A Comparison of Two Cognition-driven Human Reliability Analysis Processes - CREAM and IDHEAS

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Abstract: Years of technology development has witnessed the increasing reliability and robustness of instruments in modern complex systems, while humans, still constitute the major incidents contributor. This article proposes a new taxonomy of various HRA methods based on how the basic probability is determined. Next focusing on the cognition-driven HRA methods, the article summarizes the general quantification model in cognitive-driven category. CREAM and IDHEAS, two representative HRA methods, are compared in terms of their analysis processes against the general qualification process. A simpler two-phase response model for new HRA is suggested and discussed.

Keywords: HRA taxonomy, cognition-driven, analysis process, CREAM, IDHEAS.

1. INTRODUCTION

Years of technology development has witnessed the increasing reliability and robustness of instruments in modern complex systems, while humans, as the most flexible while the least scrutable part of the systems [1], still constitute the major incidents contributor. HRA (Human reliability Analysis) is therefore introduced to render a description of the human contribution to risk and identify ways to reduce it by using systems engineering and behavioral science methods. Proposed firstly in 1950s, HRA gained lots of focus after the Three Mile Island Accident (TMI).

HRA is part of PRA (Probability Risk/Safety Analysis, PRA/PSA). Hollnagel [2] stated that in this PSA-cum-HRA framework, HRA has been constrained by the simplification of event trees. More and more researchers in HRA tend to believe that HRA needs combination of various disciplines like human factors, social psychology, behavior science and organization management, and so on [3,4,5,6]. Boring [7] stated that HRA can provide a comprehensive description about the contribution of human errors to safety in both qualitative and quantitative fashions. However, a comprehensive description seems impossible considering that a human itself is a highly complex system. Simplification on human behaviors has to be made and priority of HRA should be given to major behaviors that are vital to system safety. And the purpose of HRA should be the screening and evaluation of risky potentially behaviors, in lieu of analysis of every behavior.

In the past decades, various HRA methods were proposed to analyze, predict and reduce human errors in nuclear power plants, and in other process industries, for example, THERP (Technique for Human Error Rate Prediction) [8], HCR (Human Cognitive Reliability) [9], CREAM (Cognitive Reliability and Error Analysis Method) [2], SPAR-H (Accident Sequence Precursor Standardized Plant Analysis Risk Model, ASP/SPAR) [10], and so on. However, current taxonomies for HRA methods remain unclear and controversial. One objective of this article is to propose a new HRA taxonomy.

Along with increasing research on human reliability and other relevant fields like cognitive science, neural science, increasing HRA methods from 1990s transfer their focus from task to context and cognition that support tasks. Not only focusing on the behavior outcomes, recent HRA methods stress potential cognitive mechanisms and causes underlying human errors from the perspective of psychology, cognition, and neuroscience. Emphasis on the influence of context and cognition factors on the one hand make a much more reasonable and persuasive qualitative analysis possible, while it on the other hand provides a relatively vivid structure to facilitate quantitative analysis. However, the

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qualitative analysis is still open to subjective bias due to the inevitable use of task analysis and the involvement of experts. And the quantitative techniques in different HRA methods are still far from convincible, suffering inadequacy of data source, bias of expert estimation, immeasurability of performance shaping factors, and so on. This article aims to compare the analysis process of two cognition-driven methods: CREAM, a cognition-driven method, and IDHEAS, a state-of-the-art HRA method freshly proposed.

