuclear industries. It considers task
analysis, error opportunity reduction, and human performance factors for overall safety of a
system [6]. Similar to ATHEANA, this approach can also evaluate the failure of cognitive
human process such as detection, understanding, decision, and action [20]. CREAM
considers that human performance failures are mainly caused by the context in which they
are requested to perform rather than inherent human error [29].

CREAM has been developed in two versions, i.e. basic and extended versions. The
basic version evaluates task performance reliability and the extended version utilizes the
output of the basic version to investigate task actions more deeply [23, 30].

The advantage of this approach are very concise, well-structured, and HEP direct
quantification. CREAM provides a HRA framework with nine common performance
conditions to assess possible error types and probability intervals [29]. It offers HEP direct
quantification and applies same principles for predictive and retrospective analyses [25]. It
can convert expert qualitative judgments into quantitative human failure analysis [14].
However, it requires high level uses of resources, lengthy completion time periods, and
experience experts [6]. It also cannot accurately identify the human error probability [29]. When failure data is insufficient, the results of this approach is always represented in approximation [14].

**Success Likelihood Index Method using Multi-Attribute Utility Decomposition**

Success Likelihood Index Method using Multi-Attribute Utility Decomposition (SLIM-MAUD) utilizes structured expert judgment for assessing HEPs. It relies on specialist opinion on human performance factor assessment and can be used for evaluating the failure of task and action sequences in maintenance, operational and incident condition [20, 23]. It focuses on the relationship and dependency analysis of human performance factors [25].

SLIM-MAUD overcomes potential inconsistency problems raised by multiple expert judgments [19]. It is an atomistic approach, which depends very much on performance shaping factors, and can improve the reliability of the analysis. It does not need for task decomposition such as task analysis and error taxonomies [25]. However, SLIM-MAUD is a complex approach, which needs intensive resources and experienced experts. Moreover, it prone to biases and lack of known values for validation purposes [25].

Based on the PSF generation, those five approaches can be divided into two groups. In the first group, PSFs are generated based on the environmental impacts to operators, such as THERP and SPAR-H. The main objectives of these two approaches are operational human error evaluation and human error probability quantification without considering too much on the cause and reason of observable human behaviour [24]. The characteristics of human failure modes in this group are very simple, which only relate to omission error or commission error [24]. THERP is suitable for procedural tasks, which do not consider cognitive reasoning. Meanwhile, SPAR-H can represent cognitive reasoning better than THERP can do [31].

Meanwhile, in the second group, PSFs are generated based on cognitive impacts to operators, such as ATHEANA, CREAM and SLIM-MAUD [24]. The main objectives of these three approaches are on human performance factor and cognitive process evaluation [32]. Those have considered context and errors of commission prior to predicting human error and included internal and external factors for generating HPFs, such as workload, stress, and sociological as well as psychological issues [24]. CREAM and ATHEANA approaches can analyze cognitive activities but fail to define a cognitive mechanism for performing the analysis [31].

**CONCLUSION**
The five most common HRA approaches in NPPs are Technique for Human Error Rate Prediction (THERP), Standardized Plant Analysis Risk Human Reliability Assessment (SPAR-H), A Technique for Human Event Analysis (ATHEANA), Cognitive Reliability and Error Analysis Method (CREAM), and Success Likelihood Index Method using Multi-Attribute Utility Decomposition (SLIM-MAUD). THERP is suitable for procedural tasks, which do not consider cognitive reasoning. SPAR-H can represent cognitive reasoning better than THERP. CREAM and ATHEANA approaches can analyze cognitive activities but fail to define a cognitive mechanism. SLIM-MAUD can evaluate the failure of task and action sequences in maintenance, operational and incident condition. In order to success, it is necessary to choose the most appropriate HRA approach by understanding the objectives and limitations of each approach. When it is possible to perform two or more approaches, it is advisable to apply those and compare their results.

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**REFERENCES**


TANYA JAWAB
Pertanyaan:
Apakah konsep keselamatan dapat diterapkan di Lab. Termohidrolika ketika eksperimen FASSIP-01, karena ketika eksperimen sering ada ide pengembangan?

Jawaban:
Konsep keselamatan juga dapat diterapkan dengan human error dan human reliability analysis. Untuk menerapkan konsep ini dengan benar, perlu dievaluasi faktor-faktor yang berkontribusi kepada human error terkait dengan eksperimen yang akan dilakukan.