2. HRA TAXONOMY

Everdij and Blom [11] summarized 726 techniques, methods, database and models related to safety. Among them, 175 techniques or models are used for risk analysis, 171 for human performance analysis, which can be adopted in nuclear power, healthcare, aviation, and other safety-critical industries. Bell and Holroyd [12] reviewed 17 methods out of 35 HRA in detail, but some developing methods like IDAC and IDHEAS are not included. Lyons et al. [13] summarized 35 HRA methods adopted in medical industries rather than in nuclear power plants. As for so many methods, researchers tried to develop taxonomies according to some common characteristics [2, 4, 14]. It's widely accepted that HRA can be classified into two categories: The first generation and the second generation. However, differences between two generations methods remain indistinct. CREAM is a typical representative of the second generation HRA. Its developer, Hollnagel, stated that two differences can be used to differentiate two generations: 1) the second generation HRA methods should extend the dichotomy of events or behaviors, and further analyse the error mechanism. 2) Influence of conditions on performance should be considered explicitly in HRA. The first difference reflects that the second generation HRA tries to explore the internal error mechanism, based on the cognitive process of human behaviors. And the second one reflects that the operation conditions do influence operators' performance in some researchers' view. In CREAM, Hollnagel addressed the importance of analysis of cognitive processes in HRA, and he developed a way to correspond tasks to different cognitive functions. Actually those first generation HRA methods did as well consider the influence of operation conditions by including performance shaping factors (PSFs) related to operation conditions. For this reason, it's the focus on the analysis of cognitive processes rather than the influence of operation conditions that differentiate CREAM from those HRAs developed earlier than it. Besides, the influence of context on performance is also considered as another distinction between the first and second generation HRA [14]. ATHEANA (A Technique for Human Error Analysis) is a HRA method that emphasizes such influence [15]. Chronological sequence is as well a criterion to classify the first and second generation HRA, but controversies remain. If all HRAs later than ATHEANA are classified into the second generation, then how can we classify SPAR-H? It was published in 2004, later than ATHEANA, while it is a succinct version of THERP without considering cognitive processes analysis. Classification according to chronological sequence fails to describe any significant characteristics of HRA methods although this taxonomy is simple to use.

Spurgin [14] categorized HRAs according to how the basic HEP (human error probability) is calculated: task-defined, time defined and context-defined methods. In his taxonomy, SPAR-H is treated as context-defined methods. HEP (human error probability) of SPAR-H nevertheless is pre-defined by its developer and context factors are merely used to adjust the HEP, therefore it seems more reasonable to put SPAR-H into task-defined category. In addition, since available time to complete a task constitutes one of task attributes, it may be better to integrate the time-defined category into task-defined one. The taxonomy by Spurgin is inspiring though. A new taxonomy based on how the HEP is determined is proposed in this article: task-driven HRA, cognition-driven HRA, and context-driven HRA. Illustration of three categories is showed in Table 1.

Table 1 HRA Taxonomy

Taxonomy Category	Representative Methods
Task-driven	THERP, ASEP, HCR, HEART, NARA, SPAR-H
Context-driven	SLIM, SLIM-MAUD, ATHEANA, HDT, IDAC
Cognition-driven	CREAM, IDHEAS

3. COGNITION-DRIVEN HRA METHODS: CREAM vs. IDHEAS

Whatever category a HRA method is in, the quantification process for one HFE (human failure event) consists of three general sub-processes: 1) derive the basic HEP for each sub-task; 2) adjust the basic HEP with adjusting coefficients; 3) Integrate sub-tasks and derive the HEP with dependency model [16]. What differs various HRA methods is how the basic HEP is determined in our taxonomy. For the cognition-driven category, unlike other two categories, a cognitive function analysis is conducted to decompose the HFE before the basic HEP is determined. To summarize therefore, cognition-driven HRA methods can be generally made up with four steps: 1) Conduct cognitive functions analysis; 2) derive basic probability; 3) derive adjusting coefficients; 4) calculate the final probability with dependency model. And HRA methods in cognition-driven categories vary in their approaches to realize each step.

3.1. CREAM

CREAM stresses the significance of cognitive factors in HRA, which differentiates it from its previous HRA methods. There are two versions of CREAM: Basic CREAM and extended CREAM. The basic CREAM is used to analyze operators' control modes which further determine the probability interval of human error. To obtain specific error probability, the extended CREAM is required, which can be decomposed into four sub-steps. 1) Describe the cognitive activities of target tasks; 2) identify possible cognitive failure types for each cognitive activity; 3) assess the effects of CPCs (if the basic CREAM has not been adopted); 4) calculate human error probability. There are 15 different cognitive activities in CREAM, and each cognitive activity can be mapped to one or two cognitive functions. 4 cognitive functions are identified (observation, interpretation, planning, and execution). Each cognitive function can be further mapped to several cognitive failure types. There are 13 cognitive failure types in total. After analysts identify cognitive activities and corresponding cognitive functions and cognitive failure types, they can then derive the basic HEP (CFP_0) of each sub-task. Then formula (1) and (2) are used to derive the error probability of HFE.

$$CFP_i = CFP_0 \times \text{Weight(CPCs)} \qquad (1)$$

$$CFP_{Total} = \sum_i (CFP_i \times K) \qquad (2)$$

CFP_i denotes the error probability of i^{th} cognitive activity. The weight of CPCs can be derived by the relation between CPCs levels and four cognitive functions, and K is from expert estimation.

3.2. IDHEAS

The Integrated Decision-tree Human Event Analysis System (IDHEAS) is the latest HRA method developed under the support of the U.S. Nuclear Regulatory Commission (USNRC) [17, 18]. To address the limitations in existing HRA methods, researchers conducted elaborate review in psychology, cognition, team performance, and other related fields, which has been summarized in NUREG-2114 [19]. There are two important concepts in IDHEAS: macrocognition and proximate cause. Macrocognition is a high-level description on what humans do with their brains [17]. The macrocognition model in IDHEAS is composed of five functions: detecting/noticing, sensemaking/understanding, decision making, action, and team coordination. The concept of proximate cause is developed to describe the cause of the failure of a macrocognition function [19]. Based on these two concepts, IDHEAS provides guidance to define HFE led by crew response tree (CRT), and further constructs a cause-based quantification model [20].

Crew Failure Mode (CFM) and Decision Trees (DTs) are two major elements of IDHEAS [20]. 14 CFMs are defined and categorized into three phases of response model (plant status assessment, response planning, and execution). After a CFM is identified, a decision tree (DT) is developed for each CFM, and branching point represents the one of Performance Influencing Factors (PIFs) that is most relevant to the CFM. And analysts can select PIFs from Groth and Molesh [21]. Based upon the CFMs and DTs, the HEP in scenario S can therefore be calculated by formula (3):

$$\text{HEP (HFE|S)}=\sum_{CRT\ sequence} \sum_{CFM} Prob(CFM|CRT\ sequence, \text{S}) \quad (3)$$

3.3. Comparison between CREAM and IDHEAS

IDHEAS so far is developing and its quantification model is incomplete to some extent. For example, dependency model, DTs for internal events, and data at the end point of DTs remain unsolved [20, 22]. In another words, IDHEAS currently is not mature enough to be put into practice. Therefore this comparison would focus on their analysis processes as figure 1 shows, rather than the quantification results.

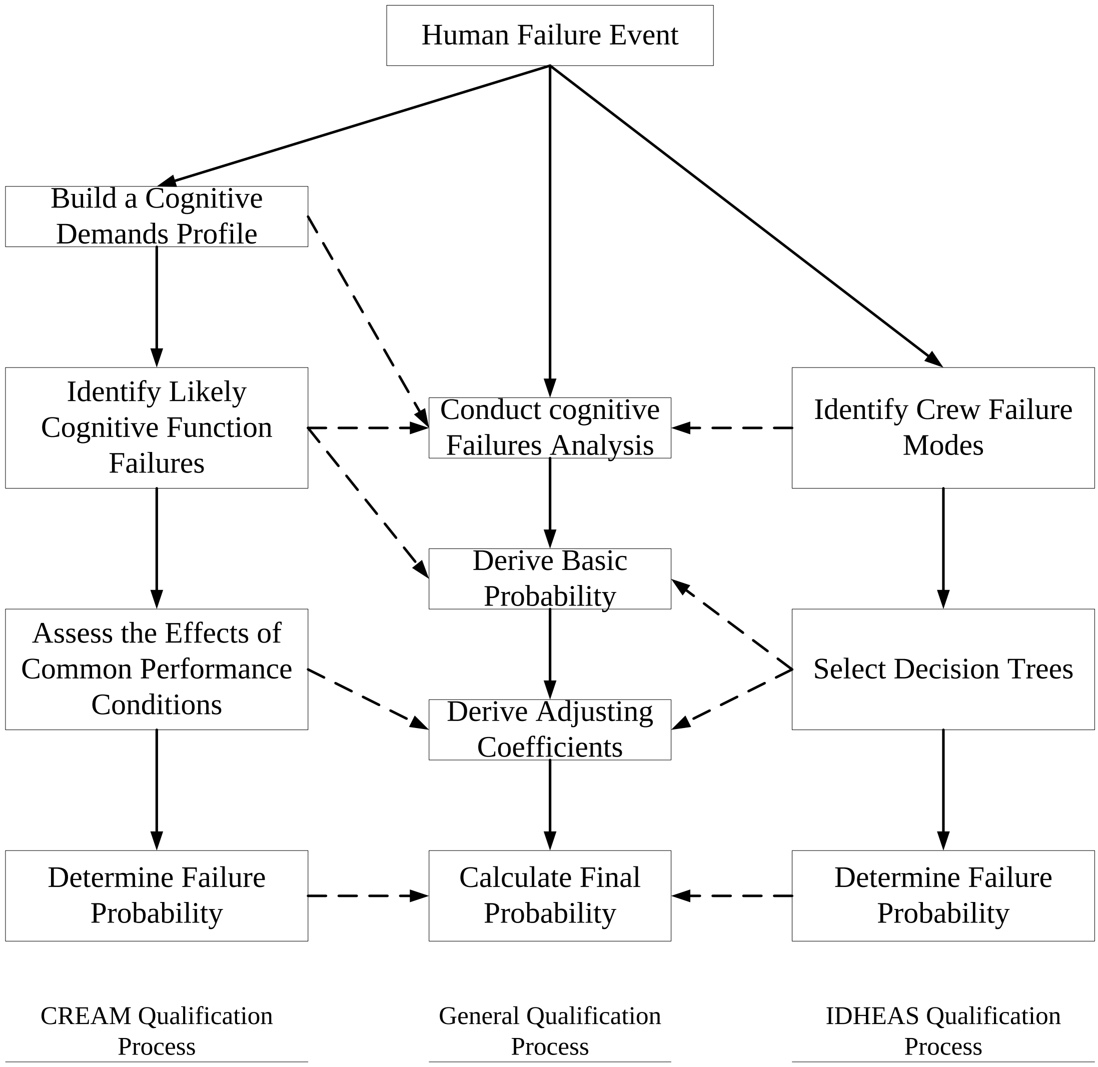

Figure 1: Comparison of Analysis Processes of Different HRA Methods

Conduct cognitive failures analysis

Cognitive failure analysis makes cognition-driven HRA methods distinct from the others. CREAM and IDHEAS differ a lot in how to analyze cognitive failures. CREAM requires analysts to identify the cognitive activities of a HFE before they identify the likely cognitive failures via four contextual control model functions (COCOM functions) [23], while in IDHEAS, analysts can identify the likely cognitive failures directly without considering cognitive demands explicitly. Both methods categorize various cognitive failures in response model which describes how operators respond plant status cognitively. Since the presentation of cognitive functions has already facilitated the identification of cognitive failures to a great extent, the 15 cognitive activities in CREAM seems no more than a white elephant that merely manifests how CREAM stresses the cognitive demands instead of facilitating the quantification. In addition, noted by Hollnagel himself, the list of critical cognitive activities is limited by its source so that it cannot be proved complete or even correct [2]. When it comes to the cognitive failures, analysts using CREAM could identify the most credible failures while in IDHEAS, analysts have to identify all relevant ones. Emphasis on the predominant failures helps CREAM analysts circumvent the dependency issue among cognitive failures, while IDHEAS developers have to face this challenging issue if they insist on considering all relevant failures (crew failure modes).

It's suggested in this article that identifying cognitive failure modes directly by response model in IDHEAS is more reasonable than CREAM. However, how to develop the response model needs further discussion. Hollnagel [2] proposed a 4-phase model: observation, interpretation, planning, and execution, while in IDHEAS, researchers put up with a three-phase model: plant status assessment, response planning, and execution. Besides, other models were proposed. For example, in the famous Information Processing Model of Decision Making [24], 5 phases are specified: sense, perception, diagnosis, choice, and execution. Current controversy lies in how to classify the processes before execution. Actually it is difficult to draw a clear line between different cognitive processes. Take "plant status assessment" and "response planning" as an example in IDHEAS. The essence of plant status assessment is information acquisition which still requires the involvement of response planning, since operator has to make "decision within decision" [24], that is, s/he has to decide where and when to collect the information, whether to stop collecting information when s/he finds an important piece of information. This kind of interaction between plant status assessment and response planning makes the selection of CFMs in each category depend on each other. Moreover, to integrate HRA with the context factors, influences of dominant factors on both cognitive and action performance need more empirical research in the process industry. However, immeasurability of cognitive process leaves no choice for most researchers in human factors but to measure merely the outcome of cognition, like diagnosis accuracy or diagnosis time [25, 26], while a few researchers tried to measure cognitive process costly using devices like eye trackers, NMR equipment (nuclear magnetic resonance) [27, 28]. To fractionize the cognitive process makes it even harder to measure. Since there is a vivid and uncontested difference between diagnosis and execution, it is suggested in this article therefore to adopt two phase response model, just diagnosis and execution as SPAR-H [10], to circumvent both issues mentioned above.

<u>Calculate sub-task probability (Derive basic probability and adjusting coefficients)</u>

Like most HRA methods, basic probability and adjusting coefficients in CREAM are assessed separately: The basic probability is determined by the cognitive failures while the adjusting coefficients are obtained by assessing the effect of CPCs. And CREAM provides quantification equation (formula 1) to integrate adjusting coefficients with the basic probability. Instead, from limited publications about IDHEAS, probabilities at the end points of DTs have already been adjusted by context factors, namely, IDHEAS provides probabilities under various scenarios. Unlike CREAM to provide basic probabilities from nowhere, IDHEAS developers show their attempts to assign probability at the end points of DTs from various data sources [20].

<u>Calculate final probability with dependency model</u>

The final step is to calculate the probability of the whole HFE by combining the sub-component of the HFE. In another word, dependency model constitutes the crux of the combination issue. Two types of dependency are identified: dependency between sub-tasks within one HFE, and dependency between separate HFEs [29]. Although the selection of dependency model highly influences the results [29, 30], most dependency models in the current HRA practice merely focus on the dependency within one HFE. In CREAM, Hollnagel suggested to solve the combination by considering the event sequence, improved and summarized later by He et al. [31]. In contrast, another type of dependency in IDHEAS between CFMs relevant to one subtask arises. No matter the dependency between two HFEs or between subtasks in one HFE, events or sub-tasks can be sorted out by time and space, making dependency model based on time or space possible, while CFMs relevant to one sub-task cannot be sorted chronologically. Since the dependency between CFMs is new, current dependency models may not fit for IDHEAS, at least not for its CFMs combination process. A good dependency model is still expected in IDHEAS.

4. CONCLUSION

This article proposes a new taxonomy (task-driven, context-driven, and cognition-driven category) of various HRA methods based on how the basic probability is determined. Next focusing on the cognition-driven HRA methods, the article summarizes the general quantification model in cognitive-driven category. CREAM and IDHEAS, two representative HRA methods, are compared. Considering the limited publications and incomplete quantification model about IDHEA, the comparison was based on the analysis process for quantification of both methods, rather than on their quantification results of a case study. A simpler two-phase response (Diagnosis/Execution) model is suggested and discussed due to the controversial definition on and immearuability of cognitive sub-processes.

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References

[1] R. B. Fuld. “The fiction of function allocation”, Ergonomics in Design, 1, pp. 20-24, (1993).
[2] E. Hollnagel. “Cognitive Reliability and Error Analysis Method”, Elsevier, 1998, Oxford.
[3] K. P. LaSala. “Human Performance Reliability: A Historical Perspective”, IEEE Transaction on Reliability, 47 (3), pp. 365~371, (1998).
[4] P. Pyy. “Human Reliability Analysis Methods for Probabilistic Risk Assessment”, [2014-02-24]. http://www.vtt.fi/inf/pdf/publications/2000/P422.pdf.
[5] S. Hirschberg. “CSNI Technical Opinion Papers (No.4): Human Reliability Analysis in Probabilistic Safety Assessment for Nuclear Power Plants”, 2004, [2014-02-24]. https://www.oecd-nea.org/nsd/reports/2004/nea5068-HRA.pdf
[6] X. H. He and X. R. Huang. “Human reliability analysis in industrial systems: Theory, methods and practise”, Tsinghua Press, 2007, Beijing.
[7] R. L Boring. “Dynamic Human Reliability Analysis: Benefits and Challenges of Simulating Human Performance (INL/CON-07-12773)”, 2007, [2014-02-24]. http://www.inl.gov/technicalpublications/Documents/3735688.pdf
[8] A. D. Swain and H. E. Guttmannn. “Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications (NUREG/CR-1278)”, USNRC, 1983, Washington D.C.
[9] EPRI. “Operator Reliability Experiments Using Power Plant Simulators (Final Report), EPRI NP-6937-L”, EPRI, 1991, Palo Alto.
[10] D. Gertman, H. Blackman, J. Marble, J. Byers and C. Smith. “The SPAR-H Human Reliability Analysis Method (NUREG/CR-6883)”, USNRC, 2004, Washington D.C.
[11] M. H. C. Everdij and H. A. P. Blom. “Safety Methods Database (Version 0.9)”, 2010, [2014-02-24]. http://www.nlr.nl/documents/flyers/SATdb.pdf
[12] J. Bell and J. Holroyd. “Review of Human Reliability Assessment Methods. Health and Safety Laboratory for the Health and Safety Executive 2009, Report RR 679”, [2014-02-24] http://www.hse.gov.uk/research/rrpdf/rr679.pdf
[13] M. Lyons, M. Woloshynowych, S. Adams and C. Vincent. “Error Reduction in Medicine”, Imperial College 2005, London.

[14] A. J. Spurgin. “Human Reliability Assessment: Theory and Practice”, CRC Press, 2010, Boca Raton.
[15] S. E. Cooper, A. M. Ramey-Smith, J. Wreathall, G. W. Parry, D. C. Bley, W. J. Luckas, J. H. Taylor and M. T. Barriere. “A Technique for Human Error Analysis (ATHEANA), NUREG/CR-6350”. USNRC, 1996, Washington D.C.
[16] S.J. Lee, J. Kim and S.C. Jang. “Development of a human reliability analysis tool for conventional and advanced main control rooms in nuclear power plant”. Paper presented at the meeting of NPIC & HMIT 2012.
[17] A. M. Whaley, S. M. L. Henderickson, R. L. Boring, J. C. Joe, K. L. L. Blanc and J. Xing. “Bridging human reliability analysis and psychology, part 1: The psychological literature review for IDHEAS method (INL/CON-12-24798)”, 2012, [2014-02-24], http://www.inl.gov/technicalpublications/documents/5517275.pdf.
[18] A. M. Whaley, S. M. L. Henderickson, R. L. Boring and J. Xing. “Bridging human reliability analysis and psychology, part 2: A cognitive framework to support HRA (INL/CON-12-24797)”, 2012, [2014-02-24], http://www.inl.gov/technicalpublications/Documents/5517274.pdf.
[19] A. M. Whaley, J. Xing, S. M. L. Henderickson, R. L. Boring, J. C. Joe and K. L. L. Blanc. “Building a psychological foundation for human reliability analysis (NUREG-2114)”. USNRC, 2012, Washington D.C.
[20] H. Liao, K. M. Groth and S. Steven-Adams. “Leveraging existing human performance data for quantifying the IDHEAS HRA method”. Safety, Reliability and Risk Analysis: Beyond the Horizon-Steenbergen et al. (Eds), pp. 563-569, (2014).
[21] K. M. Groth and A. Molesh. “A data-informed PIF hierarchy for model-based Human Reliability Analysis”, Reliability Engineering and System Safety, 108, pp. 154-174, (2012).
[22] J. Xing. “SRM-061020 on HRA methods: Progress and status in 2013”, 2013, [2014-02-24], http://pbadupws.nrc.gov/docs/ML1400/ML14009A355.pdf.
[23] E. Hollnagel. “Human reliability analysis: Context and control”, Academic Press, 1993, London.
[24] C. D. Wickens, and J. G. Hollands. Engineering Psychology and Human Performance (3rd Edition). NJ: Prentice Hall, (2000).
[25] G. A. Jamieson. 2003. “Ecological Interface Design for Petrochemical Process Control: Integrated Task- and System-Based Approaches.” (CEL_02_01). Cognitive Engineering Lab: University of Toronto.
[26] K. J. Vicente, N. Moray, J. D. Lee, J. Rasmussen, B. G. Jones, R. Brock, and R. DJEMIL. “Evaluation of A Ranking Cycle Display for Nuclear Power Plant Monitoring and Diagnosis,” Human Factors, 38, pp. 506-521., (1996).
[27] K. J. Chen, and Z. Z. Li. Eveluation of human-system interfaces with different information organization using an eye tracker. The 5th International Conference, HCI International 2013, Las Vegas, NV, USA, July 21-26, 2013.
[28] J. H. Goldberg, and X. P. Kotval.. Eye movement-based evaluation of the computer interface. In: S. K. Kumar (ed.), Advances in Occupational Ergonomics and Safety, 529–532. Amsterdam: ISO Press.(1998)
[29] M. Cepin. “DEPEND-HRA—A method for consideration of dependency in human reliability analysis”, Reliability Engineering and System Safety, 93, 1452 – 1460, (2008).
[30] M. Cepin. “Comparison of Methods for Dependency Determination between Human Failure Events within Human Reliability Analysis.” 2008, [2014-02-24], http://www.hindawi.com/journals/stni/2008/987165/.
[31] X. H. He, Y. Wang, Z. P. Shen and X. R. Huang. “A simplified CREAM prospective quantification process and its application”, Reliability Engineering and System Safety, 93, pp. 298-306, (2008).